Rock Filter Dams (Instream)

INSTREAM PRACTICES

Flow Control		No Channel Flow	✓	Dry Channels	✓
Erosion Control		Low Channel Flows	✓	Shallow Water	
Sediment Control	✓	High Channel Flows		Deep Water	

RFD

Symbol

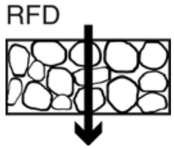

Photo 1 – Rock filter dam with geotextile filter

Photo 2 – Rock filter dam with aggregate filter

Key Principles

1. Primarily used within constructed drainage channels, not natural streams, due to the degree of bed and banks disturbance that occurs during installation and removal of the rock.
2. Sediment trapping is achieved by both particle settlement within the settling pond formed upstream of the dam (Photo 1), and by the filtration of water passing through the aggregate or geotextile filter (Photo 2).
3. The critical design parameter for optimising particle settlement is the 'surface area' of the settling pond. The hydraulic properties of the rock embankment are critical in achieving the desired stage-discharge relationship to achieve optimum settling pond conditions.
4. The critical design parameters for the filtration process are the design flow rate for water passing through the filter, which is related to the depth of water (hydraulic head), and the surface area and flow resistance of the filter.
5. Geotextile filters provide superior filtration performance and should be favoured.

Design Information

The following design information specifically relates to instream installations. The design of off-stream rock filter dams is discussed within a separate fact sheet.

Rock filter dams may contain up to three different categories of rock, those being:

- The primary core rock, which makes up the bulk of the rock embankment.
- Armour rock, which protects the downstream face of the embankment from overtopping flows, and also used for scour protection downstream of the embankment.
- Filter layer aggregate, which is placed on the upstream face of the rock embankment.

In most cases, the same rock is specified for the core of the embankment as well as the armour protection of the downstream face. The minimum rock size is 225mm nominal diameter for angular (fractured) rock. If round rock is used, a practice **not** recommended, then the minimum nominal rock diameter is 300mm.

The entire embankment should **not** be formed from filter aggregate as shown in Photo 3.

Typical size of filter aggregate is 15 to 25mm nominal diameter.

The use of geotextile filters (minimum 'bidim' A34 or equivalent) is preferred in most instream situations where the rock filter dam is likely to have an operational life of a few months. For long-term installations, aggregate filters (Figure 1) may be preferred to simplify maintenance procedures.

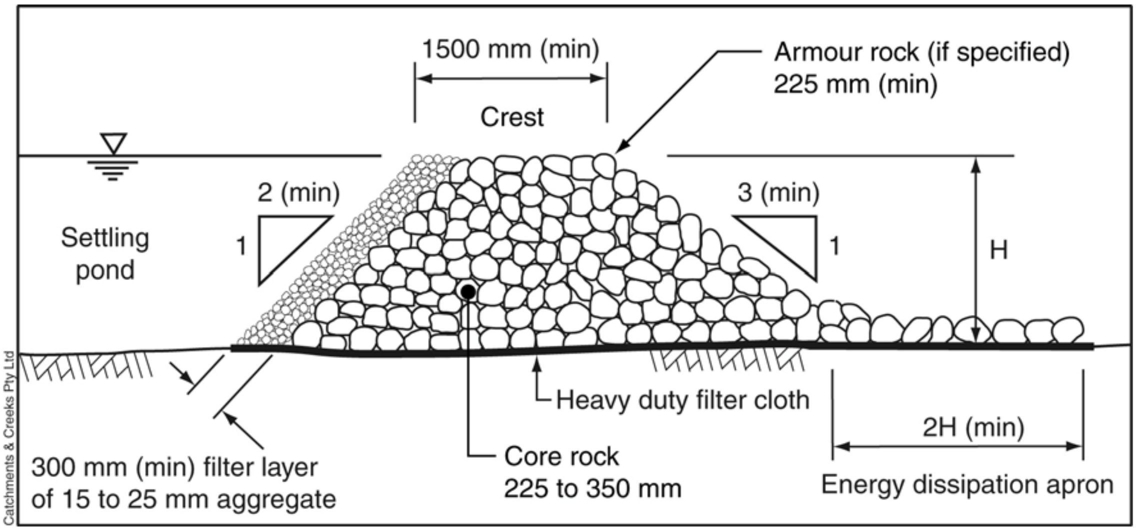

Figure 1 – Rock filter dam with aggregate filter

Rock filter dams with geotextile filters (Figure 2) usually require the use of an aggregate layer to achieve the desired stage-discharge flow conditions for the embankment for the purpose of achieving the optimum settling pond conditions (refer to 'Design Procedure' over page).

