

Chapter 11

Slope Stabilization and Stability of Cuts and Fills

"Construct cut and fill slopes that are flat enough to be stable over time and that can be revegetated."

THE OBJECTIVES OF ROUTINE ROAD CUTS AND FILLS are 1) to create space for the road template and driving surface; 2) to balance material between the cut and fill; 3) to remain stable over time; 4) to not be a source of sediment; and 5) to minimize long-term costs. Landslides and failed road cuts and fills can be a major source of sediment, they can close the road or require major repairs, and they can greatly increase road maintenance costs (*Photo 11.1*). Vertical cut slopes should not be used unless the cut is in rock or very well cemented soil. Long-term stable cut slopes in most soils and geographic areas are typically made with about a 1:1 or $\frac{3}{4}$:1 (horizontal: vertical) slope (*Photo 11.2*). Ideally, both cut and fill slopes should be constructed so that they can be vegetated (*Photo 11.3*), but cut slopes in dense, sterile soils or rocky material are often difficult to vegetate.

Fill slopes should be constructed with a 1 1/2:1 or flatter slope. Over-steep fill slopes (steeper than a 1 1/2 :1 slope), commonly formed by side-casting loose fill material, may continue to ravel with time, are diffi-

cult to stabilize, and are subject to sliver fill failures (*Photo 11.4*). A rock fill can be stable with a 1 1/3:1 slope. Ideally, fills should be constructed with a 2:1 or flatter slope to promote growth of vegetation and slope stability (*Photo 11.5*). Terraces or benches are desirable on large fill slopes to break up the flow of surface water.



Photo 11.1 Over-steep slopes, wet areas, or existing slide areas can cause instability problems for a road and increase repair and maintenance costs, as well as sediment production.

Photo 11.2 Construct cut slopes at a 3/4:1 or flatter slope in most soils for long-term stability. In well-cemented soils and rock, a 1/4:1 cut clope will usually be stable.



Photo 11.3 A well-stabilized cut slope, with about a 1:1 slope, that is well covered with vegetation.



Photo 11.4 Avoid loose, over-steep fill slopes (steeper than 1 1/5:1), particularly along streams and at drainage crossings.



Table 11.1 presents a range of commonly used cut and fill slope ratios appropriate for the soil and rock types described. Also Figure 11.1 and Figure 11.2 show typical cut slope and fill slope design options, respectively, for varying slope and site conditions. Note, however, that local conditions can vary greatly, so determination of stable slopes should be based upon local experience and judgment. Groundwater is the major cause of slope failures.

Slope failures, or landslides, typically occur where a slope is oversteep, where fill material is not compacted, or where cuts in natural soils encounter groundwater or zones of weak material. Good road location can often avoid landslide areas and reduce slope failures. When failures do occur, the slide area should be stabilized by removing the slide material, flattening the slope, adding drainage, or using structures, as discussed below. Figure 11.3 shows some of the common causes of slope failures along with common solutions. Designs are typically site specific and may require input from geotechnical engineers and engineering geologists. Failures that occur typically impact road operations and can be costly to repair. Failures near streams and channel crossings have an added risk of impact to water quality.

A wide range of slope stabilization measures is available to the engineer to solve slope stability problems and cross an unstable area. In most excavation and embankment work, relatively flat slopes, good compaction, and adding needed drainage will typically eliminate routine instability problems (Photo 11.6). Once a failure has occurred,



Photo 11.5 Construct fill slopes with a 1 1/2:1 or flatter slope (to promote vegetation growth) and stabilize the fill slope surface. Use benches (terraces) on large fill slopes to intercept any flow of surface water.

