

## Chapter 6

# Tools for Hydraulic and Road Design

*"Protect against scour! Incorporate adequate riprap size and filters into streambank protection measures."*

**H**YDRAULIC DESIGN involves several basic concepts that must be considered to build successful projects with a minimum risk of failure (*Photo 6.1*). Use of **Manning's Formula** to determine flow capacity and velocity, use adequately sized **Riprap** for stream bank and scour protection, use **Filter Zones** to prevent piping and scour, and use gravels or **Geotextiles** to stabilize the road structure. Basic road drainage design often uses Manning's Formula for the determination of flow velocities in natural channels, for determining the quantity of that flow (as an alternative to methods discussed in Chapter 5), and for determining the flow capacity of canals and ditches. The use of Manning's Formula to determine stream velocities and flow quantity is well documented in many engineering and

hydraulics manuals. Road engineers doing basic hydraulic design should become familiar with it and its applications. Complex channels with rapidly varying, unsteady, or critical flows should be evaluated by an experienced Hydraulic Engineer.



**Photo 6.1** Scour behind a bridge abutment caused by insufficient channel and stream bank protection during a flood.

## Manning's Formula

Channel discharge quantity ( $Q$ ) is the product of the mean channel velocity ( $V$ ) and the area ( $A$ ) of the channel. To determine the discharge ( $Q$ ) in natural drainages, canals, and non-pressure pipes, the following formula is used:

$$\text{Discharge} = (\text{Velocity}) \times (\text{Area})$$

or

$$Q = VA$$

where:

$Q$  = discharge, in cubic meters per second ( $\text{m}^3/\text{s}$ )

$V$  = average flow velocity, in meters per second ( $\text{m}/\text{s}$ )

$A$  = cross sectional area, in square meters ( $\text{m}^2$ ).

Manning's Formula can be used to compute the average flow velocity ( $V$ ) in any channel or natural stream with uniform flow as shown to the right. Manning's Formula can be readily solved for a given channel when the known or assumed depth of flow is used. However, to determine the depth that a given discharge will produce in a channel, a trial and error solution is required. More detailed information on the use of Manning's Formula is presented in references, such as the *Minimum Impact Low-Volume Roads Manual*, the FHWA Manual *HDS4-Introduction to Highway Hydraulics*, or *Open-Channel Hydraulics*, by V.T. Chow.

## Riprap Use

High flow velocities in channels or along local stream banks often lead to bank erosion, scour, or the formation of gullies. Scour can undermine and cause failure of bridges

## MANNING'S FORMULA

To calculate average flow velocity...

$$V = \frac{1}{n} (R^{2/3})(S^{1/2})$$

where:

$V$  = average flow velocity (meters/second)

$n$  = roughness coefficient (usually 0.04 - 0.07 for natural channels); see handbooks for specific  $n$  values

$S$  = channel slope (meter/meter)

$R$  = hydraulic radius (meters) =  $A/P$

where  $A$  and  $P$  are:

$A$  = channel cross-sectional area

$P$  = wetted perimeter

*Roughness Coefficient ( $n$ )* varies considerably, depending on the characteristics of a channel or the smoothness of a canal, pipe, etc. Manning's "n" values for various natural and manmade channels are found in many hydraulics manuals and handbooks. Smooth, open stream channels with gravel bottoms have values around 0.035-0.055. Very winding, vegetated, or rocky channels have values around 0.055 to 0.075. Smooth earth or rock channels have values of 0.020 to 0.035. Roughness values typically increase as channel vegetation and debris increase, as channel sinuosity increases, and as the mean size of channel materials increases. The value decreases slightly as flow depth increases.

*Slope ( $S$ )* of the canal or drainage channel is determined for the local reach of the channel being analyzed by dividing the rise, or change in elevation in that reach by the distance of that reach. This slope is typically measured in the actual stream channel, upslope and downslope of the site, and ideally is also checked on a topographic map.

*Hydraulic radius ( $R$ )* is determined from the channel cross-sectional area ( $A$ ) divided by the wetted perimeter ( $P$ ). The wetted perimeter is simply the distance along the channel bottom and/or sides that is under water, or within the area ( $A$ ) of flow. Area should be determined from one or a couple representative cross-sections of the flow channel.





**Photo 6.2** Riprap used for stream bank slope protection to prevent scour at the entrance of a structure. Note the use of willows for additional “biotechnical” root strength.

and culverts. Riprap, or large stone, is commonly used to protect stream banks and structures against scour (*Photo 6.2*). Rock may be used in conjunction with vegetation or other measures such as root wads, gabions, or jetties to provide bank protection (*Photo 6.3*). Riprap rock size, as well as use of other measures, is commonly determined as a function of stream velocity and local channel conditions.