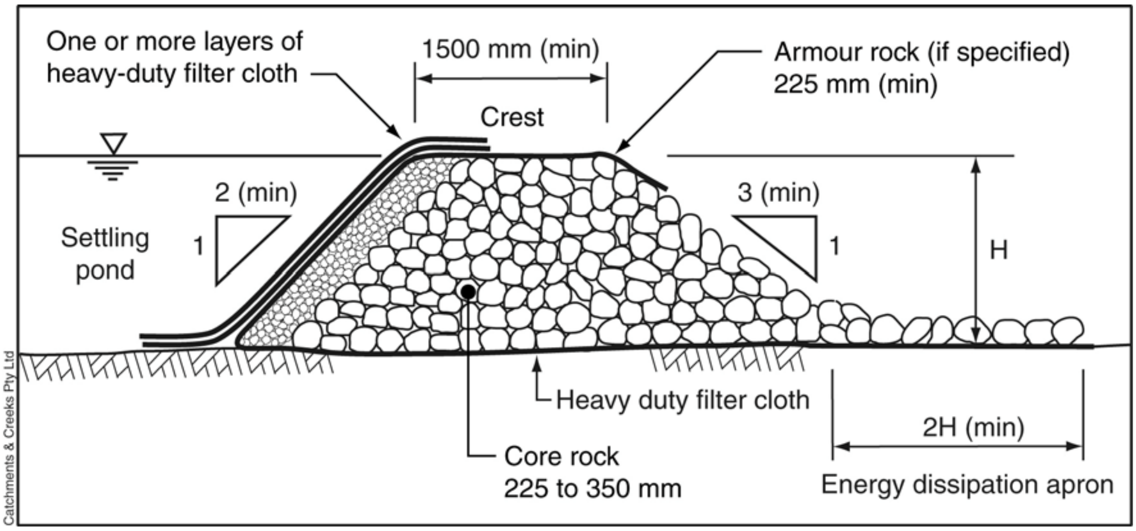

Figure 2 – Rock filter dam with geotextile (filter cloth) filter

The geotextile fabric is normally extended over the crest of the rock filter dam to enhance the stability of the spillway crest (Photo 1). In long-term operations, consideration should also be given to the placement of several layers of overlapping fabric (Figure 2), thus allowing each layer to be removed individually once the fabric becomes blocked with sediment.

If an excavated sediment collection pit/trench is incorporated into the settling pond, then the use of a geotextile filter should be considered essential.

Design Procedure

1. Determine the primary design discharge (Q) for water passing through the rock embankment just prior to flows overtopping the spillway (Figure 3). This is normally set equal to the expected dry weather flow rate of the stream.
2. Determine the weir design discharge (Q_{WEIR}) for overtopping flows (Figure 4). The appropriate design event may be set by the licence conditions (set by State or local authority), otherwise choose a stream flood frequency of at least 10 times the expected operational life of the structure, but at least a 1 in 1 year channel flow.
3. Determine the desirable settling pond surface area (A_s) from Table 1 based on the design discharge (Q). Where practical, a critical particle size of 0.05mm should be chosen.
4. Determine the maximum allowable water level within the settling pond. This may be based on-site constraints, or related to flooding and/or public safety issues.
5. Determine the required width of the rock filter dam (W). The width (perpendicular to the direction of flow) may be limited by site constraints, or controlled by the hydraulic management of overtopping flows. The hydraulic analysis of overtopping flows is normally based on broad-crested weir equations—refer to the separate fact sheet *'Chutes Part 1: General Information'*.
6. Select the required crest elevation of the rock filter dam to achieve the desired settling pond surface area. Ensure the spillway crest is sufficiently below the maximum allowable water elevation to allow for expected overtopping flows (possibly an iterative design step).

   Operators should **avoid** circumstances where the settling pond needs to be excavated (expanded) to achieve the required surface area as this can cause undesirable channel damage.
7. Select the type of filtration system using Table 3 as a guide.
8. Determine the maximum allowable head loss (ΔH) through the rock embankment including filter medium. If flow conditions downstream of the rock filter dam are such that there is little or no backwater effects during the design discharge (Q), then assume ΔH is equal to the height of the rock filter dam (H).