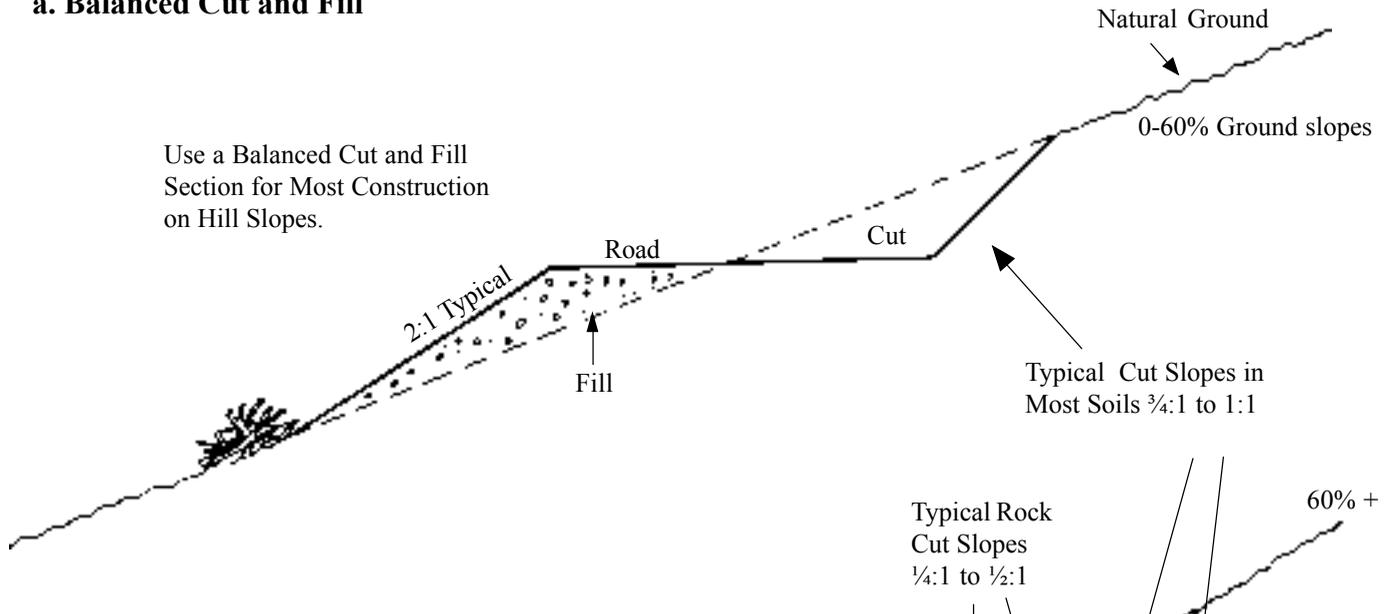
Table 11.1

COMMON STABLE SLOPE RATIOS FOR VARYING SOIL/ROCK CONDITIONS

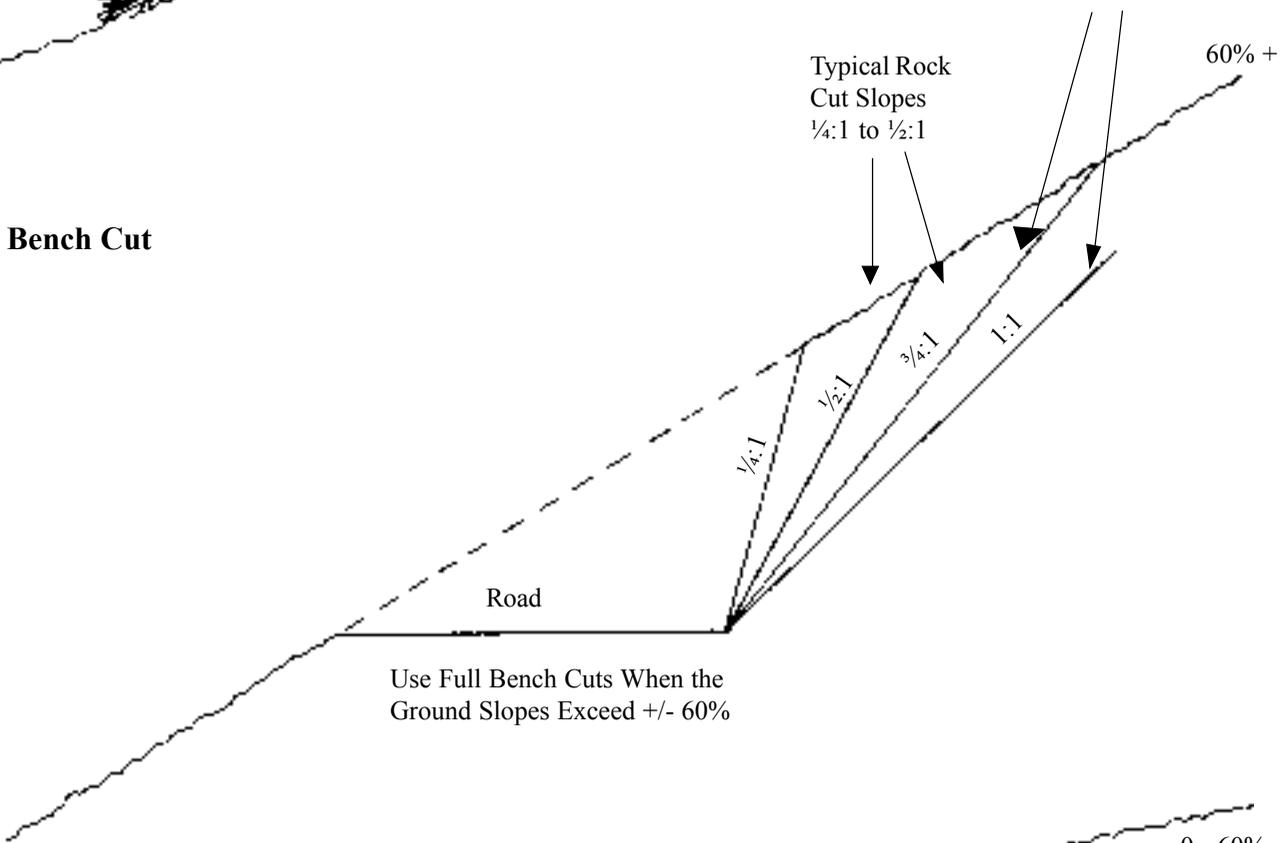
Soil/Rock Condition	Slope Ratio (Hor:Vert)
Most rock	¼:1 to ½:1
Very well cemented soils	¼:1 to ½:1
Most in-place soils	¾:1 to 1:1
Very fractured rock	1:1 to 1 ½:1
Loose coarse granular soils	1 ½:1
Heavy clay soils	2:1 to 3:1
Soft clay rich zones or wet seepage areas	2:1 to 3:1
Fills of most soils	1 ½:1 to 2:1
Fills of hard, angular rock	1 1/3:1
Low cuts and fills (<2-3 m. high)	2:1 or flatter (for revegetation)

