Rock Linings

DRAINAGE CONTROL TECHNIQUE

Low Gradient	✓	Velocity Control		Short Term	✓
Steep Gradient	✓	Channel Lining	✓	Medium-Long Term	✓
Outlet Control		Soil Treatment		Permanent	[1]

[1] The design of permanent installations may require consideration of issues not covered in this fact sheet, such as the effects of sedimentation and vegetation growth across the rock-lined surface.

Symbol → (RR) →

Photo 1 – Rock-lined emergency spillway of a sediment basin

Photo 2 – Permanent, rock-lined batter chute

Key Principles

1. The critical design parameter is rock size, which is primarily dependent on flow velocity, rock shape and density, and bed slope.
2. Critical operational issues include ensuring supply of the specified rock size, and ensuring the rocks are appropriately recessed into the terrain to allow the unrestricted entry of water into the chute or channel.

Design Information

This fact sheet does ***not*** *discuss all the design issues required for consideration in the design of rock protection works for coastal zones and watercourses.*

Table 1 provides the recommended design equations for sizing rock on the bed of channels and chutes.

Tables 8 to 14 provide design, mean rock size (rounded up to the next 0.1m unit) for a safety factor of 1.2 and 1.5, based on Equation 3 for S_o = 0.1% and Equation 1 for all other bed slopes.

The recommended maximum batter slope is 2:1(H:V) un-vegetated, or 2.5:1 if vegetated. Equations 1 to 6 can be used for sizing rock on the bank of straight and near-straight reaches of channels and chutes provided the bank slope (relative to the horizontal) does not exceed a gradient of 2:1. Rock size should be increased 25% for bank slopes of 1.5:1.

Rock sizing for channels and chutes:

Recommended design equations for sizing rock on the bed of channels and chutes are provided in Table 1.

Table 1 – Recommended rock sizing equations for channels and chutes [1]

Bed slope (%)	Design equations
Preferred equation: $S_o < 50\%$	Uniform flow conditions only, $S_e = S_o$ $d_{50} = \frac{1.27.SF.K_1.K_2.S_o^{0.5}.q^{0.5}.y^{0.25}}{(s_r - 1)}$ (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 equation based on velocity and bed slope: $S_o < 33\%$	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
A simplified equation based on velocity and flow depth: $S_o < 10\%$	Uniform flow conditions only, $S_e = S_o$ $d_{50} \approx \frac{K_1.V^{3.9}}{C.y^{0.95}(s_r - 1)}$ (4) C = 120 and 68 for SF = 1.2 and 1.5 respectively
Partially drowned waterway chutes: $S_o < 50\%$	Steep gradient, non-uniform flow conditions, $S_e \neq S_o$ $d_{50} = \frac{1.27.SF.K_1.K_2.S_o^{0.5}.V^{2.5}.y^{0.75}}{V_o^{2.0}(s_r - 1)}$ (5)
A simplified, velocity-based equation for small low-gradient drains, and non-critical conditions only: $S_o < 5\%$	Low gradient, non-uniform flow conditions [2] $d_{50} \approx \frac{K_1.V^2}{2.g.K^2(s_r - 1)}$ (6) K = 1.10 for low turbulent, subcritical flow conditions, or 0.86 for high turbulent and/or supercritical flow conditions

[1] The above equations, with the exception of Equation 2, are based on Manning's 'n' roughness being determined from Equation 10.

[2] This equation represents a modification of the equation presented by Isbash, S.V., 1936 (*Construction of dams by depositing rock in running water*, Transactions, Second Congress on Large Dams, Washington, D.C. USA) based on the data set used to develop Equations 1 to 5.

Equation 1 was developed from a best-fit analysis of both field and laboratory data. Equations 2 to 5 where developed from the same data set as Equation 1, but are considered either not as accurate, or appropriate for a smaller range of bed slopes. Equation 6 is a modification of the equation originally presented by Isbash (1936).

Terminology used in Equations 1 to 6:

d_{50} = nominal rock size (diameter) of which 50% of the rocks are smaller [m]
A & B = equation constants
K = equation constant based on flow conditions
= 1.10 for low turbulent, subcritical flow conditions, or 0.86 for high turbulent and/or supercritical flow conditions
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
S_e = slope of energy line [m/m]
S_o = bed slope = tan(θ) [m/m]
SF = factor of safety (refer to Table 2)
V = actual depth-average flow velocity at location of 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]
Φ = angle of repose of rock [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.	• Embankment chutes where failure of the structure is likely to result in easily repairable soil erosion. • Permanent chutes that are likely to experience significant sedimentation and vegetation growth before experiencing the high flows. • Temporary (<2yrs) spillways 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).	• Waterway chutes where failure of the chute may cause severe gully erosion and/or damage to the waterway. • Sediment basin or dam spillways located immediately up-slope of a residential area or busy roadway where an embankment failure could cause property flooding or loss of life. • Spillways and chutes designed for a storm frequency less than 1 in 10 years.

Design flow velocity:

Wherever practical, the flow velocity used to determine rock size should be based on the ‘local’ velocity (i.e. the depth-average flow velocity at a given location) rather than a flow velocity average over the whole cross-section.

