Rock Sizing for Single Pipe Outlets

STORMWATER MANAGEMENT PRACTICES

Photo 1 – Rock stabilised pipe outlet

Photo 2 – Rock pad outlet structure

1. Introduction

The primary performance objectives typically relate to minimising the risk of bed erosion at the outlet, and preventing undermining of the outlet head wall. The critical design parameters are the mean rock size (d_{50}) and length of rock protection (L).

The various design charts and tables presented in this fact sheet are based on the acceptance that some degree of rock movement (rearrangement) is expected following installation and that some degree of bed scour will still occur downstream of the rock pad during major flows. The minimum pad length is based on practicality issues and will not necessarily prevent all bed scour, especially when high tailwater levels exist.

2. Sizing rock for single pipe outlet structures

Recommended minimum mean (d_{50}) rock sizes are presented in tables 2 and 3. These values have been rounded up to the next 100 mm increment in recognition of the limited availability of rock sizes and the high variability of expected outcomes. Mean rock sizes are also presented graphically in Figure 1. Some minor variations should be expected between Figure 1 and the tabulated values.

A 36% increase in rock size is recommended if rounded rocks are used instead of angular rock.

The rock pad should be straight and aligned with the direction of the discharge. The recommended minimum length of rock protection (L) may be determined from tables 4 & 5. The recommended minimum width of the rock pad immediately downstream of the outlet (W_1) is the greater of the width of the outlet apron or the pipe diameter plus 0.6 m, and at the downstream end of the rock pad (W_2) the greater of W_1 or (D + 0.4L) as shown in Figure 2.

In circumstance where the width of the rock pad is governed by the width of the receiving channel, then the rock protection may need to extend partially up the banks of the channel if suitable vegetation cannot be established on the channel banks.

The thickness of the rock pad should be based on at least two layers of rock. This typically results in an overall pad thickness as presented in Table 1.

The surface elevation of the downstream end of the rock pad should be level with the invert of the receiving channel, i.e. the rocks should be recessed into the outlet channel (Figure 3) to minimise the risk of erosion around the outer edges of the rock pad.

The placement of filter cloth under the rock pad is generally considered mandatory for all permanent structures; however, if heavy sedimentation is expected within the rock voids, then the 'need' for the filter cloth is reduced. The placement of filter cloth is essential in circumstances where it is only practical to place a single layer of rock.