Figure 11.1 Cut slope design options.

a. Balanced Cut and Fill



b. Full Bench Cut



c. Through Cut

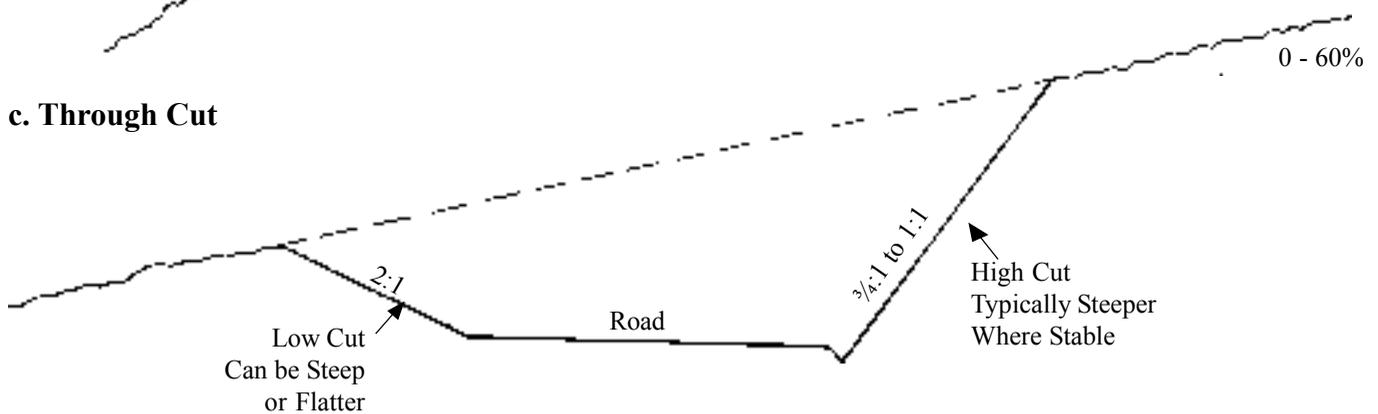
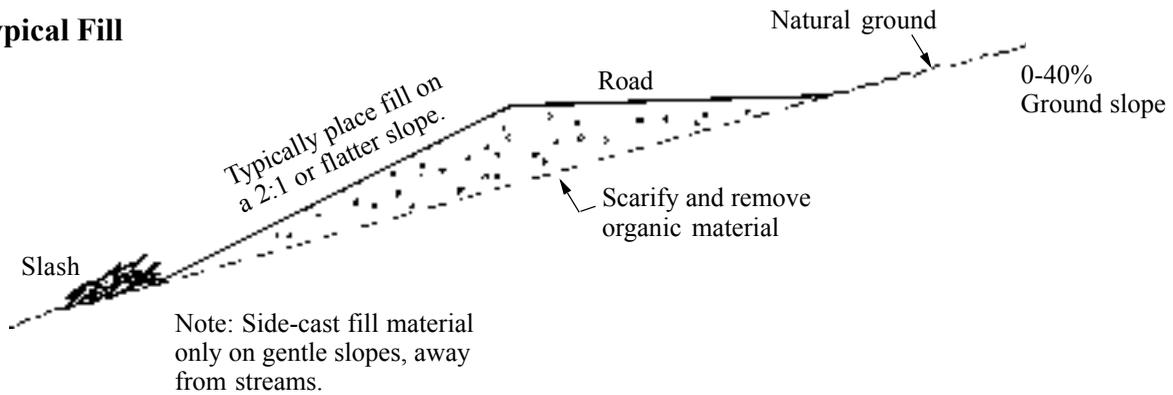
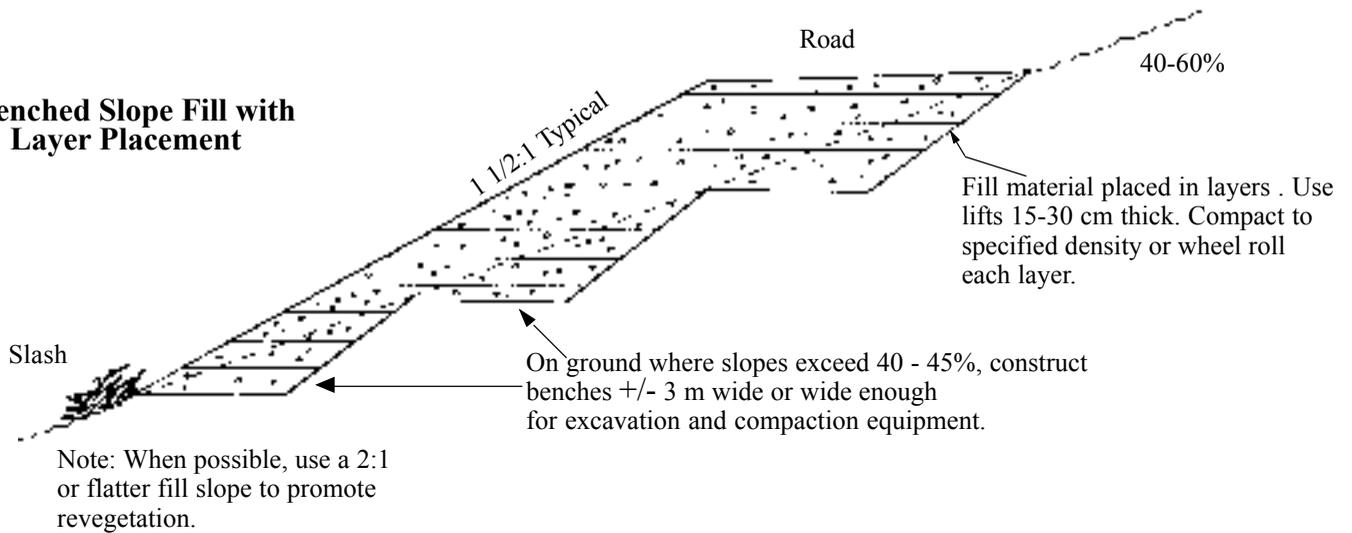