Rock placed on the **outside** bank of drainage and waterway channels can be sized using Equations 4 or 6 (as appropriate) provided the bank slope does not exceed 2:1. In such circumstances the terms as used in Equations 4 and 6 are defined below:

V = flow velocity adjacent bank (V_{bend})
y = depth of flow measured to the toe of the bank
S_o = slope of main channel bed (not the slope of the bank)

In large channels, the local flow velocity on the outside of any significant channel bend should be adopted as 1.33 times the average channel velocity, unless otherwise supported by physical modelling.

Rock type, size and grading:

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 its length. Generally, crushed (angular) rock is more stable than rounded stone.

Suggested relative densities of various types of rock are provided in Table 3.

Table 3 – Typical 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

The maximum rock size should generally not exceed twice the nominal (d_{50}) rock size.

Table 4 provides a typical rock size distribution for use in preliminary design. Table 4 is provided for general information only, it does **not** represent a recommended design specification.

Table 4 – Typical distribution of rock size [1]

Rock size ratio	Assumed distribution value
d_{100}/d_{50}	2.00
d_{90}/d_{50}	1.82
d_{75}/d_{50}	1.50
d_{65}/d_{50}	1.28
d_{40}/d_{50}	0.75
d_{33}/d_{50}	0.60
d_{10}/d_{50}	> 0.50

[1] Wide variations in the rock size distribution can occur unless suitably controlled by the material contract specifications.

Thickness of rock protection:

The thickness of the rock protection should be sufficient to allow at least two overlapping layers of the nominal (d_{50}) rock size.

The thickness of rock protection must also be sufficient to accommodate the largest rock size.

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 5.

Table 5 – 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

Backing material or filter layer:

Non-vegetated armour rock must be placed over a layer of suitably graded filter rock or geotextile filter cloth (minimum 'bidim' A24 or equivalent). The geotextile filter cloth must have sufficient strength and must be suitably overlapped to withstand the placement of the rock.

Armour rock that is intended to be vegetated by appropriately filling all voids with soil and pocket planting generally will usually not require an underlying filter layer, unless the long-term viability of the vegetation is questioned due to possible high scour velocities, or limited natural light or rainfall conditions.

If the soils adjacent to the rock surface are dispersive (e.g. sodic soils), then **prior** to placing the filter cloth or filter layer, the exposed bank **must** first be covered with a layer of non-dispersive soil (Figure 2), typically minimum 200mm thickness, but preferably 300mm.

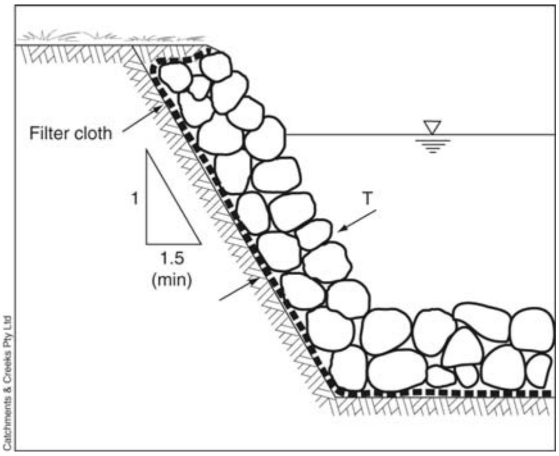

Figure 1 – Rock placement (without vegetation) on non-dispersive soil

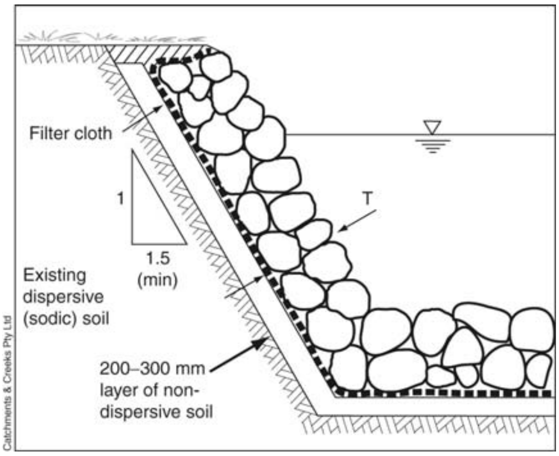

Figure 2 – Rock placement (without vegetation) on dispersive soil

Maximum bank gradient:

The recommended maximum batter slope is 2:1(H:V) un-vegetated, or 2.5:1 if vegetated.

Typical angles of repose for dumped rock are provided in Table 6.

Table 6 – Typical angle of repose for rock

Rock shape	Angle of repose (degrees)	
	Rock size >100mm	Rock size >500mm
Very angular rock	41^o	42^o
Slightly angular rock	40^o	41^o
Moderately rounded rock	39^o	40^o

Placement of vegetation over the rock cover:

Vegetating rock-lined channels and chutes can significantly increase the stability of these drainage structures, but can also reduce the hydraulic capacity of the structure.

Relying on wild revegetation of rock-protected surfaces can encourage the invasion of weed species, and is therefore not recommended.

Manning roughness of rock-lined surfaces:

The Manning's (n) roughness for rock-lined surfaces may be determined from Table 7 or Equation 7.