Average stream channel velocity ( $V_{AVE}$ ) can be determined using Manning’s Formula. Also, stream velocities can be estimated in the field if the surface flow can be measured during storm events. Stream velocity is the distance an object, such as a log or stick, travels in the middle of the stream divided by some short period of time. The average stream velocity will be about 0.8, or 80% of the value of the surface velocity. Common average peak velocities in streams

and rivers range from 1.5-3 m/sec in flat terrain to 2-4 m/sec in steep mountain channels. Flatter channels may actually experience faster flow velocities than steeper channels because of their typically lower roughness characteristics.

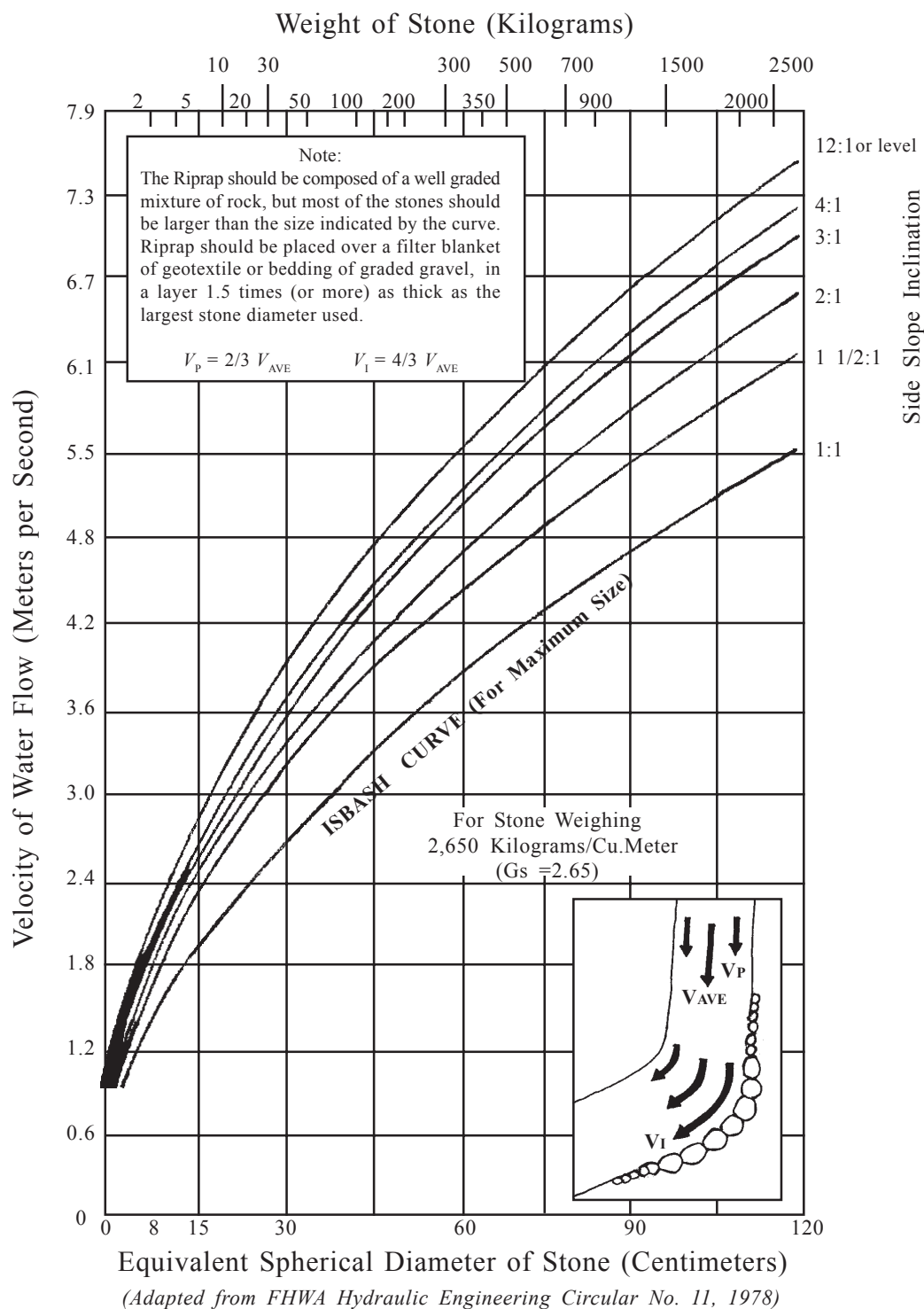


**Photo 6.3** A root wad, log, and rock armored stream bank built for protection against scour. Logs and vegetation can offer an attractive alternative to riprap in relatively low stream velocity areas.