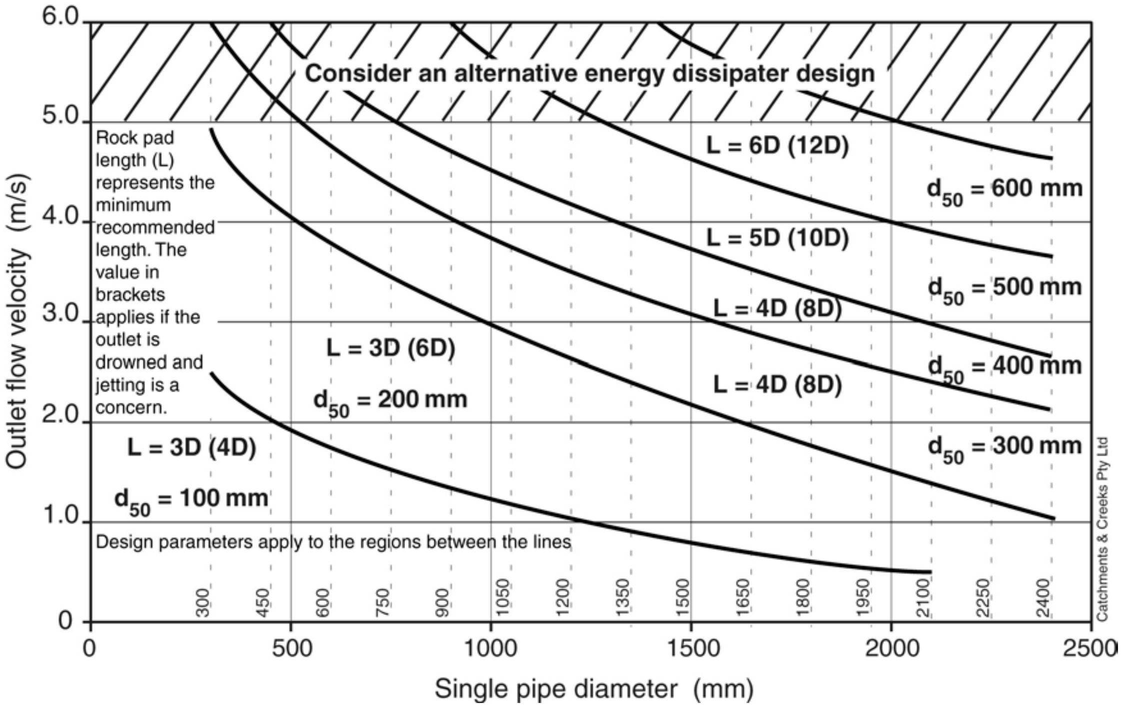

Figure 1 – Sizing of rock pad outlet structures for single pipe outlets

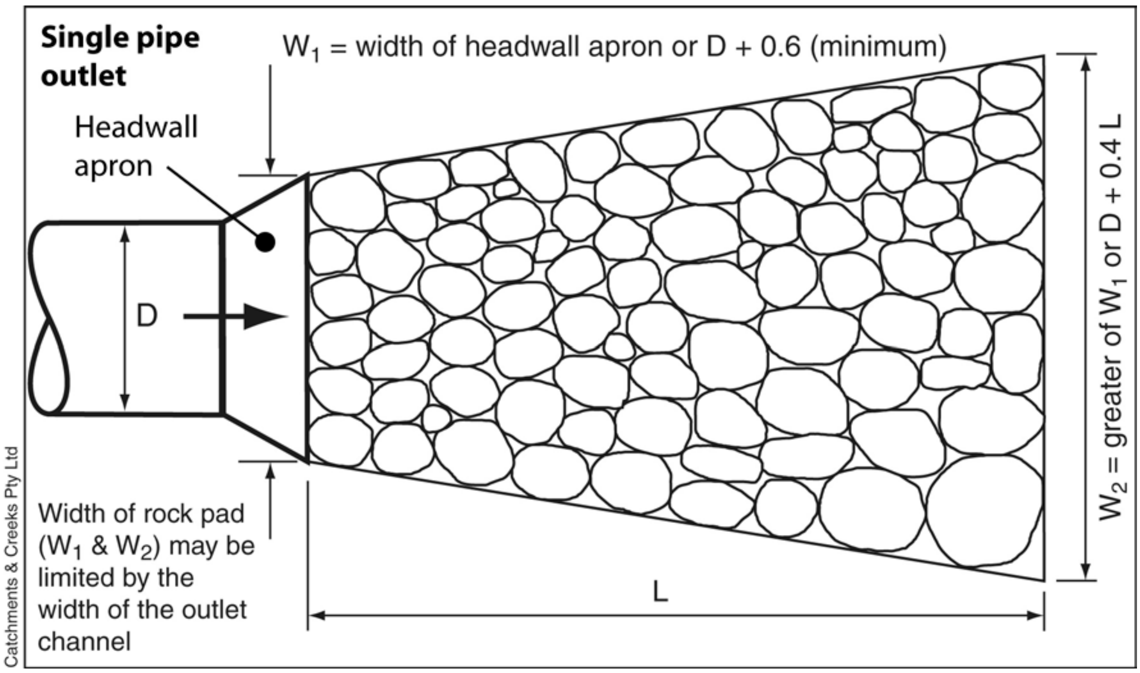

Figure 2 – Typical layout of a rock pad for single pipe outlet (plan view)

Table 1 – Minimum thickness (T) of rock pad

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

[1] d_{50} = nominal rock size (diameter) of which 50% of the rocks are smaller (i.e. the mean rock size).

3. Selecting the appropriate length of rock protection

During low tailwater conditions (TW < D/2) flow exiting the pipe will normally spread rapidly unless confined within the receiving discharge channel. Under such tailwater conditions the rock pad provides scour control benefits as well as energy dissipation. Typically the nominated minimum length of rock protection is considered adequate under these conditions.