Table 7 – 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

The roughness values presented in Table 7 have been developed from Equation 7. Equation 7 (Witheridge, 2002) was developed to allow estimation of the Manning's n of rock lined channels in shallow water.

$$n = \frac{{d_{90}}^{1/6}}{26\left(1 - 0.3593^{(X)^{0.7}}\right)} \qquad \text{(Eqn 7)}$$

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} = mean 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.

Placement of rock:

It is important to ensure that the top of the rock surface is level with, or slightly below, the surrounding land surface to allow the free entry of water including lateral inflows (if required) as shown in Figure 4.

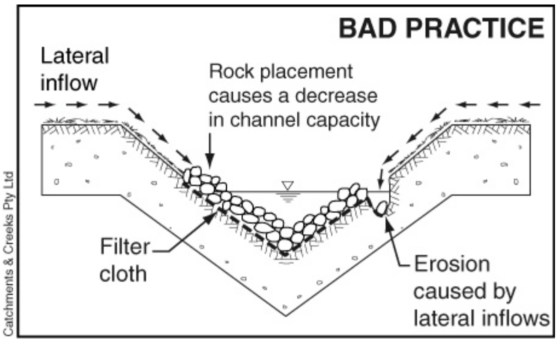

Figure 3 – Incorrect placement of rock causing loss of flow area and erosion along the outer limits of the rock

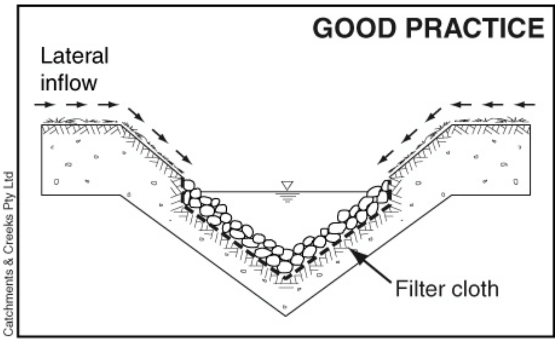

Figure 4 – Rock recessed into the soil to allow the free entry of lateral inflows

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 channels and chutes are usually most vulnerable to damage in the first year or two after placement while the voids remain open and free of sedimentation.

Where appropriate, permanent rock-lined channels and chutes should be topped with a light covering of soil and planted to accelerate the integration of these structures into the surrounding environment. Revegetation is not however always advisable, and should be assessed on a case-by-case basis.

Photo supplied by Catchments & Creeks Pty Ltd

Photo 3 – An example of the rock-lining being correctly recessed into the topography

Photo supplied by Catchments & Creeks Pty Ltd

Photo 4 – Note how runoff from the adjacent batter is able to spill freely into the drain

Photo 5 – Placement of the rock <u>on</u> the soil can result in erosion problems if significant lateral inflows occur

Photo supplied by Catchments & Creeks Pty Ltd

Photo 6 – In this example, placement of the rock has resulted in the rock-lined table drain being higher than the road shoulder

Photo supplied by Catchments & Creeks Pty Ltd

Photo 7 – Rounded rock can be significantly less stable than angular, fractured rock, especially when placed on steep slopes

Photo supplied by Catchments & Creeks Pty Ltd

Photo 8 – Placement of a few large, anchor rocks down a steep slope will not help stabilise adjacent, under-sized rocks, and will likely cause flow diversion

Table 8a – Preferred rock sizing table, d_{50} (m) based on unit flow rate, SF = 1.2 [1]

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 (%)**							
	0.2	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**
0.2	0.05	0.05	0.05	0.05	0.10	0.10	0.10	0.10
0.4	0.05	0.05	0.10	0.10	0.10	0.10	0.20	0.20
0.6	0.05	0.05	0.10	0.10	0.20	0.20	0.20	0.20
0.8	0.05	0.10	0.10	0.20	0.20	0.20	0.20	0.20
1.0	0.05	0.10	0.10	0.20	0.20	0.20	0.30	0.30
2.0	0.10	0.20	0.20	0.30	0.30	0.30	0.40	0.40
3.0	0.10	0.20	0.20	0.30	0.40	0.40	0.50	0.50
4.0	0.20	0.20	0.30	0.40	0.40	0.50	0.60	0.60
5.0	0.20	0.30	0.30	0.40	0.50	0.60	0.60	0.70
6.0	0.20	0.30	0.40	0.50	0.60	0.70	0.70	0.80
7.0	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
8.0	0.20	0.30	0.40	0.60	0.70	0.80	0.90	0.90
9.0	0.20	0.30	0.50	0.60	0.70	0.80	0.90	1.00
10.0	0.30	0.40	0.50	0.70	0.80	0.90	1.00	1.10
15.0	0.30	0.50	0.60	0.80	1.00	1.20	1.30	1.40
20.0	0.40	0.60	0.70	1.00	1.20	1.40	1.50	1.70

[1] Tabulated results are applicable to uniform flow conditions only.