*Figure 6.1* presents a useful correlation between water velocity (Velocity of Flow) and the size of riprap (Diameter) needed to protect the stream bank and not move. The flow along a long tangent section of stream, or the flow parallel ( $V_p$ ) to the stream, is assumed to be about 2/3, or 67%, of the average velocity ( $V_{AVE}$ ). The flow in a curved section of stream, with an impinging flow, has an assumed impinging velocity ( $V_i$ ) equal to about 4/3, or 133%, of the average velocity ( $V_{AVE}$ ). Thus, riprap in an area with relatively fast flow, such as a bend in the channel, will have higher stresses and require larger rock than the size needed in a straight part of the channel.

Note that most of the rock should be as large or larger than the size indicated in *Figure 6.1*. The Isbash Curve indicates the maximum size rock that might be considered in a critical application. If suitably large rock is not available,

**Figure 6.1** Size of stone that will resist displacement for various velocities of water flow and side slopes.





then the use of cement grouted rock, masonry, or gabions should be considered.

*Table 6.1* presents common gradations, sizes, and weights of classes of riprap. Riprap installation details are shown in *Figure 6.2*, as well as in the Note in *Figure 6.1*. Ideally riprap should be placed upon a stable foundation and upon a filter layer made either of coarse sand, gravel, or a geotextile. The riprap itself should be graded to have a range of sizes that will minimize the voids and form a dense layer. The riprap should be placed in a layer with a thickness that is at least 1.5 times the size (diameter) of the largest specified stone, with the thickest zone at the base of the rock. In a stream channel, the riprap layer should cover the entire wetted channel sides, with some freeboard, and it should be placed to a depth equal or greater than the depth of expected scour.

### Filters

A filter serves as a transitional layer of small gravel or geotextile placed between a structure, such as riprap, and the underlying soil. Its purpose is to 1) prevent the movement of soil behind riprap or gabions, or into underdrains, and 2) allow groundwater to drain from the soil without building up pressure. Specific filter criteria, documented in other references, will establish the particle size and gradation relationships needed between the fine native soil, a filter material, and coarse rock such as drain rock or riprap. Also, specific geotextile requirements information exists for filter applications, as found in the Selected References.



**Photo 6.4** Use of geotextiles placed against fine soil to provide adequate filtration for an underdrain.

Traditionally, coarse sand or well-graded, free draining gravel have been used for filter materials. A sand or gravel filter layer is typically about 15 to 30 cm thick. In some applications, two filter layers may be needed between fine soil and large rock. Today, geotextiles are commonly used to provide filter zones between materials of different size and gradation because they are economical, easy to install, and perform well with a wide range of soils (*Photo 6.4*). *Figure 6.2* shows the application of a gravel or geotextile filter between a streambank soil and the riprap rock protection.

### Use of Geotextiles

Geotextiles are commonly used to provide a filter between rock and soil, thus preventing scour and soil movement. They are relatively easy to install under most conditions. The fabric should be pulled tight across the soil area to be protected before the rock is placed (*Photo 6.5*). The geotextile can be a wo-

ven monofilament or a needle-punch nonwoven geotextile, and it must be permeable. The geotextile needs to have an apparent opening size of 0.25 to 0.5 mm. In the absence of other information, a 200 g/m<sup>2</sup> (6.0 oz/yd<sup>2</sup>) needle-punch nonwoven geotextile is commonly used for many soil filtration and separation applications.

Other common geotextile or geosynthetic material applications on roads include subgrade reinforcement to reduce the thickness of needed aggregate over very weak soils; separation of aggregate from soft subgrade soils; reinforcement of soils in structures such as retaining walls and reinforced fills; and entrapment of sediment with silt fences (*Photo 6.6*), as seen in *Figure 6.3*. If knowledgeable engineers are not available, then geotextile distributors or manufacturers should be consulted regarding the function and appropriate types of geotextile to use in various engineering applications.