Figure 11.2 Fill slope design options

a. Typical Fill

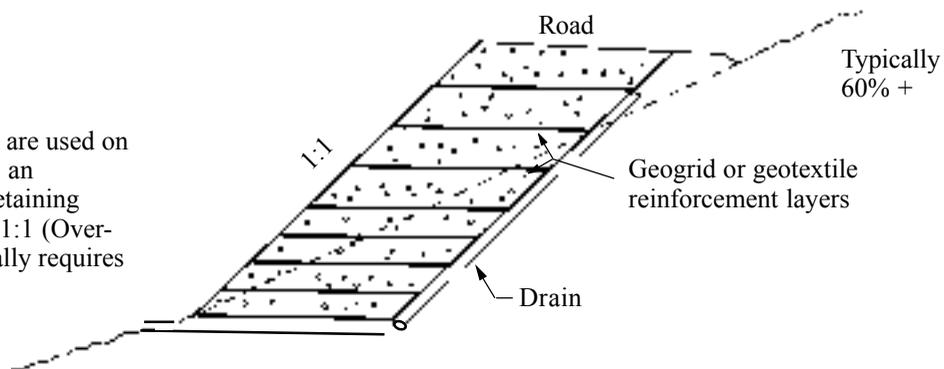


b. Benched Slope Fill with Layer Placement



c. Reinforced Fill

Reinforced fills are used on steep ground as an alternative to retaining structures. The 1:1 (Over-steep) face usually requires stabilization.



d. Through Fill

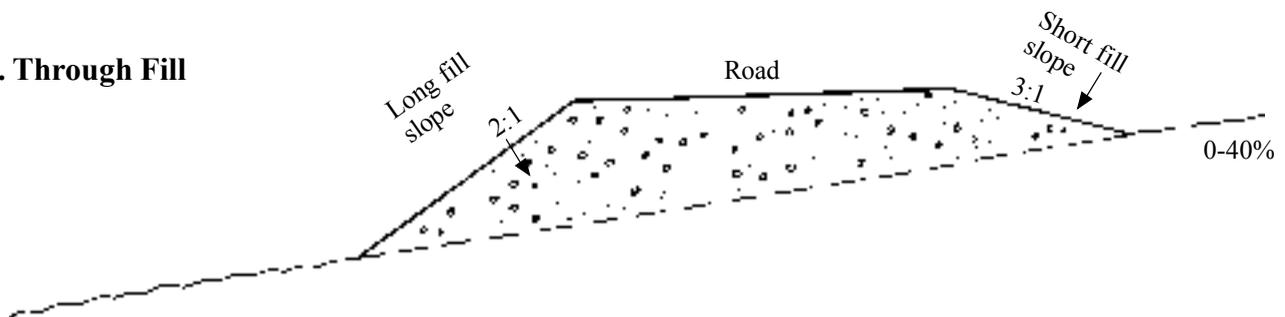


Figure 11.3 Slope problems and solutions with stabilization measures.