Table 8b – Preferred rock sizing table, d_{50} (m) based on unit flow rate, SF = 1.2 [1]

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 (%)**							
	8.0	**9.0**	**10.0**	**15.0**	**20.0**	**25.0**	**33.3**	**50.0**
0.2	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.30
0.4	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.40
0.6	0.20	0.20	0.30	0.30	0.30	0.40	0.40	0.50
0.8	0.30	0.30	0.30	0.30	0.40	0.40	0.50	0.60
1.0	0.30	0.30	0.30	0.40	0.40	0.50	0.60	0.70
2.0	0.50	0.50	0.50	0.60	0.70	0.70	0.90	1.00
3.0	0.60	0.60	0.60	0.80	0.90	1.00	1.10	1.30
4.0	0.70	0.70	0.80	0.90	1.00	1.20	1.30	1.60
5.0	0.80	0.80	0.90	1.10	1.20	1.30	1.50	1.80
6.0	0.90	0.90	1.00	1.20	1.40	1.50	1.70	2.10
7.0	1.00	1.00	1.10	1.30	1.50	1.70	1.90	
8.0	1.10	1.10	1.20	1.40	1.60	1.80	2.10	
9.0	1.10	1.20	1.30	1.50	1.80	1.90	2.20	
10.0	1.20	1.30	1.40	1.60	1.90	2.10		
15.0	1.60	1.70	1.80	2.10	2.40			
20.0	1.90	2.00	2.10					

[1] Tabulated results are applicable to uniform flow conditions only.

Table 9a – Rock sizing table, d_{50} (m) based on uniform flow velocity, SF = 1.2 [1]

Safety factor, SF = 1.2			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Uniform velocity (m/s)	**Bed slope (%)**							
	0.1	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**
0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1.0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1.3	0.05	0.05	0.05	0.10	0.10	0.10	0.10	0.10
1.5	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.20
1.8	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.20
2.0	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
2.3	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30
2.5	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.40
2.8	0.20	0.30	0.30	0.30	0.40	0.40	0.40	0.40
3.0	0.30	0.30	0.30	0.40	0.40	0.40	0.50	0.50
3.5	0.40	0.40	0.40	0.50	0.50	0.60	0.60	0.70
4.0	0.50	0.50	0.50	0.60	0.70	0.80	0.80	0.80
4.5	0.60	0.60	0.70	0.80	0.90	0.90	1.00	1.10
5.0	0.70	0.70	0.80	1.00	1.10	1.10	1.20	1.30
6.0	1.00	1.00	1.20	1.40	1.50	1.60	1.70	1.80

[1] Tabulated results are applicable to uniform flow conditions, and Manning's n based on Equation 7.

Table 9b – Rock sizing table, d_{50} (m) based on uniform flow velocity, SF = 1.2 [1]

Safety factor, SF = 1.2			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Uniform velocity (m/s)	**Bed slope (%)**							
	8.0	**9.0**	**10.0**	**15.0**	**20.0**	**25.0**	**33.3**	**50.0**
0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.8	0.05	0.05	0.05	0.05	0.05	0.05	0.10	0.10
1.0	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.20
1.3	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.20
1.5	0.20	0.20	0.20	0.20	0.20	0.20	0.30	0.30
1.8	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.40
2.0	0.30	0.30	0.30	0.30	0.30	0.40	0.40	0.50
2.3	0.30	0.30	0.30	0.40	0.40	0.50	0.50	0.60
2.5	0.40	0.40	0.40	0.50	0.50	0.60	0.60	0.70
2.8	0.50	0.50	0.50	0.60	0.60	0.70	0.70	0.80
3.0	0.50	0.60	0.60	0.70	0.70	0.80	0.90	1.00
3.5	0.70	0.70	0.80	0.90	1.00	1.00	1.10	1.30
4.0	0.90	1.00	1.00	1.10	1.20	1.30	1.50	1.70
4.5	1.10	1.20	1.20	1.40	1.50	1.70	1.90	2.10
5.0	1.40	1.50	1.50	1.70	1.90	2.00	2.20	
6.0	1.90	2.00	2.10	2.40	2.70			

[1] Tabulated results are applicable to uniform flow conditions, and Manning's n based on Equation 7.

Table 10a – Rock sizing table, d_{50} (m) based on uniform flow depth, SF = 1.2 [1]

Safety factor, SF = 1.2			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Uniform flow depth (m)	**Bed slope (%)**							
	0.1	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**
0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.2	0.05	0.05	0.05	0.10	0.10	0.10	0.10	0.10
0.4	0.05	0.05	0.10	0.20	0.20	0.20	0.20	0.20
0.6	0.05	0.10	0.10	0.20	0.20	0.30	0.30	0.30
0.8	0.05	0.10	0.20	0.30	0.30	0.30	0.40	0.40
1.0	0.10	0.20	0.20	0.30	0.40	0.40	0.50	0.50
1.2	0.10	0.20	0.20	0.40	0.40	0.50	0.60	0.60
1.4	0.10	0.20	0.30	0.40	0.50	0.60	0.60	0.70
1.6	0.10	0.20	0.30	0.50	0.60	0.60	0.70	0.80
1.8	0.20	0.20	0.30	0.50	0.60	0.70	0.80	0.90
2.0	0.20	0.30	0.40	0.60	0.70	0.80	0.90	1.00
2.2	0.20	0.30	0.40	0.60	0.70	0.90	1.00	1.10
2.4	0.20	0.30	0.40	0.70	0.80	0.90	1.10	1.20
2.6	0.20	0.30	0.50	0.70	0.90	1.00	1.20	1.30
2.8	0.20	0.40	0.50	0.80	0.90	1.10	1.20	1.40
3.0	0.20	0.40	0.50	0.80	1.00	1.20	1.30	1.50

[1] Tabulated results are applicable to uniform flow conditions, and Manning's n based on Equation 7.

