Rock Sizing for Waterway Riffles

WATERWAY MANAGEMENT PRACTICES

Photo 1 – Constructed riffle

Photo 2 – Constructed fishway ramp

1. Introduction

A riffle is an isolated section of channel bed where the steepness of the bed allows for the exposure of the bed rocks and gravels during periods of low flow, often resulting in the formation of whitewater conditions (Photo 1). In pure hydraulic terms, riffles are the same as rock chutes; however, their small size and low gradient means the design procedures used for sizing the rock are normally different from those used in the design of batter chutes and spillways. A rock-lined fish ramp (Photo 2) is also a type of rock chute, and in essences, also a riffle.

The shape and placement of the rock within these waterway structures primarily depends on the functions of the structure; however, the size of the rock is generally governed by the following hydraulic parameters:

- the maximum flow velocity during which the rock is required to be stable;
- the degree of exposure of the rock to direct river flow (i.e. does the rock sit sheltered amongst other similarly sized rock such as in a classical riffle, or does the rock sit above the surrounding bed material such as in a rock weir); and
- the degree of turbulence within the water flow—this usually varies with water depth and flow velocity.

In some cases the rock size is governed by the requirements for fish passage. In such cases the rocks may be significantly smaller than that required for hydraulic stability. This is often the case in the design of 'ridge rock' rock ramps (Photo 3). This means that the exposed ridge rocks often need to be anchored to the bed of the stream with the aid of concrete—a highly undesirable design scenario, especially in moving-bed alluvial streams.

Photo 3 – Ridge rock fishway

Photo 4 – Rock weirs

Rock weirs (Photo 4) are often used in medium-gradient streams to provide bed stability while also allowing for fish passage. These rocks also site above the normal bed level, which increases their exposure to direct hydraulic forces and impact by flood debris.

Unlike natural riffle systems, most constructed riffles, rock chutes, fishway ramps, ridge rock fishways and rock weirs are required to be stable during a wide variety of stream flows. Natural riffles, on the other hand, are usually formed from natural bed gravels that are expected to migrate down the stream during flood events. In some cases, the whole riffle structure migrates a short distance down the stream during each flood event.

Constructed riffles, however, usually need to contain rocks that are substantially larger than those found in natural riffles. This means their performance, especially with regards to fish passage, can vary substantially from natural riffles.

2. Rock sizing for waterway riffles

One of the biggest differences between the rock used in the construction of rock chutes (which are normally used in the stabilisation of gullies) and the rocks used in the construction of fishways and riffles, is the required distribution of rock sizes. Rock chutes are normally constructed from rocks of a near uniform size, with special interest being paid to the larger rocks. On the other hand, constructed riffles and other fishways need to be constructed from rocks containing sufficient quantities of small rocks to minimise interflow (flow through the rock voids). This means that special attention is given to the distribution of rock sizes.

The stability of the rocks used in constructed riffles needs to be checked for a variety of flow conditions. Typically, the mean rock size (d_{50}) is determined as the **largest** of the rock sizes calculated from Sections 2.1 and 2.2 below for both low and high-flow conditions.

2.1 Rock sizing for low-flow conditions

In most cases, the required rock size will not be governed by low flow conditions. Low flow conditions are likely to only influence the design of long, steep-gradient riffles.

This hydraulic check requires the determination of the maximum flow velocity that occurs on the riffle prior to the riffle being drown-out by downstream flow conditions (Figure 1). This usually requires numerical modelling of the stream for a range of flow conditions. Minimum, mean rock size is determined from Equation 1.

$$d_{50} = \frac{SF.K_1.V^2}{(A - B.\ln(S_o)).(s_r - 1)} \quad (1)$$

where:

- A & B = equation constants: A = 3.95 and B = 4.97 for SF = 1.2
- d_{50} = nominal rock size (diameter) of which 50% of the rocks are smaller [m]
- K_1 = correction factor for rock shape
  = 1.0 for angular (fractured) rock, 1.36 for rounded rock (i.e. smooth, spherical rock)
- SF = factor of safety = 1.2 (recommended)
- S_o = gradient of the riffle face [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 = maximum depth-average flow velocity over the rocks during low flow [m/s]