The Problem



Solutions

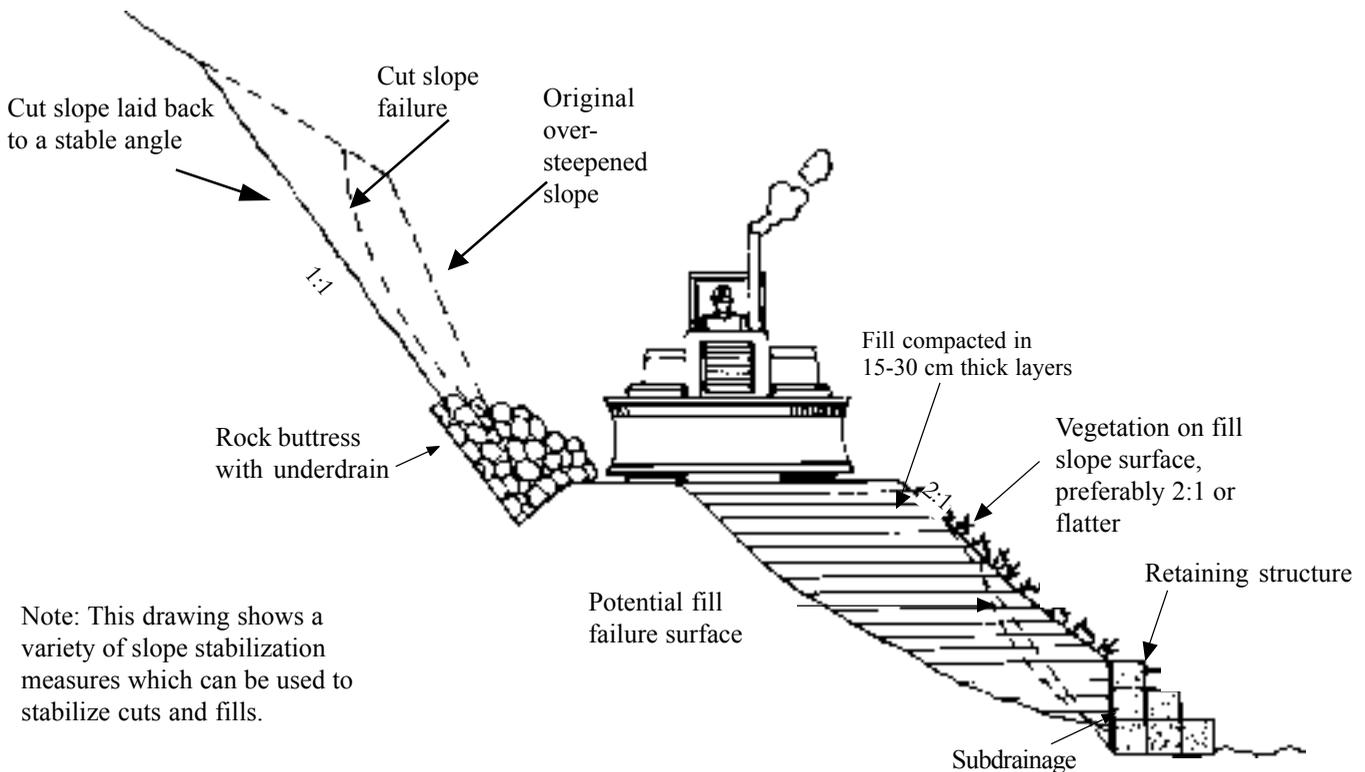




Photo 11.6 Simple hand compaction behind a low rock wall. Compaction is important behind any retaining structure or fill. It can be achieved by hand or, preferably, using equipment such as a wacker or small compactor.

the most appropriate stabilization measure will depend on site-specific conditions such as the size of the slide, soil type, road use, alignment constraints, and the cause of the failure. Here are a range of common slope stabilization options appropriate for low-volume roads, presented roughly from simplest and least expensive, to the most complex and expensive:

- Simply remove the slide material.
- Ramp over or align the road around the slide.
- Revegetate the slope and add spot stabilization (See *Photo 13.10*).
- Flatten or reconstruct the slope.
- Raise or lower the road level to buttress the cut or remove weight from the slide, respectively.
- Relocate the road to a new stable location.

- Install slope drainage such as deep cutoff trenches or dewater with horizontal drains.
- Design and construct buttresses (*Photo 11.7*), retaining structures, or rock anchors.