Table 10b – Rock sizing table, d_{50} (m) based on uniform flow depth, SF = 1.2 [1]

Safety factor, SF = 1.2			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Uniform flow depth (m)	**Bed slope (%)**							
	8.0	**9.0**	**10.0**	**15.0**	**20.0**	**25.0**	**33.3**	**50.0**
0.1	0.10	0.10	0.10	0.10	0.10	0.20	0.20	0.20
0.2	0.20	0.20	0.20	0.20	0.20	0.30	0.30	0.40
0.4	0.30	0.30	0.30	0.40	0.40	0.50	0.50	0.70
0.6	0.40	0.40	0.40	0.50	0.60	0.70	0.80	1.00
0.8	0.50	0.50	0.60	0.70	0.80	0.90	1.00	1.30
1.0	0.60	0.60	0.70	0.80	1.00	1.10	1.30	1.60
1.2	0.70	0.80	0.80	1.00	1.20	1.30	1.50	1.90
1.4	0.80	0.90	0.90	1.10	1.30	1.50	1.70	2.20
1.6	0.90	1.00	1.10	1.30	1.50	1.70	2.00	
1.8	1.00	1.10	1.20	1.50	1.70	1.90	2.20	
2.0	1.20	1.20	1.30	1.60	1.90	2.10		
2.2	1.30	1.30	1.40	1.80	2.10			
2.4	1.40	1.50	1.60	1.90	2.30			
2.6	1.50	1.60	1.70	2.10				
2.8	1.60	1.70	1.80	2.20				
3.0	1.70	1.80	1.90	2.40				

[1] Tabulated results are applicable to uniform flow conditions, and Manning's n based on Equation 7.

Table 11a – Preferred rock sizing table, d_{50} (m) based on unit flow rate, SF = 1.5 [1]

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 (%)							
	0.1	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**
0.2	0.05	0.05	0.05	0.10	0.10	0.10	0.10	0.10
0.4	0.05	0.05	0.10	0.10	0.20	0.20	0.20	0.20
0.6	0.05	0.10	0.10	0.20	0.20	0.20	0.20	0.30
0.8	0.05	0.10	0.20	0.20	0.20	0.20	0.30	0.30
1.0	0.10	0.10	0.20	0.20	0.30	0.30	0.30	0.30
2.0	0.10	0.20	0.20	0.30	0.40	0.40	0.50	0.50
3.0	0.20	0.20	0.30	0.40	0.50	0.50	0.60	0.60
4.0	0.20	0.30	0.40	0.50	0.60	0.60	0.70	0.80
5.0	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
6.0	0.20	0.30	0.40	0.60	0.70	0.80	0.90	1.00
7.0	0.30	0.40	0.50	0.70	0.80	0.90	1.00	1.10
8.0	0.30	0.40	0.50	0.70	0.90	1.00	1.10	1.20
9.0	0.30	0.40	0.60	0.80	0.90	1.10	1.20	1.30
10.0	0.30	0.50	0.60	0.80	1.00	1.10	1.20	1.40
15.0	0.40	0.60	0.80	1.10	1.30	1.50	1.60	1.80
20.0	0.50	0.70	0.90	1.30	1.50	1.80	1.90	2.10

[1] Tabulated results are applicable to uniform flow conditions only.

Table 11b – Preferred rock sizing table, d_{50} (m) based on unit flow rate, SF = 1.5 [1]

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 (%)							
	8.0	**9.0**	**10.0**	**15.0**	**20.0**	**25.0**	**33.3**	**50.0**
0.2	0.20	0.20	0.20	0.20	0.20	0.20	0.30	0.30
0.4	0.20	0.20	0.20	0.30	0.30	0.40	0.40	0.50
0.6	0.30	0.30	0.30	0.40	0.40	0.40	0.50	0.60
0.8	0.30	0.30	0.40	0.40	0.50	0.50	0.60	0.70
1.0	0.40	0.40	0.40	0.50	0.60	0.60	0.70	0.80
2.0	0.60	0.60	0.60	0.70	0.80	0.90	1.10	1.30
3.0	0.70	0.80	0.80	1.00	1.10	1.20	1.40	1.70
4.0	0.90	0.90	1.00	1.20	1.30	1.50	1.70	2.00
5.0	1.00	1.00	1.10	1.30	1.50	1.70	1.90	2.30
6.0	1.10	1.20	1.20	1.50	1.70	1.90	2.20	
7.0	1.20	1.30	1.40	1.70	1.90	2.10		
8.0	1.30	1.40	1.50	1.80	2.10			
9.0	1.40	1.50	1.60	1.90	2.20			
10.0	1.50	1.60	1.70	2.10				
15.0	2.00	2.10	2.20					
20.0	2.40							

[1] Tabulated results are applicable to uniform flow conditions only.