   If flow depths downstream of the rock filter dam are expected to be significant, then the maximum allowable head loss (ΔH) should be taken as the expected variation in water level across the dam during the design discharge.
9. Select a 'design' blockage factor (B.F.) using Table 4 as a guide.
10. Use the design information provided below to determine the make-up and thickness of the filter medium that is required achieve the desired stage–discharge relationship.
11. If the available pond surface area is insufficient to settle the required particle size, then the efficiency of the sediment trap may be improved by placing filter cloth across the upstream face of the rock filter dam (if not already used). In addition, *Filter Tubes* (refer to *Filter Tube Dams*) can be incorporated into the dam. Note the filter tube intake pipes would need to be set at an elevation above the expected settled sediment depth.
12. Determine the rock size required for the spillway (i.e. downstream face of the rock embankment). Refer to section (d) below and Table 2.

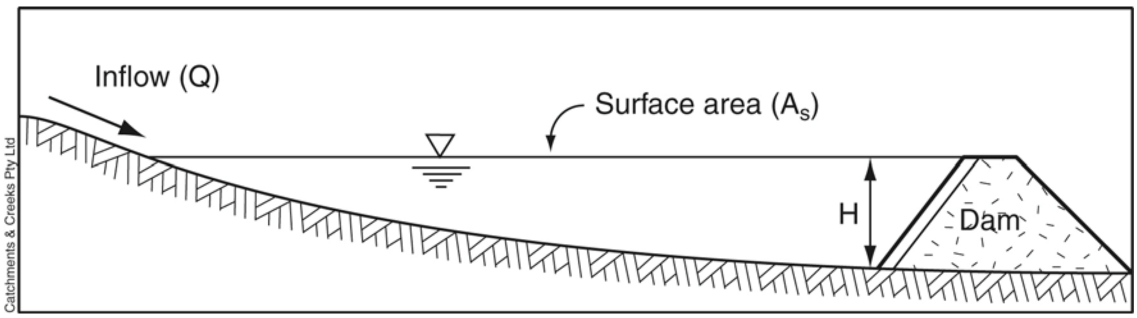

Figure 3 – Minimum design flow condition

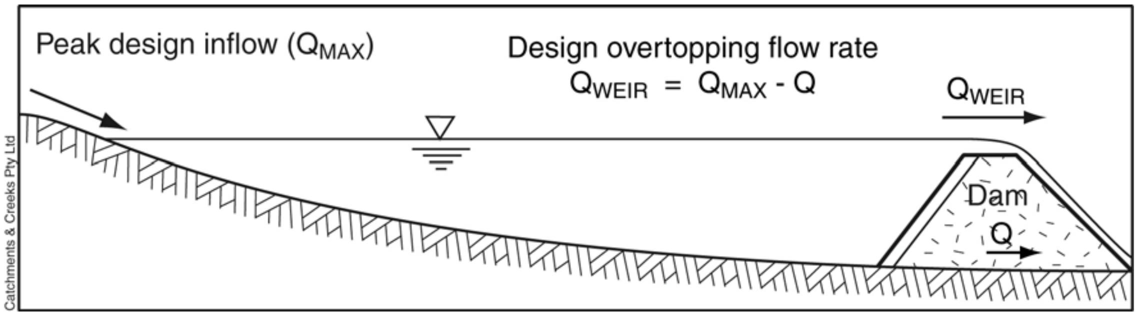

Figure 4 – Maximum design flow condition

(a) Settling pond:

Table 1 provides the required pond surface area per unit flow rate for various nominated 'critical' sediment particle sizes. The critical sediment particle size for a rock filter dam may be assumed to be 0.05mm; however, this may not always be practical within instream installations. The chosen critical sediment size should reflect the environmental values of the waterway and the expected weather conditions.

Ideally, the settling pond should have a length (in the main direction of flow) at least three times its average width. If the pond length is less than three times its average width, then the pond area should be increase by 20% from the values presented in Table 1.

If it is practical to achieve the minimum pond surface area, then a greater focus should be placed on the design of the filter medium placed on the upstream face of the dam.

Table 1 – Minimum settling pond surface area per unit inflow rate

Design standard	Critical sediment size (mm)	Surface area of settling pond per unit discharge ($m^2/m^3/s$) [1]			Allowable through-velocity (m/s)
		10° C [2]	15° C [2]	20° C [2]	
Type 3 sediment trap	0.50	6	5.2	4.6	0.3
	0.20	38	33	29	0.3
	0.15	67	60	52	0.3
Type 2 sediment trap	0.10	150	130	115	0.2
	0.05	600	525	460	0.2
Type 1 sediment trap	0.04	940	820	720	0.2
	0.02	3700	3230	2860	0.2

[1] Pond area is based on a rectangular pond operating with uniform inflow conditions across its width.

[2] Assume a pond temperature the same as the typical rainwater temperature during the time of year when the pond is likely to be operating at capacity.

(b) Rock embankment:

Minimum desirable top width (in direction of flow) = 1.5m.