Retaining structures are relatively expensive but necessary in steep ar-

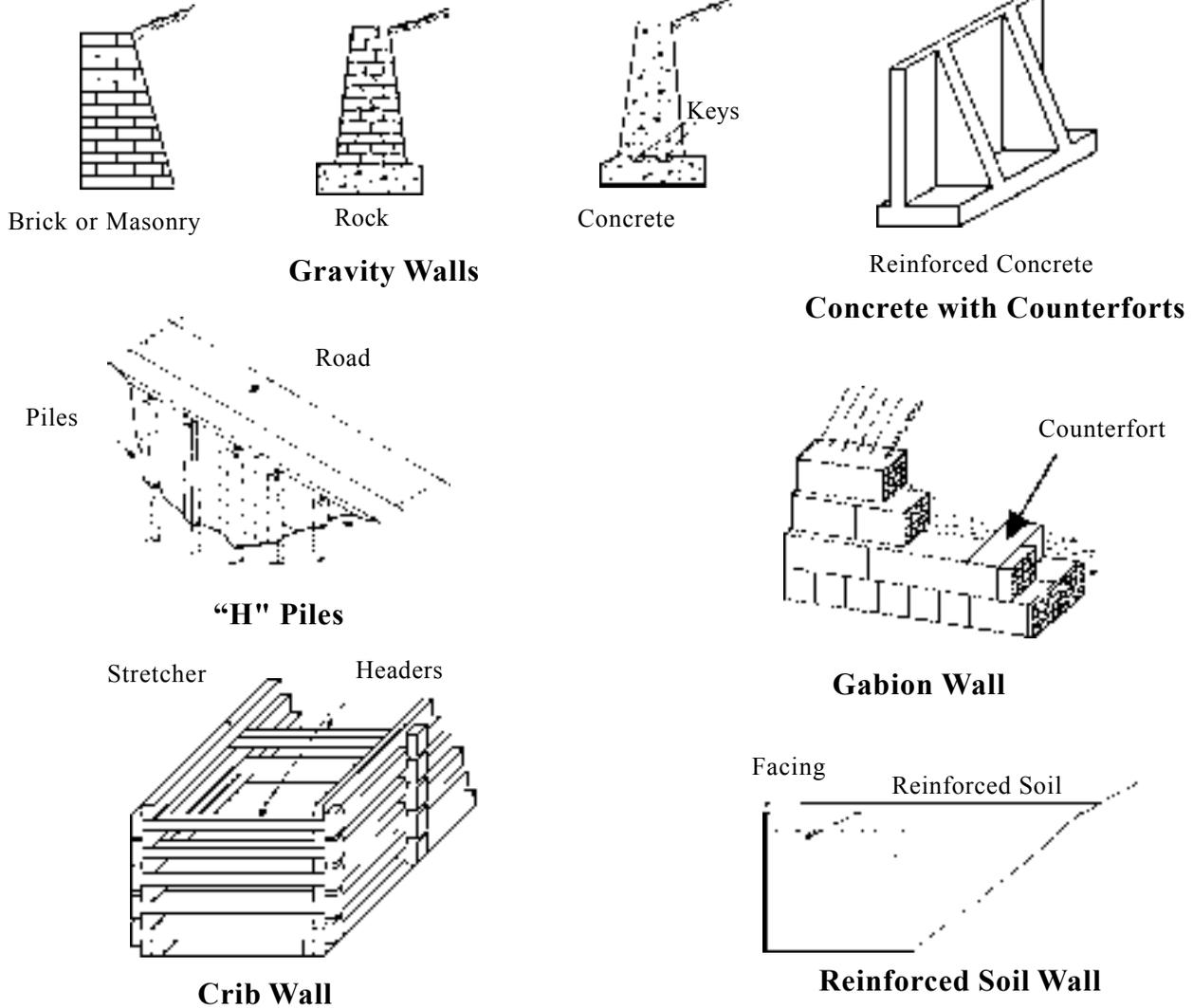


Photo 11.7 A drained rock buttress can be used to stabilize a cut slope failure area.

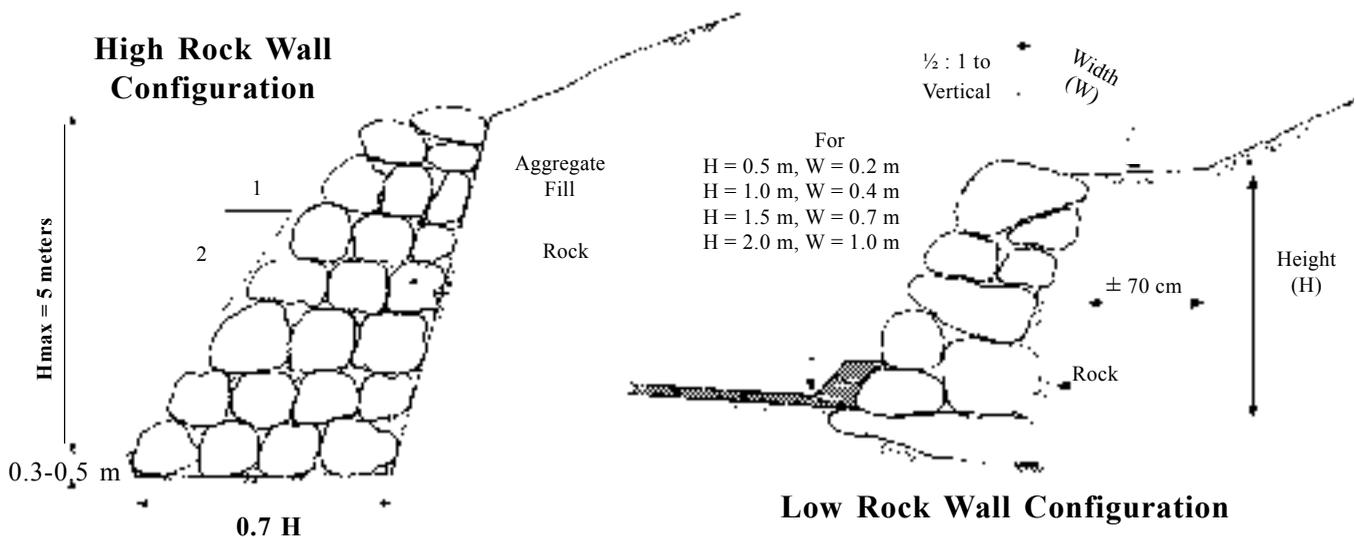
reas to gain roadway space or to support the roadbed on a steep slope, rather than make a large cut into the hillside. They can also be used for slope stabilization. *Figure 11.4 (a and b)* presents information on common types of retaining walls and simple design criteria for rock walls, where the base width is commonly **0.7 times the wall height** (*Photo 11.8*). *Figure 11.4c* presents common gabion gravity wall designs and basket configurations for varying wall heights. Gabion structures are very commonly used for walls up to 6 meters high, particularly because they use locally available rock and are labor intensive (*Photo 11.9*).