Table 12a – Rock sizing table, d_{50} (m) based on uniform flow velocity for SF = 1.5 [1]

Safety factor, SF = 1.5			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Uniform velocity (m/s)	**Bed slope (%)**							
	0.1	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**
0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1.0	0.05	0.05	0.05	0.10	0.10	0.10	0.10	0.10
1.3	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.20
1.5	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.20
1.8	0.20	0.20	0.20	0.20	0.20	0.20	0.30	0.30
2.0	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.30
2.3	0.20	0.20	0.30	0.30	0.30	0.40	0.40	0.40
2.5	0.30	0.30	0.30	0.40	0.40	0.40	0.50	0.50
2.8	0.30	0.30	0.40	0.40	0.50	0.50	0.60	0.60
3.0	0.40	0.40	0.40	0.50	0.60	0.60	0.70	0.70
3.5	0.50	0.50	0.60	0.70	0.80	0.80	0.90	0.90
4.0	0.60	0.70	0.80	0.90	1.00	1.10	1.10	1.20
4.5	0.80	0.80	0.90	1.10	1.20	1.30	1.40	1.50
5.0	0.90	1.00	1.10	1.40	1.50	1.60	1.80	1.90
6.0	1.30	1.40	1.60	1.90	2.10	2.30	2.50	2.60

[1] Tabulated results are applicable to uniform flow conditions, and Manning's n based on Equation 7.

Table 12b – Rock sizing table, d_{50} (m) based on uniform flow velocity for SF = 1.5 [1]

Safety factor, SF = 1.5			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Uniform velocity (m/s)	**Bed slope (%)**							
	8.0	**9.0**	**10.0**	**15.0**	**20.0**	**25.0**	**33.3**	**50.0**
0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.8	0.05	0.05	0.05	0.10	0.10	0.10	0.10	0.10
1.0	0.10	0.10	0.10	0.10	0.20	0.20	0.20	0.20
1.3	0.20	0.20	0.20	0.20	0.20	0.20	0.30	0.30
1.5	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.40
1.8	0.30	0.30	0.30	0.40	0.40	0.40	0.50	0.50
2.0	0.40	0.40	0.40	0.40	0.50	0.50	0.60	0.70
2.3	0.50	0.50	0.50	0.50	0.60	0.60	0.70	0.80
2.5	0.50	0.60	0.60	0.70	0.70	0.80	0.90	1.00
2.8	0.60	0.70	0.70	0.80	0.90	0.90	1.00	1.20
3.0	0.80	0.80	0.80	0.90	1.00	1.10	1.20	1.40
3.5	1.00	1.10	1.10	1.30	1.40	1.50	1.70	1.90
4.0	1.30	1.40	1.40	1.60	1.80	1.90	2.10	2.50
4.5	1.70	1.70	1.80	2.00	2.20	2.40		
5.0	2.00	2.10	2.10	2.50				
6.0	2.80							

[1] Tabulated results are applicable to uniform flow conditions, and Manning's n based on Equation 7.

Table 13a – Rock sizing table, d_{50} (m) based on uniform flow depth, SF = 1.5 [1]

Safety factor, SF = 1.5			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Uniform flow depth (m)	**Bed slope (%)**							
	0.1	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**
0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.10	0.10
0.2	0.05	0.05	0.05	0.10	0.10	0.10	0.20	0.20
0.4	0.05	0.10	0.10	0.20	0.20	0.20	0.30	0.30
0.6	0.05	0.10	0.20	0.20	0.30	0.30	0.40	0.40
0.8	0.10	0.20	0.20	0.30	0.40	0.40	0.50	0.50
1.0	0.10	0.20	0.20	0.30	0.40	0.50	0.60	0.60
1.2	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.70
1.4	0.20	0.20	0.30	0.50	0.60	0.70	0.80	0.80
1.6	0.20	0.30	0.40	0.50	0.70	0.80	0.90	0.90
1.8	0.20	0.30	0.40	0.60	0.70	0.80	1.00	1.00
2.0	0.20	0.30	0.40	0.60	0.80	0.90	1.10	1.20
2.2	0.20	0.30	0.50	0.70	0.90	1.00	1.20	1.30
2.4	0.20	0.40	0.50	0.80	1.00	1.10	1.30	1.40
2.6	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.50
2.8	0.30	0.40	0.60	0.90	1.10	1.30	1.50	1.60
3.0	0.30	0.40	0.60	0.90	1.20	1.40	1.60	1.70

[1] Tabulated results are applicable to uniform flow conditions, and Manning's n based on Equation 7.