Maximum height at centreline of the embankment = 1.5m. Otherwise the design should be assessed for stability by a suitably qualified person (e.g. geotechnical engineer).

Maximum side slopes of 2:1(H:V) on the up-slope face, and 3:1(H:V) on the down-slope face.

The spillway crest on rock embankment higher than 0.5m should be flat and perpendicular to the alignment of the spillway chute, otherwise a slightly curved profile can be used.

Rock abutments should extend at least 450mm (in elevation) above the spillway crest.

The primary core rock should be well graded, hard, erosion resistant stone. Minimum mean rock size (d_{50}) of 225mm, and a maximum of 350mm. If the rock size required for scour protection on the downstream face is greater than 350mm, then separate 'core' and 'armour' rock should be specified.

Prior to the placement of the rock, the footprint of the dam should be covered by heavy-duty filter cloth (minimum 'bidim' A34 or equivalent) with minimum 600mm overlap at joints.

(c) Emergency spillway (downstream face of embankment):

Guidance on the hydraulic analysis of broad-crested weirs is provided in the separate fact sheet *'Chutes Part 1: General Information'* located within the Drainage Structures sub-category.

The maximum design storm (Q_{MAX}) may be set by State licence conditions, otherwise choose a stream flood frequency of at least 10 times the expected operational life of the structure, but at least a 1 in 1 year channel flow.

The design flow rate for the overtopping weir (Q_{WEIR}) is the difference between the maximum design storm flow rate (Q_{MAX}) and the design flow rate for the filter medium (Q).

Desirable longitudinal gradient of spillway no steeper than 3:1(H:V), absolute maximum of 2:1.

The desirable minimum thickness of armour rock lining is 500mm, or twice the nominal rock size, whichever is larger (if specifications for the armour rock are different from that of the embankment core rock).

The required mean rock size can be determined from either of the following:

- *'Chutes Part 5: Rock linings'* fact sheet, see the 'Drainage Structures' sub-category;
- *'Rock Linings'* fact sheet, see the 'Channel and Chute Linings' sub-category;
- Table 2, assuming angular rock with a specific gravity of 2.4, and safety factor of 1.2.

Table 2 – 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 [2] = 5:1**		**Bed slope = 4:1**		**Bed slope = 3:1**		**Bed slope = 2:1**	
	y (m)	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**	**y (m)**	**d_{50}**
0.1	0.09	**0.10**	0.09	**0.10**	0.09	**0.20**	0.09	**0.20**
0.2	0.15	**0.20**	0.14	**0.20**	0.14	**0.20**	0.14	**0.30**
0.3	0.19	**0.20**	0.19	**0.20**	0.19	**0.30**	0.18	**0.30**
0.4	0.23	**0.30**	0.23	**0.30**	0.23	**0.30**	0.22	**0.40**
0.5	0.27	**0.30**	0.27	**0.30**	0.26	**0.40**	0.26	**0.40**
0.6	0.31	**0.30**	0.30	**0.40**	0.30	**0.40**	0.29	**0.50**
0.8	0.37	**0.40**	0.37	**0.40**	0.36	**0.50**	0.35	**0.60**
1.0	0.43	**0.40**	0.42	**0.50**	0.42	**0.60**	0.41	**0.70**
1.2	0.49	**0.50**	0.48	**0.50**	0.47	**0.60**	0.46	**0.70**
1.4	0.54	**0.50**	0.53	**0.60**	0.52	**0.70**	0.51	**0.80**
1.6	0.59	**0.60**	0.58	**0.70**	0.57	**0.70**	0.56	**0.90**
1.8	0.64	**0.60**	0.63	**0.70**	0.62	**0.80**	0.60	**1.00**
2.0	0.68	**0.70**	0.67	**0.70**	0.66	**0.90**	0.65	**1.00**

[1] Uniform flow depth down face of spillway is expected to be highly variable due to turbulence.

[2] Bed slope is the slope of the spillway (i.e. downstream face of the rock filter dam).

(d) Downstream channel protection:

A rock apron should extend downstream from the toe of the dam (at zero gradient) a sufficient distance to prevent channel erosion, or a distance equal to the height of the dam, whichever is the greater. Disturbance to the channel bed while installing the rock apron must be minimised.

(e) Filter medium:

The entire upstream face of the rock structure should be covered with an appropriate filter media. The properties of the various filter media are presented in Table 3.

