

11.0 EROSION PROTECTION DESIGN

11.1 Riprap

11.1.1 General

In general, the use of riprap is the preferred method for preventing erosion due to high flow velocities or wave action.

Typically, the riprap protection consists of at least one riprap layer and a primary bedding layer. In cases where the rock particles of the riprap become very large, a secondary coarser bedding layer may be required to prevent particle migration through the riprap. In some cases (i.e. non-critical locations) non-woven geotextiles or a thicker layer of primary bedding gravel, rather than a second bedding layer, may be provided,

Bedding material is required to prevent the underlying insitu or fill materials from being washed out through the voids. The bedding layer(s) may be designed using the following filter criteria.

- $$\frac{D_{15 \text{ FILTER}}}{D_{85 \text{ PROTECTED MATERIAL}}} \leq 5 \text{ to prevent particle migration,}$$
- $$\frac{D_{50 \text{ FILTER}}}{D_{50 \text{ PROTECTED MATERIAL}}} \leq 25 \text{ to prevent particle migration,}$$
- $$\frac{D_{15 \text{ FILTER}}}{D_{15 \text{ PROTECTED MATERIAL}}} \geq 5 \text{ to provide adequate drainage.}$$
- The filter material should be well-graded and its grain size curve should be approximately parallel with that of the protected material, particularly for the finer sizes.

Normally, the thickness of any layer of bedding material should not be less than the maximum particle size of the bedding material, or 200 mm, whichever is greater.

Where riprap is required at locations that coincide with critical embankment or structure drainage/seepage discharge locations, a zone of filter sand must be provided to separate the fill material and the bedding material. Examples of these critical locations include the downstream end of conduits within embankments as shown on Figures 13-1, 13-2, and 18-1, and adjacent to structures where the underslab granular drainage material drains through a vertical drainage blanket adjacent the sidewalls as shown on Figure 17-9. At these critical locations, geotextiles must not be used.

Material requirements for riprap, bedding, and geotextiles are discussed in Sections 3.2.3 and 3.10, respectively. Guidelines for establishing the riprap thickness are outlined in the following sections.

Technical literature suggests that angular riprap provides greater internal friction and therefore better stability than rounded riprap with the same gradation, and that the D_{50} of the rounded rock would have to be increased to achieve the same stability as would be provided by angular rock. Quarried rock is the most angular material available; however, fieldstone that has a glacial origin and is perhaps most commonly used for riprap on the Province's projects is generally quite angular as well. However, it is also acknowledged that the stability of the riprap installation is controlled by its gradation and quality of placement rather than by the shape of the rock alone. Given that the rock shape likely has only a marginal benefit, it is preferred that locally available and therefore more cost effective rock (i.e. either quarried rock or fieldstone from sources located close to the site) be used. Rock rounded by fluvial processes and obtained from alluvial deposits is usually only available in smaller sizes. It is perhaps most commonly used in gabions on the Province's projects.

11.1.2 High Velocity Flow Areas

The sizing of riprap erosion protection for areas subjected to high flow velocities will depend on many factors including the effects of flow concentrations or turbulence; slope of receiving surface (e.g. canal or channel sideslope); rock characteristics including gradation, shape (e.g. angular versus spherical), and specific gravity; and the degree of damage that can be tolerated.

For sizing riprap located within the outlet channel immediately downstream of stilling basins or other types of terminal structures, or similar areas where highly turbulent flow is anticipated, guidance can be obtained from USACE EM 1110-2-1603 (1990), USACE HDC (1987), USBR (1984), and Smith (1995).

For sizing riprap at other locations including natural channels, guidance can be obtained from various references including USACE EM 1110-2-1601 (1991), USACE HDC (1987), California Department of Public Works (1970), Smith (1995), Maynard et al (1989), and Stevens et al. (1976), and TRANS (1995). For riprap placed on the banks of natural channels, riprap aprons to prevent damage due to toe scour should be considered.

Once the riprap size, usually based on D_{50} , has been determined, the appropriate riprap gradation can be chosen from Table 3-1. Gradation requirements for larger riprap sizes can be developed taking into account the factors noted in Section 3.2.3.

The required thickness of riprap will depend on a number of factors including riprap gradation, durability of the rock, placement conditions (e.g. in the dry versus underwater), exposure conditions (e.g. ice action or floating debris), the design condition under consideration (i.e. Usual, Unusual, Extreme), and the degree of damage that can be tolerated.