Table 13b – Rock sizing table, d_{50} (m) based on uniform flow depth, SF = 1.5 [1]

Safety factor, SF = 1.5			Specific gravity, s_r = 2.4			Size distribution, d_{50}/d_{90} = 0.5		
Uniform flow depth (m)	**Bed slope (%)**							
	8.0	**9.0**	**10.0**	**15.0**	**20.0**	**25.0**	**33.3**	**50.0**
0.1	0.10	0.10	0.10	0.10	0.20	0.20	0.20	0.20
0.2	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.40
0.4	0.30	0.30	0.30	0.40	0.50	0.50	0.60	0.80
0.6	0.40	0.50	0.50	0.60	0.70	0.80	0.90	1.10
0.8	0.60	0.60	0.60	0.80	0.90	1.00	1.20	1.50
1.0	0.70	0.70	0.80	1.00	1.10	1.30	1.50	1.80
1.2	0.80	0.90	0.90	1.20	1.30	1.50	1.80	2.20
1.4	1.00	1.00	1.10	1.30	1.60	1.80	2.00	
1.6	1.10	1.20	1.20	1.50	1.80	2.00		
1.8	1.20	1.30	1.40	1.70	2.00			
2.0	1.40	1.40	1.50	1.90	2.20			
2.2	1.50	1.60	1.70	2.10				
2.4	1.60	1.70	1.80	2.30				
2.6	1.70	1.90	2.00					
2.8	1.90	2.00						
3.0	2.00							

[1] Tabulated results are applicable to uniform flow conditions, and Manning's n based on Equation 7.

Table 14a – Alternative design table for mean rock size for specific gravity, s_r = 2.6 [1]

Safety factor, SF = 1.5			Specific gravity, s_r = 2.6			Size distribution, d_{50}/d_{90} = 0.5		
Uniform flow depth (m)	**Bed slope (%)**							
	0.1	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**
0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.10
0.2	0.05	0.05	0.05	0.10	0.10	0.10	0.10	0.20
0.4	0.05	0.05	0.10	0.20	0.20	0.20	0.20	0.30
0.6	0.05	0.10	0.20	0.20	0.30	0.30	0.30	0.40
0.8	0.10	0.10	0.20	0.30	0.30	0.40	0.40	0.50
1.0	0.10	0.20	0.20	0.30	0.40	0.40	0.50	0.60
1.2	0.10	0.20	0.30	0.40	0.50	0.50	0.60	0.70
1.4	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80
1.6	0.20	0.20	0.30	0.50	0.60	0.70	0.80	0.90
1.8	0.20	0.30	0.40	0.50	0.70	0.80	0.90	1.00
2.0	0.20	0.30	0.40	0.60	0.70	0.80	1.00	1.10
2.2	0.20	0.30	0.40	0.60	0.80	0.90	1.00	1.20
2.4	0.20	0.30	0.50	0.70	0.90	1.00	1.10	1.30
2.6	0.20	0.40	0.50	0.70	0.90	1.10	1.20	1.40
2.8	0.20	0.40	0.50	0.80	1.00	1.20	1.30	1.50
3.0	0.20	0.40	0.60	0.90	1.10	1.20	1.40	1.60

[1] Tabulated results are applicable to uniform flow conditions, and Manning's n based on Equation 7.

Table 14b – Alternative design table for mean rock size for specific gravity, s_r = 2.6 [1]

Safety factor, SF = 1.5			Specific gravity, s_r = 2.6			Size distribution, d_{50}/d_{90} = 0.5		
Uniform flow depth (m)	**Bed slope (%)**							
	8.0	**9.0**	**10.0**	**15.0**	**20.0**	**25.0**	**33.3**	**50.0**
0.1	0.10	0.10	0.10	0.10	0.10	0.20	0.20	0.20
0.2	0.20	0.20	0.20	0.20	0.20	0.30	0.30	0.40
0.4	0.30	0.30	0.30	0.40	0.40	0.50	0.60	0.70
0.6	0.40	0.40	0.50	0.60	0.60	0.70	0.80	1.00
0.8	0.50	0.60	0.60	0.70	0.80	0.90	1.10	1.30
1.0	0.60	0.70	0.70	0.90	1.00	1.20	1.30	1.70
1.2	0.80	0.80	0.90	1.10	1.20	1.40	1.60	2.00
1.4	0.90	0.90	1.00	1.20	1.40	1.60	1.90	2.30
1.6	1.00	1.10	1.10	1.40	1.60	1.80	2.10	
1.8	1.10	1.20	1.30	1.60	1.80	2.00		
2.0	1.20	1.30	1.40	1.70	2.00			
2.2	1.30	1.40	1.50	1.90	2.20			
2.4	1.50	1.60	1.70	2.10				
2.6	1.60	1.70	1.80	2.20				
2.8	1.70	1.80	1.90	2.40				
3.0	1.80	1.90	2.10					

[1] Tabulated results are applicable to uniform flow conditions, and Manning's n based on Equation 7.

Description

The rock lining of drainage channels, chutes and spillways. The rock can be left uncovered (open voids), or lightly covered with soil and pocket planted (closed voids).

Purpose

Scour protection of the bed and banks of drainage channels, chutes, and spillways.

Most commonly used when flow velocities are expected to be high.

Also used in arid areas where a good vegetation cover cannot be expected.

Limitations

In some circumstances, long-term success often depends on the introduction of suitable vegetation to anchor the rocks.

Rock should not be placed directly on dispersive soils. A layer of non-dispersive soil must be placed over the dispersive soil before placement of the rock.