Table 3 – Properties of various filter media

Type	Material	Properties
Filter cloth	Heavy-duty filter cloth (minimum 'bidim' A34 or equivalent) one or more layers	Short-term sediment traps (< 6-months) Medium trapping efficiency
Aggregate	Minimum 300mm thick layer of 15 to 25mm aggregate	Short to medium-term traps (6 to 12-months) Initially poor filtering capacity until partial sediment blockage of the aggregate occurs, after which medium trapping efficiency Medium maintenance requirements
	Minimum 300mm thick layer of 25 to 75mm aggregate	Long-term sediment traps (> 12-months) Low trapping efficiency Low to medium maintenance requirements

The filter medium is required to perform the following two tasks:

- slow the passage of water through the embankment so that an upstream settling pond will form with the required surface area to allow adequate gravitational settlement; and
- filter sediment from the water that passes through the filter medium.

(f) Aggregate filter hydraulics:

The head loss (ΔH) of a rock filter can be determined using Equation 1, which is based on the dimensions of an equivalent rectangular rock-filled medium.

$$\Delta H^{1.5} = \frac{1000.Q.T^{0.5}}{B.F.[15.2 - 0.0068(d)].W.d^{0.5}} \qquad \text{(Eqn 1)}$$

Notes on Equation 1:

- It is assumed that the effective height of the rock filter (H) is equal to the head loss (ΔH) through the structure, i.e. it is assumed that there is no hydraulic back pressure on the downstream face of the rock filter.
- The equation was developed from research work presented by Jiang et al., within Fifield (2001).
- Given the complexity of many rock filters, the equation may not be accurate in all circumstances, but is assumed to be satisfactory for design purposes.

If the core of the rock embankment contains rock larger than 100mm in diameter, then it may be assumed that this rock does not provide any measurable hydraulic resistance to the passage of water through the dam.

Alternatively, if the maximum allowable head loss (ΔH) is known, then the allowable flow rate (Q) can be determined using Equation 2.

$$Q = (B.F.)[15.2 - 0.0068(d)]\frac{W.\Delta H^{1.5}.d^{0.5}}{1000\ T^{0.5}} \qquad \text{(Eqn 2)}$$

where:

Q = Flow rate (assuming no blockage) [m^3/s]
d = mean (d_{50}) size of the filter rock [mm]
W = width of rock filter dam across the direction of flow [m]
ΔH = head loss through rock filter [m]
T = thickness of rock filter in the direction of flow [m]

Table 4 – Blockage factors for filter mediums

Blockage factor (B.F.)	Appropriate usage
1.0	When assessing the 'As Constructed' maximum flow rate.
0.9	Sediment traps operating in coarse-grained soils where the runoff of fine silts and clays is expected to be only minor.
0.5	Default design value. Sediment traps likely to experience more than one storm event.

Ideally, rock filter dam should be able to fully discharge (de-water) the settling pond over **no less** than 8 hours to allow sufficient time for particle settlement. Settling ponds that can drain (from full) in less than 8 hours may not achieve optimum sediment capture. Settling ponds that drain (from full) over a period greater than 8 hours may indicated the need for maintenance of the filter medium.

(g) Filter cloth hydraulics:

The head loss through a layer of filter cloth can be determined from the permittivity (ψ) of the reported fabric in accordance with AS 3706-9.

$$\Delta H = \frac{Q}{(B.F.).A.\psi} \qquad \text{(Eqn. 3)}$$

where:

- ΔH = Hydraulic head loss through geotextile [m]
- Q = Total flow rate through the geotextile [m^3/s]
- A = Surface area of the geotextile [m^2]
- ψ = Permittivity of the geotextile (AS 3706-9) [s^{-1}]

The permittivity for various grades of 'bidim' filter cloth can be determined from Table 5.

Table 5 – Flow rate per unit width for various grades of 'bidim' filter cloth (no blockage allowance)

bidim grade =	A12	A14	A24	A29	A34	A44	A64
Flow rate @ 100mm head [1] ($L/s/m^2$)	512	454	342	242	217	161	118
Permittivity (AS 3706-9) 'ψ' (s^{-1})	5.12	4.54	3.42	2.42	2.17	1.61	1.18

[1] Manufacturer's specified flow rate at a constant head of 100mm based on AS 3706-9.

Figures 5 to 9 provide examples of typical rock filter dam profiles and the equivalent filter barrier hydraulic analysis profile.