**Table 6.1**

## CLASSIFICATION AND GRADATION OF RIPRAP (by Weight & Size of Rock)

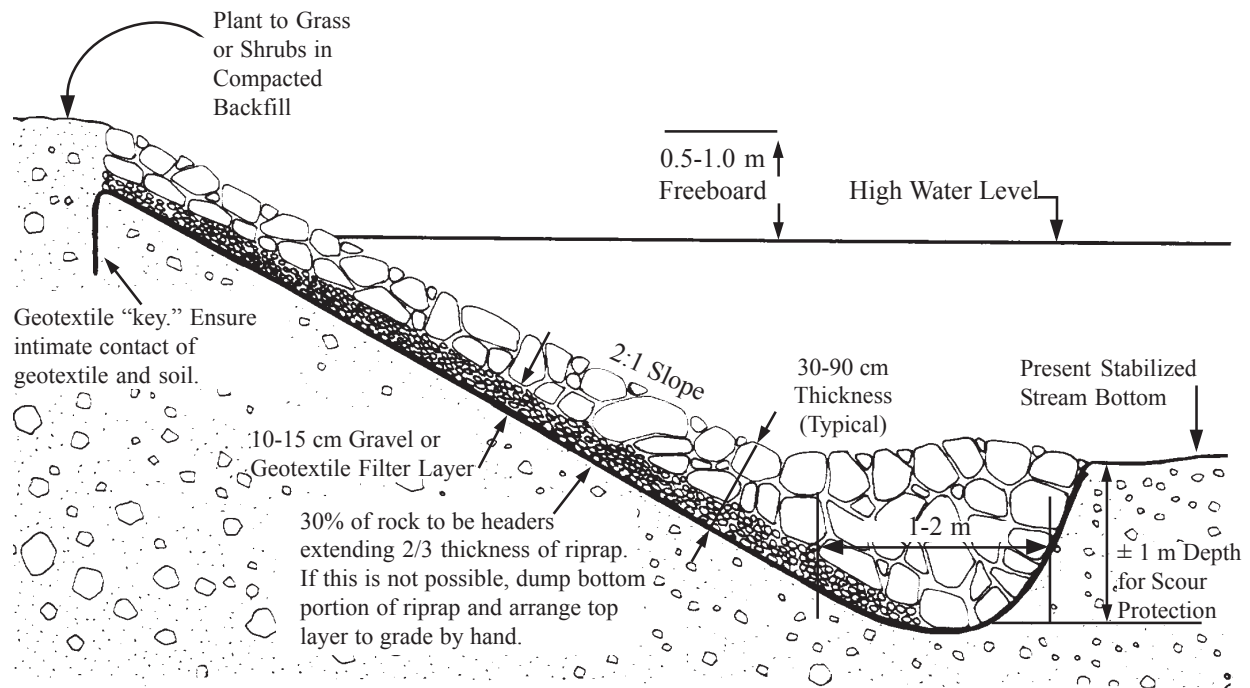
Category	Weight	Size of Rock*	Percent Passing (total minus the diameter indicated)
	Kilograms (pounds)	Centimeters	
Class I	5 (11)	15	100
	2.5 (5)	12	80
	0.5 (1)	7	50
	0.1 (.2)	3	10 maximum
Class II	25 (55)	25	100
	15 (35)	20	80
	5 (11)	15	50
	0.5 (1)	8	10 maximum
Class III	50 (100)	30	100
	30 (60)	25	80
	10 (25)	20	50
	1 (2)	10	10 maximum
Class V	100 (220)	45	100
	70 (150)	35	70
	35 (75)	25	30
	7 (15)	15	10 maximum
Class VII	300 (650)	60	100
	200 (440)	50	70
	100 (220)	40	30
	10 (22)	20	10 maximum
Class VIII	1,000 (2,200)	90	100
	600 (1,320)	70	70
	200 (440)	50	30
	30 (65)	25	10 maximum
Class X	2,000 (4,400)	120	100
	1,000 (2,200)	90	80
	300 (660)	60	50
	40 (90)	30	10 maximum

Source: Adapted from USDA-Forest Service.