A review of the referenced literature indicates that a riprap thickness ranging between D_{MAX} and $1.5D_{MAX}$ is typically recommended for high velocity flow areas. For durable rock placed in the dry,

the Province has commonly used a thickness of D_{MAX} and the riprap has performed well. One reason for the good performance is the expertise developed by local contractors in placing rock such that a dense, well-interlocked, uniform layer of riprap is attained. Therefore, it is suggested that a minimum riprap thickness of D_{MAX} plus some allowance for attaining the specified placement tolerance should be used, except for critical locations (i.e. immediately downstream of terminal structures). For critical locations, the minimum riprap thickness shown in Table 11-1 is suggested.

Table 11-1
Riprap Thickness for Critical Locations

Description ¹	D_{MAX} . (mm)	Minimum Riprap Thickness for Critical Locations (mm)
Riprap with $D_{50} = 175$ mm	300	400
Riprap with $D_{50} = 300$ mm	500	700
Riprap with $D_{50} = 500$ mm	800	1100

¹ Refer to Table 3-2 for riprap gradation.

11.1.3 Areas Exposed to Wave Action

For areas exposed to wind generated waves, riprap may be designed in accordance with the following equation taken from the USACE Shore Protection Manual (1977).

$$W_{50} = \frac{w_r H^3}{K_{RR} (S_R - 1)^3 \cot \theta}$$

where: W_{50} = mass of the D_{50} stone (kg),
 w_r = density of the stone (kg/m^3),
 H = design wave height (m) based on SMB equations USACE Shore Protection Manual (1977),
 S_R = specific gravity of the stone,
 θ = angle of the structure slope from horizontal, and
 K_{RR} = dimensionless stability coefficient.

It is noted that the current approach for predicting design wave heights is to use the Sverdrup-Munk-Bretschneider (SMB) equations as outlined in the USACE Shore Protection Manual (1977) rather than the JONSWAP equations presented in the USACE Shore Protection Manual (1984). Comparative work by Bishop et al. (1987) suggests that the JONSWAP equations could result in significant overestimation of the design wave heights.

The value for K_{RR} is dependent on factors such as stone shape, wave heights, exposure conditions, slopes, degree of tolerable damage. The value also varies considerably between different agencies and authors. Therefore, special care is required in determining an appropriate value for a particular installation.

Riprap gradation may be based on the following USACE Shore Protection Manual (1984) requirements.

- $W_{MAX} = 4W_{50}$
- $W_{MIN} = 0.125W_{50}$

A review of the referenced literature indicates that a riprap thickness ranging between $1.5D_{50}$ and $2D_{50}$ is typically recommended for protecting areas subjected to wave action. For durable rock placed in the dry, the Province has commonly used a thickness of D_{MAX} and the riprap has performed well. One reason for the good performance is the expertise developed by local contractors in placing rock such that a dense, well-interlocked, uniform layer of riprap is attained. Therefore, it is suggested that a minimum riprap thickness of D_{MAX} should normally be used. In some situations, consideration can be given to using a greater thickness of riprap rather than a larger rock size as outlined in Peters and Towle (1979).

Additional reference information for sizing riprap is provided in SEBJ (1997).

Furthermore, the incorporation of beach (i.e. relatively flat) slopes protected with granular material, as outlined in Peters and Towle (1979), rather than steep slopes with riprap may be a viable alternative, particularly where flat embankment slopes are required for stability, or riprap is costly.

11.2 Gabions

Technical information respecting the design of gabion structures is provided in publications produced by the various gabion manufacturers.

Gabions are used instead of riprap when the required riprap size is very large or not available, but cobbles are. The decision to use gabions should also consider the expected longevity of the wire mats and baskets, particularly where accessibility is a problem.

Where gabions are employed as erosion protection, the maximum allowable flow velocity is typically dependent on the thickness of the gabion and the D_{50} of the stones. Some guidance can be obtained from the gabion manufacturer.

For water control structures designed using gabions, particular care is required to prevent the migration of soil particles through the gabions. A layer of granular bedding material and/or geotextile is normally provided to limit the migration of soil particles.

In addition, the provision of a concrete cap in areas susceptible to damage due to debris, particularly at high velocity locations (e.g. weir crest), should be considered.

11.3 Precast Concrete Blocks and Other Proprietary Systems

As outlined in Section 3.12.3, erosion control systems have generally included interlocking concrete blocks, concrete blocks tied together with cables to form a mat, and a fabric form that is filled with cast-in-place concrete.

In general, technical information respecting the design and use of these systems is provided in publications produced by the individual manufacturer. Special care is required in evaluating whether or not a particular product can meet the design objectives, and provide long-term performance with minimal maintenance.

Typically with the precast concrete block systems, a layer of granular bedding material and/or geotextile is provided to limit the migration of soil particles through openings or gaps in the blocks. Notwithstanding the use of granular bedding materials and geotextiles, problems associated with the loss of the underlying subgrade materials, particularly when used in areas with high flow velocities, or where the flow impinges onto the block, have been encountered.