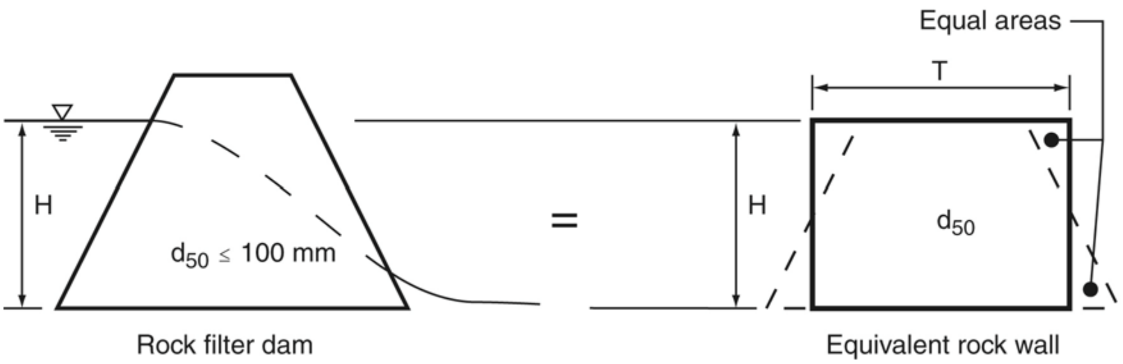

Figure 5 – Rock filter dams formed only from small filter rock (not recommended)

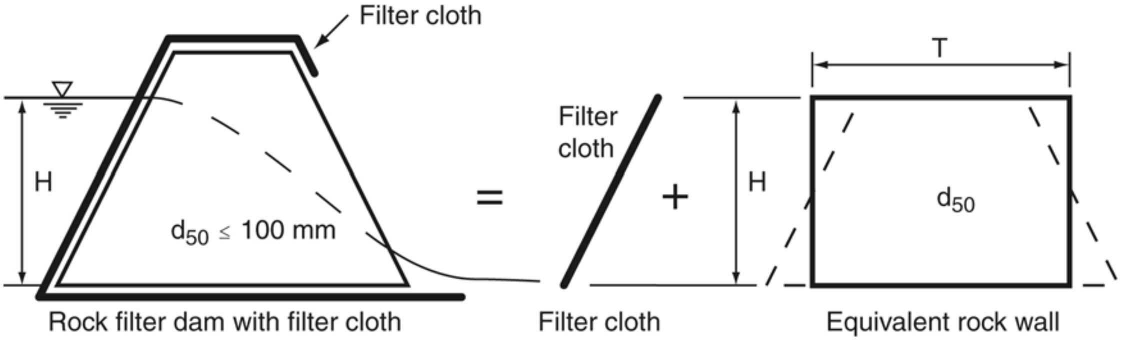

Figure 6 – Rock filter dam formed from small filter rock with upstream filter cloth

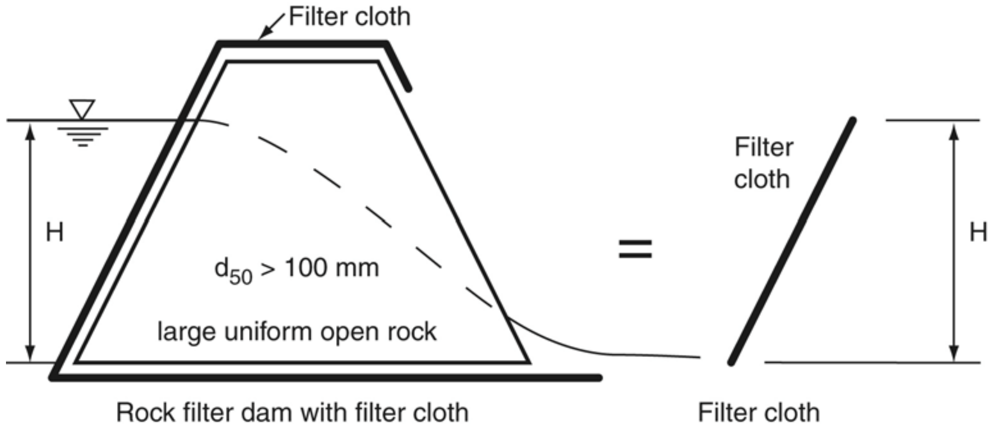

Figure 7 – Rock filter dam formed from large, free-draining rock with upstream filter cloth