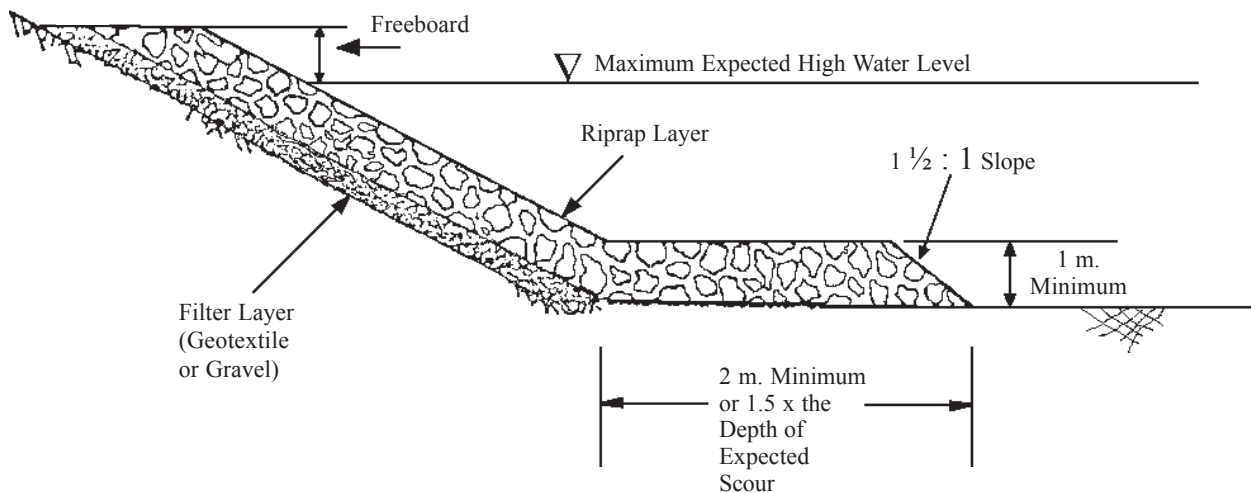
\*equivalent spherical diameter



**Figure 6.2 Two examples of typical riprap stream bank protection.**



#### **a. Rock Toe and Blanket Detail**



#### **b. Details of Rock Riprap Layer Placed on the Stream Channel Bottom for Scour Protection**



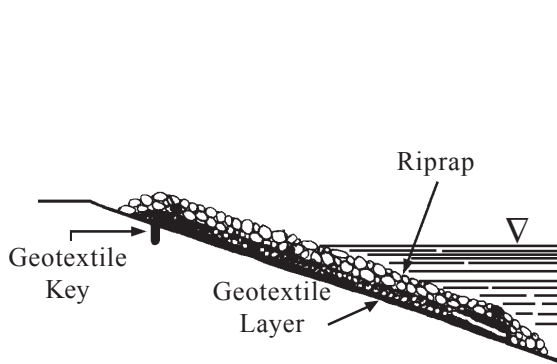
**Photo 6.5** A filter cloth (geotextile) backing behind a loose rock slope buttress to provide a filter for drainage and to prevent movement of fine soil into the rock. *(Photo by Richard Van Dyke)*



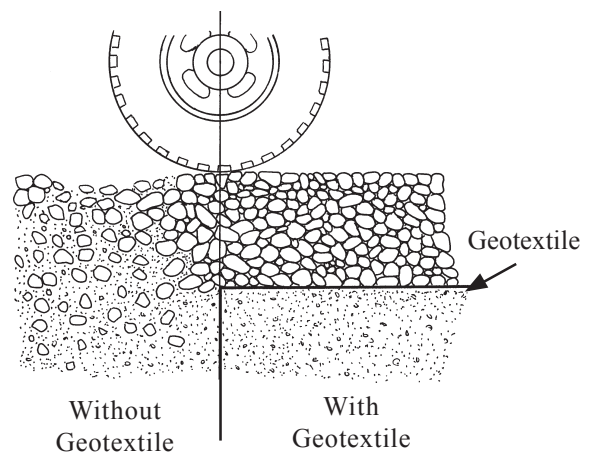
**Photo 6.6** Use of a geotextile as a “silt fence” to trap sediment from a construction area.



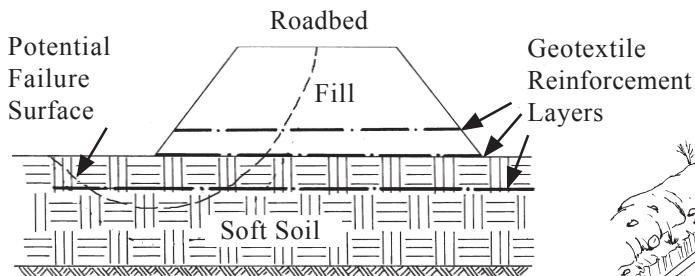
**Figure 6.3** Typical Geotextile Applications for Rural Roads. (Adapted with permission from AMOCO Fibers Corporation)