As tailwater levels increase in elevation (D/2 < TW < D) energy dissipation as a direct result of the rock pad begins to decrease causing more flow energy to pass over the rocks. In such cases the length of the rock pad may be doubled (i.e. twice the minimum length), but only if it is essential to minimise soil erosion downstream of the rock pad.

When the outlet is submerged (TW > D) an outlet 'jet' can pass over the rock pad with minimal energy dissipation. In such cases the rock pad still provides essential scour protection adjacent to the pipe outlet, but extending the rock protection beyond the nominated minimum length may not necessarily provide any significant increase in energy dissipation or scour control.

Outlet jetting occurs when the outlet is submerged and outlet velocity is significantly greater than the receiving water velocity. High velocity jets can cause bank erosion problems if the outlet is aimed at a downstream embankment. Typically, such problems only occur if an unprotected embankment is less than 10 to 13 times the pipe diameter away from the outlet.

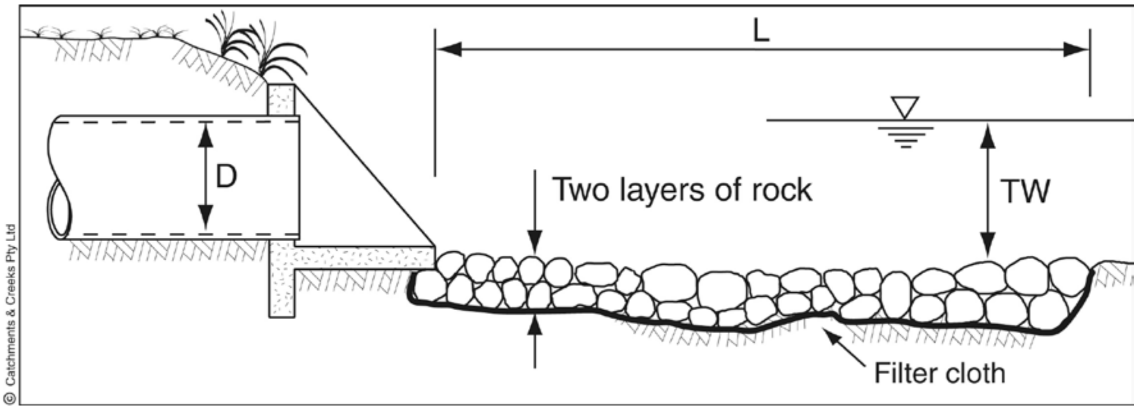

Figure 3 – Rock pad recessed into the receiving channel

4. Background to rock sizing for multi-cell culverts

The rock sizes presented in tables 2 and 3 represent an average of the values achieved by the application of the equations and design tables presented by ASCE (1992), Bohan (1970, for low tailwater) and Orange County (1989). The values have been rounded up to the next 100 mm increment in recognition of the wide variations in recommended rock sizes presented in the various literature.

Alternatively, rock size [m] may be determined from Equations 1 as presented in ASCE (1992).

$$d_{50} = 0.066\, Q^{4/3} / (TW\, .\, D) \qquad (1)$$

For multiple pipe outlets, refer to the separate fact sheet prepared for 'multi-cell pipe and culvert outlets'.

5. References

ASCE 1992, *Design and construction of urban stormwater management systems*. ASCE Manuals and Reports of Engineering Practice No. 77, and Water Environment Federation Manual of Practice FD-20, American Society of Civil Engineers, New York, USA. ISBN 0-87262-855-8

Bohan, J.P., 1970, *Erosion and riprap requirements at culvert and storm-drain outlets*. Research Report H-70-2, U.S. Army Engineer Waterway Experiment Station, Vicksburg, Mississippi, USA

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

Orange County, 1989, *Soil Erosion and Sediment Control Manual*. Orange County Planning Department, Hillsborough, North Carolina, USA