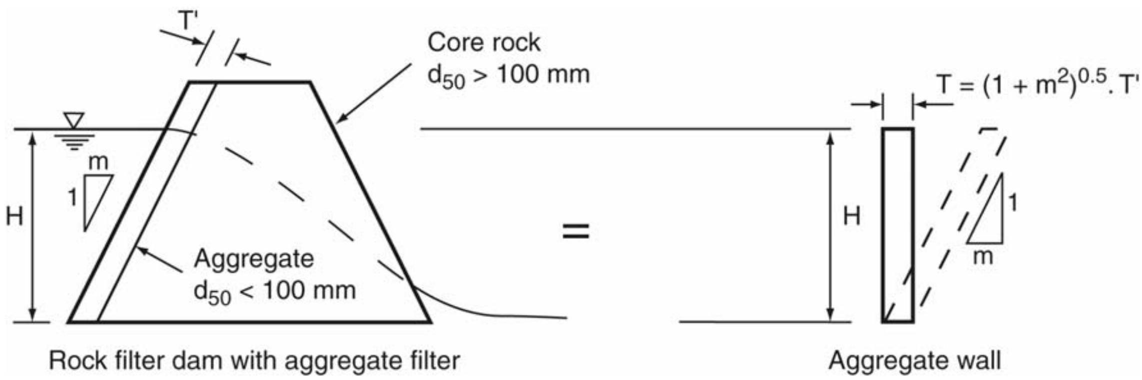

Figure 8 – Rock filter dam formed from large, free-draining rock with upstream aggregate filter

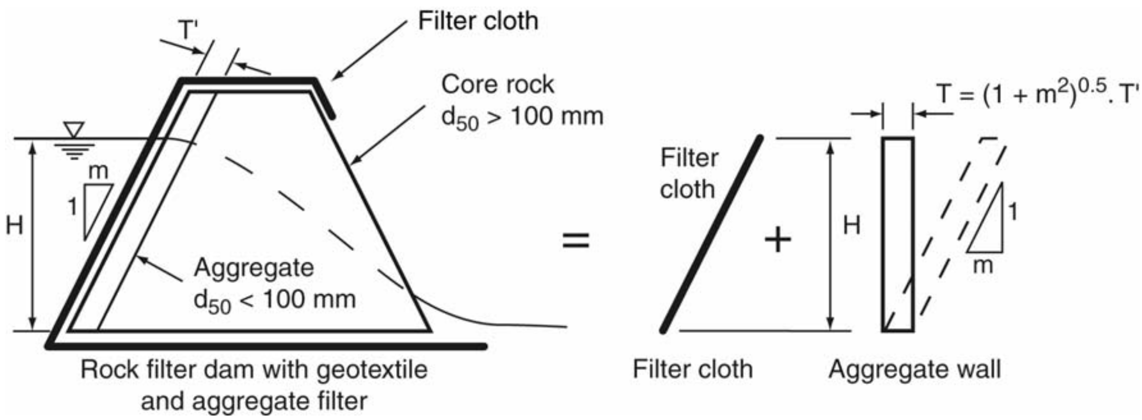

Figure 9 – Rock filter dam formed from large, free-draining rock with combined geotextile and aggregate filter

Photo 3 – The rock embankment should not be made entirely from fine aggregate

Photo 4 – If operated for extended periods the rock embankment can become saturated with fine sediments resulting in sediment release into downstream waters

Reference:

Fifield, J.S. 2001, *Designing for Effective Sediment and Erosion Control on Construction Sites.* Forester Communications, California. ISBN 0-9707687-0-2.

Description

A rock embankment usually constructed from large uniform-sized rocks, with a filter medium placed on the upstream face of the embankment. The filter medium typically consists of either one or more layers of filter cloth, and/or a layer of aggregate.

The downstream face of the rock embankment usually acts as a spillway.

Purpose

Primarily used within constructed drainage channels, not natural streams, due to the degree of bed and banks disturbance that occurs during installation and removal of the rock.

Limitations

Limited ability to control turbidity levels or trap fine sediments, except during periods of low flow.

Advantages

Can be installed while the stream is flowing, but clean (washed) rock must be used.

Easy to construct and maintain with heavy machinery.

Disadvantages

Can cause significant bed and bank disturbance as well as water quality problems while the dam is being installed and removed.

Can be costly to install and remove.

The filter medium may regularly block with sediment requiring their replacement.

Geotextile filters are very difficult to replace once covered in mud.

Fine sediments (e.g. clay particles) readily pass through most rock filter dams.

Special Requirements

Geotextile filters provide superior filtration performance and should be favoured.

Rock size should be appropriate for the expected over-topping flow rate (i.e. flood event).

Small dams (< 1m) should have a slightly curved profile (in plan view) pointing upstream to concentrate overtopping flows towards the centre of the channel.

The larger embankment rock provides the structural stability and acts as the spillway for overtopping flows.

Location

Primarily used within constructed drainage channels, not vegetated streams.

Site Inspection

Check the clarity of the outflow downstream of the dam.

Check the choice and performance of the filter medium.

Check for potential flows bypassing the filter medium.

Check for displacement of rock.

