Rock Sizing for Drainage Channels

STORMWATER MANAGEMENT PRACTICES

Photo 1 – Rock-lined drainage channel

Photo 2 – Rock-lined catch drain (during construction phase)

1. Introduction

Rock size is primarily dependent on flow velocity (V), rock shape (round or angular), and rock density (s_r).

The establishment of vegetation over the rocks can improve the aesthetics, but can significantly change the hydraulic roughness and therefore the flow capacity.

2. Sizing of rock used in lining of drainage channels

Table 1 provides the recommended design equations for sizing rock used in the lining of drainage channels. These same equations can be used to size rock placed on the banks of large drainage channels provided the bank slope does not exceed 1:2 (V:H). For a bank slope of 1:1.5 (V:H) the rock size should be increased 25%.

Table 2 provides mean rock size (rounded up to the next 50/100 mm unit) based on Equation 1.

A 36% increase in rock size is recommended for rounded rock (i.e. $K_1 = 1.36$).

Table 1 – Recommended rock sizing equations for rock-lined drainage channels

Bed slope (%)	Design equations
Suitable for low-gradient, uniform flow [1] $S_o < 10\%$	Uniform flow conditions only, $S_e = S_o$ $d_{50} = \frac{K_1 . V^{3.9}}{C . y^{0.95} (s_r - 1)}$ (1) C = 120 and 68 for SF = 1.2 and 1.5 respectively
Simplified velocity-based equation for low-gradient drainage channels [2] $S_o < 5\%$	Low gradient, uniform and non-uniform flow conditions $d_{50} = \frac{K_1 . V^{2}}{2 . g . K^{2} (s_r - 1)}$ (2) K = 1.1 for low-turbulent deepwater flow, 1.0 for low-turbulent shallow water flow, and 0.86 for highly turbulent flow (also see Table 3)

[1] Development of Equation 1 is based on Manning's 'n' roughness as determined by Equation 3.

[2] Equation 2 represents a modification of the equation originally presented by Isbash (1936).

where:

d_{50} = nominal rock size (diameter) of which 50% of the rocks are smaller [m]
g = acceleration due to gravity [m/s^2]
K = equation constant based on flow conditions
= 1.1 for low-turbulent deepwater flow, 1.0 for low-turbulent shallow water flow, and 0.86 for highly turbulent and/or supercritical flow (also refer to Table 3)
K_1 = correction factor for rock shape
= 1.0 for angular (fractured) rock, 1.36 for rounded rock (i.e. smooth, spherical rock)
S_o = channel slope [m/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)
V = actual depth-average flow velocity at location of rock [m/s]
y = depth of flow at a given location [m]

Table 2 – Rock sizing selection table, d_{50} (mm) based on uniform flow velocity [1]

Uniform flow conditions			**Angular rock (K_1 = 1.0)**			**Specific gravity, s_r = 2.4**		
Uniform velocity (m/s)	**Bed slope (%)**							
	1.0	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**8.0**	**10.0**
0.5	100	100	100	100	100	100	100	100
0.8	100	100	100	100	100	100	100	100
1.0	100	100	100	100	100	100	100	100
1.3	100	100	100	100	100	100	100	100
1.5	100	100	100	150	150	150	150	150
1.8	100	150	150	150	150	200	200	200
2.0	150	150	200	200	200	300	300	300
2.3	150	200	300	300	300	300	300	300
2.5	200	300	300	300	400	400	400	400
2.8	300	300	400	400	400	400	500	500
3.0	300	400	400	500	500	500	500	600
3.5	400	500	600	600	600	700	700	800
4.0	500	700	700	800	800	900	900	1000
4.5	600	800	900	1000	1000	1100	1200	1200
5.0	800	1000	1100	1200				

[1] Tabulated results are applicable to uniform flow conditions based on Manning's roughness determined from Equation 3.

Table 3 provides the 'K-values' that would be required for Equation 2 to produce the equivalent rock sizes determined from Equation 1 for uniform flow conditions. Table 3 indicates that as the channel slope increases and the flow becomes more turbulent, the required K-value decreases, which is consistent with the recommendations of Isbash (1936).