For low to high walls in many geographic areas today, Mechanically Stabilized Earth (MSE), or “Reinforced Soil” structures are the least expensive type of wall available. They are simple to build, and often they can use on-site granular backfill material. They are commonly constructed using layers of geotextile or welded wire placed in lifts 15 to 45 cm apart in the soil, thus adding tensile reinforce-

Figure 11.4 Construction of various types of retaining structures. (Adapted from Gray & Leiser, 1982)

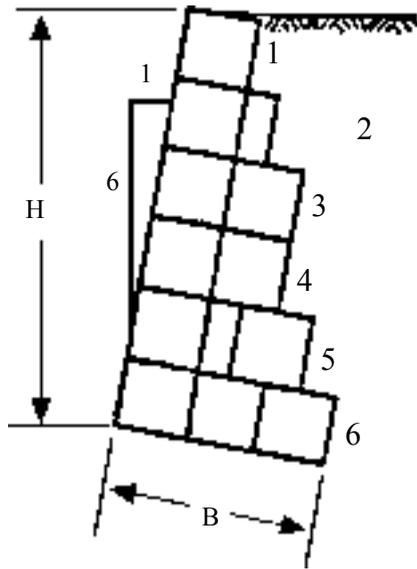


a. Common Types of Retaining Structures.



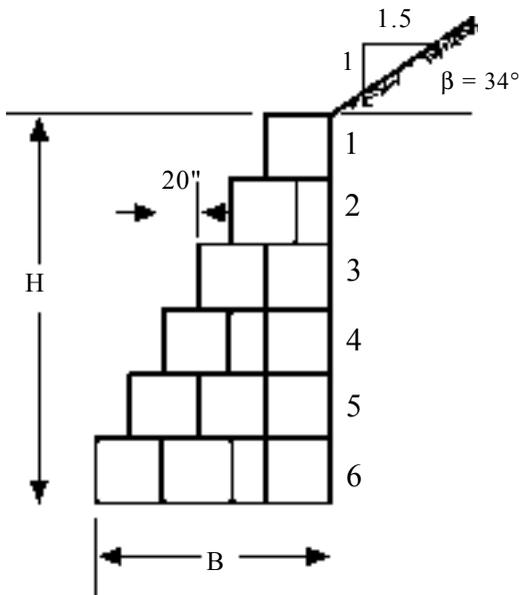
b. Typical Rock Wall Construction.

Figure 11.4 Continued. (Adapted from Gray & Leiser, 1982)



No of levels	H	B	No. of gabions (per width)
1	3' 3"	3' 3"	1
2	6' 6"	4' 3"	1 1/2
3	9' 9"	5' 3"	2
4	13' 1"	6' 6"	2
5	16' 4"	8' 2"	2 1/2
6	19' 7"	9' 9"	3

Flat Backfill (smooth face)



No. of levels	H	B	No. of gabions (per width)
1	3' 3"	3' 3"	1
2	6' 6"	4' 11"	1 1/2
3	9' 9"	6' 6"	2
4	13' 1"	8' 2"	2 1/2
5	16' 4"	9' 9"	3
6	19' 7"	11' 5"	3 1/2

Fill at 1 1/2:1 (face with steps)

Note: Loading conditions are for silty sand to sand and gravel back fill. For finer or clay rich soils, earth pressure on the wall will increase and the wall base width (B) will have to increase for each height. Backfill weight = 110 pcf. (1.8 Tons/m³) (1,762 kg/m³)

- Safe against overturning for soils with a minimum bearing capacity of 2 Tons/foot² (19,500 kg/m²)
- For flat or sloping backfills, either a flat or stepped face may be used.

b. Standard design for Gabion Retaining Structures up to 20 feet in height (6 meters) with flat or sloping backfill.

ment to the soil (see *Figure 6.3e*). Driven “H” piles or sheet piles, with or without tiebacks, are relatively expensive but are often the most environmentally acceptable type of wall. They cause less site disturbance than gravity or MSE structures that require a large foundation excavation. Most

types of retaining structures and designs provided by manufacturers are internally stable for the specified use, site conditions, and height. Most wall failures occur due to **foundation failure**. Thus structures **must** be placed on a good foundation, such as bedrock or firm, in-place soil.