Materials

- Primary core rock: well graded, hard, angular, erosion resistant rock, with mean size as specified in the approved plan, but not less than 225mm, or greater than 350mm.
- Armour rock: well graded, hard, angular, erosion resistant rock, with mean size as specified in the approved plan, but not less than 225mm.
- Aggregate filter: 15 to 25mm clean aggregate.
- Geotextile filter fabric: heavy-duty non-woven, needle-punched filter fabric, minimum 'bidim' A34 or equivalent.

Installation

1. Prior to commencing any works, obtain all necessary approvals and permits required to conduct the necessary works including permits for the disturbance of riparian and aquatic vegetation, and the construction of all permanent or temporary instream barriers and instream sediment control measures.
2. Refer to approved plans for location and construction details. If there are questions or problems with the location, or method of installation, contact the engineer or responsible on-site officer for assistance.
3. If there is flow within the watercourse or drainage channel at the time of construction of the rock filter dam, then install appropriate downstream sediment control devices and/or flow diversion systems prior to construction of the dam. Such measures should only be installed if considered appropriate for the local conditions, and only if their installation is judged to provide a net overall environmental benefit.
4. To the maximum degree practicable, construction activities and equipment must not operate within open flowing waters.
5. Clear the location for the dam; clearing only what is needed to provide access and to install the dam.
6. Remove any cleared organic matter and debris from the disturbance area and dispose of it properly. Do not use organic matter or debris to build the rock filter dam.
7. To assist in the eventual removal of all materials used in the construction of the rock filter dam, a protective layer of geotextile fabric (preferably in the form of a single sheet) should be placed over the channel area and dam abutments prior to installation of the dam. If more than one sheet of fabric is required, overlap the fabric by at least 600mm.
8. If dispersible, highly unstable, or highly erosive soils are exposed, then priority must be given to the prompt stabilisation of all such areas.
9. Place the core rock for the rock filter dam. Ensure the upstream face is 2:1(H:V) or flatter, and the downstream face is 3:1(H:V) or flatter.
10. The rock material used to form the dam should be well-graded mixture of rock with a minimum size of 225mm and a maximum of 350mm (excluding armour rock). The rock may be machine placed with the smaller rocks worked into the voids of the larger rocks.
11. Small rock filter dams (< 1m high) including should be constructed in a slightly curved profile (in plan view) pointing upstream. The centre of the dam's crest should be slightly lower (typically 200mm) than the outer abutments to promote initial overtopping at or near the centre of the channel.
12. Where necessary, extend the rock protection downstream past the toe of the formed embankment until stable conditions are reached, or a distance equal to the height of the dam, whichever is the greater.
13. Install the specified filter (aggregate and/or filter cloth) on the upstream face of the rock filter dam.
14. If filter cloth is used, then:
    (i) extend the fabric over the crest of the rock filter dam into the spillway chute;
    (ii) consider the placement of several layers of overlapping fabric, thus allowing each layer to be removed individually once the fabric becomes blocked with sediment.
15. Take all necessary measure to minimise the safety risk caused by the structure.

Maintenance

1. Inspect the rock filter dam prior to forecast rainfall, daily during extended periods of rainfall, after runoff producing rainfall, or otherwise on a weekly basis.
2. Ideally, rock filter dams should discharge (from full) over no less than 8 hours. If drainage is too rapid, then additional filter aggregate may be required to achieve optimum hydraulic performance.
3. If flow through the structure is reduced to an unacceptable level, the upstream filter medium (aggregate or filter cloth) should be removed and replaced.
4. If a greater degree of water treatment (filtration) is required, extra geotextile filter fabric should be placed over the upstream face of the structure.
5. Check the structure and downstream channel banks for damage from overtopping flows. Make repairs as necessary.
6. Immediately replace any rock displaced from the dam.
7. Remove sediment and restore original sediment storage volume when collected sediment exceeds 10% of the specified storage volume.
8. Dispose of sediment and debris in a manner that will not create an erosion or pollution hazard.

Removal

1. The rock filter dam should be removed as soon as possible after they are no longer needed.
2. If there is flow within the watercourse or drainage channel at the time of removal of the rock filter dam, then install appropriate instream sediment control devices and/or flow diversion systems prior to its removal. Such measures should only be installed if considered appropriate for the local conditions, and only if their installation is judged to provide a net overall environmental benefit.
3. All settled sediment upstream should be removed prior to the dam's removal. Dispose of the sediment in a manner that will not create an erosion or pollution hazard.
4. Remove all materials used to form the embankment including the geotextile filter cloth and dispose of in a manner that will not create an erosion or pollution hazard.
5. Restore the watercourse channel to its original cross-section, and smooth and appropriately stabilise and/or revegetate all disturbed areas.