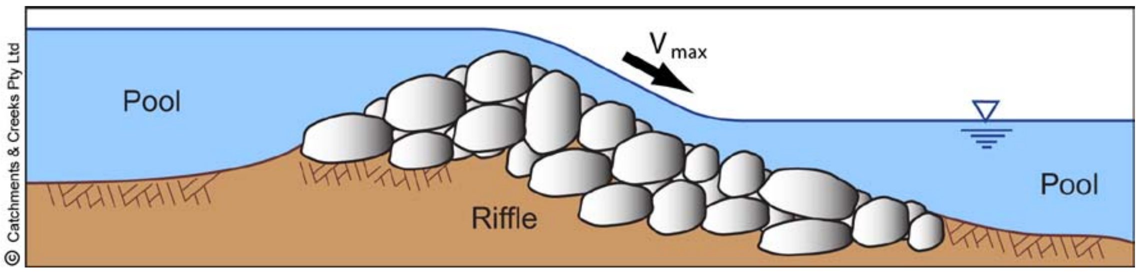

Figure 1 – Critical low-flow conditions

2.2 Rock sizing for high flow conditions

This hydraulic check requires the nomination of the maximum stream flow during which the riffle rock is required to be stable, e.g. the 1 in 10 year or 1 in 50 year discharge. This flow condition is then modelled to determine the maximum depth-average flow velocity passing over the riffle.

It is important that the depth-average velocity as determined from the hydraulic modelling is representative of the actual flow velocities above the riffle, **not** the flow velocity averaged across the full cross-section, which may be influenced by bank roughness or overbank flows.

Minimum, mean rock size for these high flow conditions may be determined from Equation 2.

$$d_{50} = \frac{K_1 . V^2}{2 . g . K^2 (s_r - 1)} \qquad (2)$$

where:

K = equation constant based on flow conditions

= 1.1 for low-turbulent deepwater flow or 0.86 for highly turbulent flow; otherwise, refer to Table 1 for suggested vales of 'K' based on the flood gradient

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

g = acceleration due to gravity [m/s^2]

Table 1 – Suggested values of 'K' for various flood gradients

Flood gradient (%)	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)							

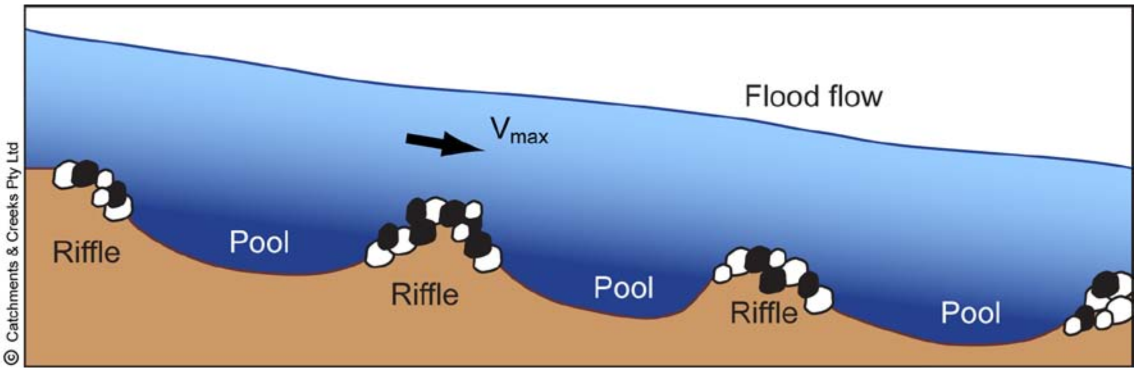

Figure 2 – Critical high-flow conditions passing over several riffles

2.3 Determination of Manning's roughness

Both Equations 1 & 2 require the assessment of hydraulic conditions based on the nomination of a channel and riffle roughness. The Manning's roughness of rock-lined surfaces for shallow-water and deep-water flow conditions may be determined from Equation 3. Rock roughness values are also presented in Table 2.

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

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 2 – 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

3. Specification of rock for constructed riffles

In circumstances where the constructed riffle is required to simulate 'natural' bed conditions, and the riffle is located in a waterway that contains natural pool–riffle systems, then the rocks used in construction of the riffle should match the size distribution of the natural riffle systems. For constructed riffles that are required to be stable during major flows, then the following rock specifications should be considered.

Crushed rock is generally more stable than natural rounded rock; however, rounded rock has a more 'natural' appearance. A 36% increase in rock size is recommended for rounded rock (i.e. K_1 = 1.36).

Broken concrete and building rubble should not be used.

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.

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

Table 3 provides a suggested distribution rock sizes for constructed riffles.

Table 3 – Recommended distribution of rock size for constructed riffles

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_{25}/d_{50}	0.45
d_{10}/d_{50}	0.20

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