PRACTICES TO AVOID

- Constructing vertical cut slopes (except in very well cemented soils and rock).
- Road locations and construction practices where the toe of the fill ends up in the creek. Do not use side-cast fill placement methods on steep slopes next to streams.
- Placing fills or “side-casting” materials on natural ground slopes steeper than 60%.
- Road locations in areas of known instability.
- Leaving cut slopes and, particularly, fill slopes barren and exposed to erosion.



Photo 11.8 Use physical slope stabilization methods, such as retaining walls, reinforced fills, or rock buttresses where necessary in areas of space limitation on steep slopes.



Photo 11.9 Gabions are a commonly used type of low gravity retaining structure because they use locally available rock and are relatively inexpensive.

RECOMMENDED PRACTICES

- Use balanced cut and fill construction in most terrain to minimize earthwork (*Figure 11.1a*).
- On steep ground (>60% slope) use full bench construction. Consider constructing a narrow, single lane road with inter-visible turnouts to minimize excavation (*Figure 11.1b*).
- Construct cut slopes in most soils using a cut slope ratio of 3/4:1 to 1:1 (horizontal: vertical) (*Figure 11.1*). Use flatter cut slopes in coarse granular and unconsolidated soils, in wet areas, and in soft or clay-rich soils. Use relatively flat cut slopes (2:1 or flatter) for low (<2-3 meters high) cuts to promote growth of vegetation.
- Construct cut slopes in rock using a cut slope ratio of 1/4:1 to 1/2:1 (*Figure 11.1*).
- Use vertical cuts (1/4:1 or steeper) only in stable rock or in very well cemented soils, such as cemented volcanic ash or in-place decomposed granite soil, where the risk of surface erosion or continued ravel from a relatively flat cut slope is great and the risk of local failures in the steep cut is low.
- Where long-term examples are available, use local experience, as well as ideally materials testing and analysis, to determine the stable cut slope angle in a particular soil type.
- Direct concentrated surface water (runoff) away from cut and fill slopes.
- Place construction slash and rocks along the toe of fill slopes (See Road Design, *Figure 4.2*) (Do not bury the slash in the fill!).
- Dispose of unsuitable or excess excavation material in locations that will not cause water quality degradation or other resource damage.
- Construct fills with a fill slope ratio of 1 1/2:1 or flatter. In most soils, a 2:1 or flatter fill slope ratio will promote vegetative growth (*Figure 11.2a*). For clay-rich tropical soils in high rainfall areas, a 3:1 fill slope is desirable.
- Compact fill slopes in sensitive areas or when the fill is constructed with erosive or weak soils. Use specific compaction procedures, such as wheel rolling, layer placement of the fill (with 15 to 30 cm lifts), or use specific compaction equipment when available (*Figure 11.2b*).
- Remove organic surface material, construct a toe bench, and bench the natural ground surface on slopes of 40-60% before the fill is placed over the native soil (*Figure 11.2b*) to prevent a “sliver fill” failure at the contact of the native soil and fill. Once a fill failure occurs on a steep slope, a retaining structure or reinforced fill is typically needed for repairs (*Photo 11.10*).
- Consider the use of reinforced fills where a 1:1 fill slope will fit (catch) on natural, stable ground (see *Figure 11.2c*). Use reinforced fills as a cost saving alternative to retaining structures.
- Use physical and bio-technical slope stabilization measures such as retaining structures, buttresses, brush layering, and drainage, as needed to achieve stable slopes (see *Figure 11.3* and *Figure 13.4*). Retaining structures may be loose rock, gabions, reinforced concrete, piles, crib walls, soil nails, or mechanically stabilized soil walls with a variety of facings such as geotextile, welded wire, timber, concrete blocks, or tires (*Photo 11.11*). Wall backfill is typically compacted to 95% of the AASHTO T-99 maximum density.
- Use retaining structures to gain roadway width in steep terrain.
- Place retaining structures only upon good foundation materials, such as bedrock or firm, in-place soils (*Photo 11.12*).

Photo 11.10 A road fill failure in steep terrain which now needs either a retaining structure or a large road cut around the failure.



Photo 11.11 A tire-faced, mechanically stabilized earth (MSE) retaining wall, with layers of geotextile reinforcement, being used to gain road width in a fill failure area. MSE (reinforced soil) structures are often the least expensive retaining structure available. Welded wire MSE walls are also commonly used.



Photo 11.12 A gabion retaining structure which will fail soon due to lack of a suitable foundation. All retaining structures, either mechanically stabilized earth (MSE) walls or gravity walls, require a **good foundation**.