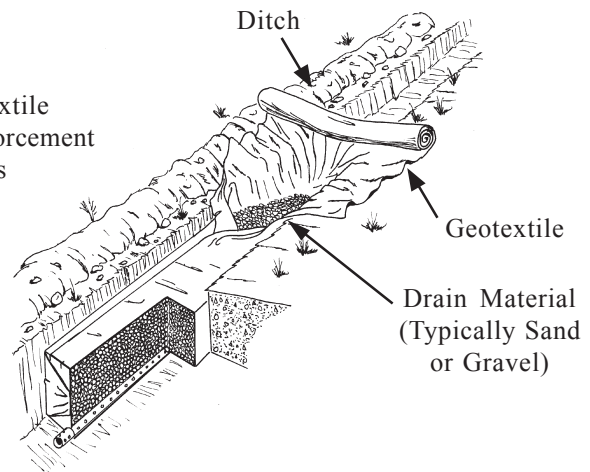
**a. Filter Behind Riprap for Stream Bank Protection.**



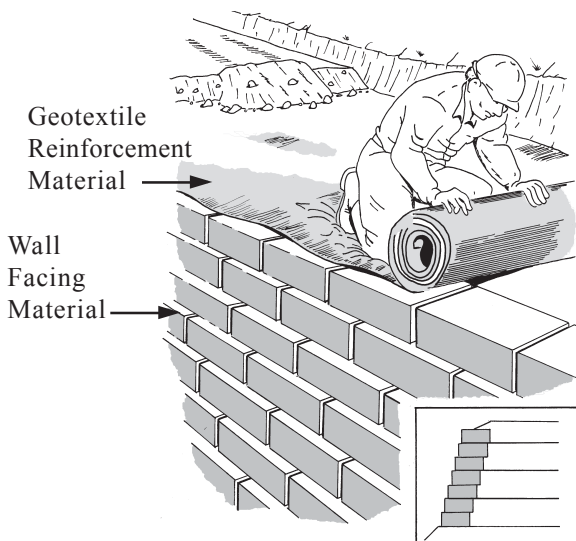
**b. Subgrade Separation and Reinforcement.**



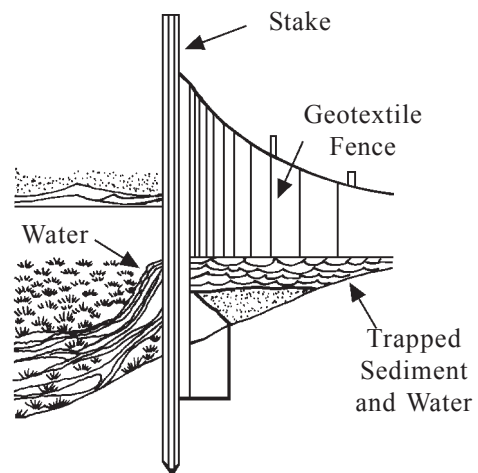
**c. Embankment Reinforcement over Soft Soil Deposit.**



**d. Filtration in an Underdrain.**



**e. Reinforced Soil Retaining Structure.**



**f. Silt Fence to Trap Sediment.**

## RECOMMENDED PRACTICES

- Determine stream channel velocities to examine scour potential, structure protection needs, and impacts on aquatic life.
- Use well graded, hard, angular, properly sized riprap where scour protection is needed. Needed rock size (and weight) as a function of average water flow velocity is shown in Figure 6.1. On curves (impinging flow) increase the rock size by 30 to 50 percent above that shown in Figure 6.1 for average flow velocities.
- Use clean sand, clean, well graded 0.5 to 1 cm gravel, or a geotextile for filters between fine erodable soils and coarse drain rock or riprap (see Figure 6.2 for typical riprap installation with filter backing).
- Use scour countermeasures to protect structures, prevent failure of structures, and avoid adverse impacts to streams. Riprap or gabions are most commonly used in high velocity or critical areas (*Photo 6.7*). Vegetation, root wads, logs, or barbs can also be used for streambank stabilization.
- Pay attention to design details where rock protection and filters are needed.
- Use geotextiles in road and hydraulic design applications to provide a filter behind riprap or around an underdrain. Use geosynthetic materials in other applications, such as for separation and reinforcement, wherever cost-effective and practical.

## PRACTICES TO AVOID

- Installing structures without adequate consideration of expected stream velocities and appropriately sized rock for bank protection.
- Installing subsurface drainage measures, such as underdrains, without filter protection (such as use of geotextiles and properly sized sand or gravel filter material).

**Photo 6.7** Riprap with a geotextile filter backing are being used to protect the road from high water flows. Note that the road is poorly located so close to the stream!