Table 2 – Mean rock size, d_{50} (mm) for culvert outlet scour protection

Outflow velocity (m/s)	Culvert height or pipe diameter (mm)						
	300	**375**	**450**	**525**	**600**	**750**	**900**
0.50	100	100	100	100	100	100	100
1.00	100	100	100	100	100	100	100
1.50	100	100	100	100	100	200	200
2.00	100	100	200	200	200	200	200
2.50	100	200	200	200	200	200	200
3.00	200	200	200	200	200	200	200
3.50	200	200	200	200	200	300	300
3.75	200	200	200	200	300	300	300
4.00	200	200	200	300	300	300	400
4.25	200	200	300	300	300	300	400
4.50	200	300	300	300	300	400	400
4.75	200	300	300	300	300	400	500
5.00	300	300	300	300	400	400	500
5.25	300	300	300	400	400	500	500
5.50	300	300	300	400	500	500	500
5.75	300	300	400	500	500	500	500
6.00	300	400	500	500	500	500	600

Table 3 – Mean rock size, d_{50} (mm) for culvert outlet scour protection

Outflow velocity (m/s)	Culvert height or pipe diameter (mm)						
	1050	**1200**	**1350**	**1500**	**1800**	**2100**	**2400**
0.50	100	100	100	100	100	100	100
1.00	100	100	200	200	200	200	200
1.50	200	200	200	200	200	300	300
2.00	200	200	200	200	300	300	300
2.50	200	300	300	300	300	400	400
3.00	300	300	300	300	400	500	500
3.50	300	400	400	400	500	500	500
3.75	400	400	400	400	500	500	600
4.00	400	400	500	500	500	600	600
4.25	400	500	500	500	600	600	600
4.50	500	500	500	500	600	600	600
4.75	500	500	500	600	600	600	700
5.00	500	500	600	600	600	700	700
5.25	500	600	600	600	600	700	700
5.50	600	600	600	600	700	700	900
5.75	600	600	600	600	700	900	900
6.00	600	600	600	700	700	900	900

Table 4 – Minimum length (L) of rock pad relative to cell height (H) for culvert outlet protection [1,2]

Outflow velocity (m/s)	Culvert height or pipe diameter (mm)						
	300	375	450	525	600	750	900
0.50	3	3	3	3	3	3	3
1.00	3	3	3	3	3	3	3
1.50	3	3	3	3	3	3	3
2.00	3	3	3	3	3	3	3
2.50	3	3	3	3	3	3	3
3.00	3	3	3	3	3	3	3
3.50	3	3	3	3	3	4	4
3.75	3	3	3	3	4	4	4
4.00	3	3	3	4	4	4	4
4.25	3	3	4	4	4	4	4
4.50	3	4	4	4	4	4	4
4.75	3	4	4	4	4	4	5
5.00	4	4	4	4	4	4	5
5.25	4	4	4	4	4	5	5
5.50	4	4	4	6	6	6	6
5.75	4	4	6	6	6	6	6
6.00	4	6	6	6	6	6	6

Table 5 – Minimum length (L) of rock pad relative to cell height (H) for culvert outlet protection [1,2]

Outflow velocity (m/s)	Culvert height or pipe diameter (mm)						
	1050	1200	1350	1500	1800	2100	2400
0.50	3	3	3	3	3	3	3
1.00	3	3	3	3	3	3	4
1.50	3	3	3	3	3	4	4
2.00	3	3	3	3	4	4	4
2.50	3	4	4	4	4	4	4
3.00	4	4	4	4	4	4	4
3.50	4	4	4	4	5	5	5
3.75	4	4	4	4	5	5	5
4.00	4	4	5	5	5	5	5
4.25	4	5	5	5	5	5	5
4.50	5	5	5	5	5	5	5
4.75	5	5	5	5	5	5	5
5.00	5	5	5	5	6	6	6
5.25	6	6	6	6	6	6	
5.50	6	6	6	6	6		
5.75	6	6	6	6	6		
6.00	6	6	6	6	6		

[1] Values represent the recommended minimum length of rock protection to prevent significant scour; however, some degree of soil erosion should be expected downstream of the rock protection.

[2] Under high tailwater conditions (TW > D/2) outlet jetting may extend beyond the rock protection during high tailwater conditions resulting in bed and/or bank erosion downstream of the rock protection. Extending the length of the rock protection will not necessarily reduce the risk of downstream bank erosion under high tailwater conditions.