Advantages

One of the most common and inexpensive forms of channel lining.

The porous nature of the rock can protect the channel from uplift—a problem associated with impervious concrete linings.

Does not necessarily require a well-formed channel cross section—as is the case for some forms of channel lining.

The surface can be fully vegetated to produce a natural channel appearance.

Disadvantages

Problems can occur due to infestation by rodents and unsightly weeds if the voids remain open.

Rock-lined chutes are most susceptible to damage during the first few years after construction.

Common Problems

Severe erosion problems if rocks are placed directly on dispersive soil. To reduce the potential for such problems, dispersive soils should be covered with a minimum 200mm layer of non-dispersive soil before rock placement.

Failure of rock-lined chutes due to the absence of a suitable filter cloth or aggregate filter layer beneath the primary armour rock layer.

Circumstances where a filter layer may not be required include:

- rock placed on a very mild slope where flow velocities are expected to be low;
- rock placement where the voids are filled with soil and pocket planted.

The latter case is most appropriate when rock protection is used on waterways and permanent rock chutes.

Weed invasion of the rock protection can become unsightly. The control of weed growth can be an expensive, labour intensive exercise.

Special Requirements

An underlying geotextile or rock filter layer is generally required unless all voids are filled with soil and pocket planted (thus preventing the disturbance and release of underlying sediments through these voids).

The upper rock surface should blend with surrounding land to allow water to freely enter the channel.

It can be difficult to de-silt a rock lined channel, so permanent rock-lined channels may need to be protected from sediment inflow while construction works continue up-slope of the channel.

Site Inspection

Check for excessive vegetation growth that may restrict the channel capacity.

Check the thickness of rock application and the existence of underlying filter layer.

Check for erosion around the outer edges of the treated area.

Ensure the rock size and shape agrees with approved plan.

Materials

- Rock: hard, angular, durable, weather resistant and evenly graded with 50% by weight larger than the specified nominal rock size and sufficient small rock to fill the voids between the larger rock. The diameter of the largest rock size should be no larger than 1.5 times the nominal rock size. Specific gravity to be at least 2.5.
- Geotextile fabric: heavy-duty, needle-punched, non-woven filter cloth, minimum ‘bidim’ A24 or equivalent.

Installation

1. Refer to approved plans for location, extent and installation details. If there are questions or problems with the location, extent, or method of installation contact the engineer or responsible on-site officer for assistance.
2. Clear the proposed channel area of trees, stumps, roots, loose rock, and other objectionable materials.
3. Excavate the channel to the lines and grades as shown on the plans. Over-cut the channel to a depth equal to the specified depth of rock placement such that the finished rock surface will be at the elevation of the surrounding land.
4. Rock must be placed within the channel as specified within the approved plans, including the placement of any specified filter layer.
5. If details are not provided on the rock placement, then the primary armour rock must be either placed on:

- a filter bed formed from a layer of specified smaller rock (rock filter layer);
- an earth bed lined with filter cloth;
- an earth bed not lined in filter cloth, but only if all voids between the armour rock are to be filled with soil and pocket planted immediately after placement of the rock.

6. If a rock/aggregate filter layer is specified, then place the filter layer immediately after the foundations are prepared. Spread the filter rock in a uniform layer to the specified depth but a minimum of 150mm. Where more than one layer of filter material has been specified, spread each layer such that minimal mixing occurs between each layer of rock.
7. If a geotextile (filter cloth) underlay is specified, place the fabric directly on the prepared foundation. If more than one sheet of fabric is required to over the area, overlap the edge of each sheet at least 300mm and place anchor pins at minimum one metre spacing along the overlap.
8. Ensure the geotextile fabric is protected from punching or tearing during installation of the fabric and the rock. Repair any damage by removing the rock and placing with another piece of filter cloth over the damaged area overlapping the existing fabric a minimum of 300mm.
9. Where necessary, a minimum 100mm layer of fine gravel, aggregate or sand should be placed over the fabric to protect it from damage.
10. Placement of rock should follow immediately after placement of the filter layer. Place rock so that it forms a dense, well-graded mass of rock with a minimum of voids.
11. Place rock to its full thickness in one operation. Do not place rock by dumping through chutes or other methods that cause segregation of rock sizes.
12. The finished surface should be free of pockets of small rock or clusters of large rocks. Hand placing may be necessary to achieve the proper distribution of rock sizes to produce a relatively smooth, uniform surface. The finished grade of the rock should blend with the surrounding area. No overfall or protrusion of rock should be apparent.
13. Immediately upon completion of the channel, vegetate all disturbed areas or otherwise protect them against soil erosion.
14. Where specified, fill all voids with soil and vegetate the rock surface in accordance with the approved plan.

Maintenance

1. Rock-lined channels should be inspected periodically and after significant storm events. Check for scour or dislodged rock. Repair damaged areas immediately.
2. Closely inspect the outer edges of the rock protection. Ensure water entry into the channel or chute is not causing erosion along the edge of the rock protection.
3. Carefully check the stability of the rock looking for indications of piping, scour holes, or bank failures.
4. Replace any displaced rock with rock of a significantly (minimum 110%) larger size than the displaced rock.