Table 3 – Values of 'K' required for Equation 2 to achieve the same rock size as Equation 1 in uniform flow conditions

Bed slope (%)	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**8.0**	**10.0**
K =	1.09	1.01	0.96	0.92	0.89	0.86	0.83	0.80
Flow conditions	Low turbulence ➔ ➔ ➔ ➔ ➔ ➔ ➔ ➔ ➔ Highly turbulent (whitewater)							

[1] Tabulated results are applicable to uniform flow conditions, and Manning's n based on Equation 3.

2.1 Manning roughness of rock-lined surfaces

The Manning's roughness of rock-lined surfaces may be determined from Equation 3, which was specifically developed for application in both shallow-water and deep-water flow conditions. Rock roughness values are also presented in Table 4.

$$n = \frac{{d_{90}}^{1/6}}{26\left(1 - 0.3593^{(X)^{0.7}}\right)} \quad (3)$$

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 (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.

Table 4 – 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

2.2 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 its length.

In most situations the nominal rock size is usually between 100 mm to 450 mm.

Maximum rock size generally should not exceed twice the nominal (d_{50}) rock size, but in some cases a maximum rock size of 1.5 times the average rock size may be specified.

Typical rock densities (s_r) are presented in Table 5.

Table 5 – 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

2.3 Thickness of rock layer

The thickness of the rock layer should be sufficient to allow at least two overlapping layers of the nominal rock size. A single layer of rock may be appropriate if a vegetative cover is to be established.

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 6.

Table 6 – 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

2.4 Backing material or filter layer

The rock 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.

If the rock is placed on a dispersive (e.g. sodic) soil, then prior to placing the 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.

2.5 Maximum bank gradient

The recommended maximum side slopes for large drainage channels is 1:2 (V:H); however, side slopes as steep as 1:1.5 can be stable if the rocks are individually placed rather than bumped. Typical angles of repose for dumped rock are provided in Table 7.

Table 7 – Typical angle of repose for rock

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

2.6 Placement of rock

Minimum recommended drain depth of 300 mm.

A minimum freeboard of 150 mm is suggested, but may not be appropriate for all drains.

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 2.

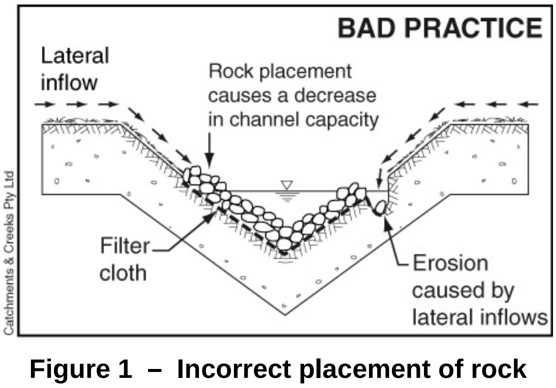

Figure 1 – Incorrect placement of rock causing loss of flow area and erosion along the outer limits of the rock

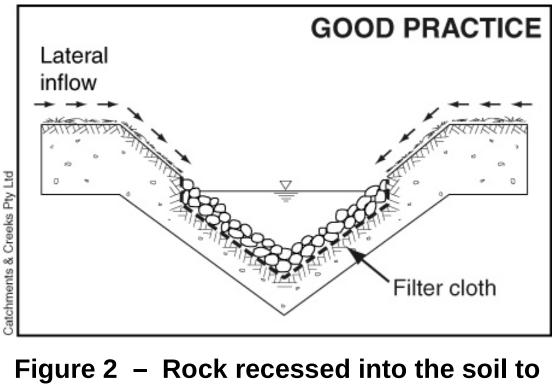

Figure 2 – Rock recessed into the soil to allow the free entry of lateral inflows

2.7 Placement of vegetation over the rock cover

Vegetating rock-lined drains can significantly increase the stability of the rock; however, it can also reduce the drain’s hydraulic capacity. Obtaining local expert advice is always recommended before establishing vegetation within drainage structures.

2.8 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.

Photo 3 – Placement of the rock on the soil can result in erosion problems if significant lateral inflows occur

Photo supplied by Catchments & Creeks Pty Ltd

Photo 4 – 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 5 – 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 6 – During construction, the drain should be excavated sufficiently to allow placement of the rock such that the finished drain has the required flow area

3. Reference

Isbash, S.V. 1936, *Construction of dams by depositing rock in running water*, Transactions, Second Congress on Large Dams, Washington, D.C. USA.

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Catchments & Creeks Pty Ltd (www.catchmentsandcreeks.com.au)
PO Box 314
Ferny Hills, Qld 4055
Australia