<table>
<thead>
<tr>
<th><strong>SIDECAST</strong></th>
<th>only stumps, logging slash and brush</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CUT</strong></td>
<td>a deep full bench about 9 m in width and 2.5 - 3.0 m in depth at the center line with the backhoe. The excavated material is then backcast and piled on the subgrade behind the hoe.</td>
</tr>
<tr>
<td><strong>LEVEL AND DITCH</strong></td>
<td>the backcast material to make the subgrade</td>
</tr>
<tr>
<td><strong>ALLOW BACKCAST</strong></td>
<td>material to sit and drain. If not, the attendant settling will block culverts and change direction of flow in ditches.</td>
</tr>
<tr>
<td><strong>BALLAST</strong></td>
<td>the subgrade</td>
</tr>
</tbody>
</table>

In deep soils, this technique also provides toe support to the cut slope, thereby reducing the occurrence of rotational cut bank slumps.

**Multi-bench system**

Multi-benching is a seldom used, but effective technique for providing stable footings for fill material with only minimal sidecast. It is best used with soils that have a high *in situ* strength, like till. The operation begins with the excavation of a small full bench, below the elevation of the planned road location. The excavated material is normally sidecast, as the small volume does not usually create an unstable situation, but it can be end hauled. After completing the first cut bench, the operator moves upslope and builds a slightly larger bench, casting the excavated material onto the lower bench. After the second bench is completed, the process is repeated upslope, which is the road elevation. The result is a fill-slope keyed into the hillslope on three or more small benches and only a relatively small amount of oversteepened sidecast. Water control is key. Drainage from culverts and waterbars must be carried over the fill-slopes by half culverts, to avoid saturating the fill.
Full-benching/end-hauling

Full-benching is a construction method which should be used in conjunction with end-hauling. A bench is cut into the rock or soil equal to the width of the road. None of the road surface is built on the fill. Where the soils are unsuitable for backcasting or where slopes are extremely steep, then end-hauling of the excavated material must be done.

End-hauling is trucking the excavated material to a more stable dump site. It is a very expensive option, costing on average four to seven times the cost of normal road construction, and therefore it should be used judiciously. However, full-benching, without end-hauling on steep slopes, is a sure recipe for sidecast failure.

End-hauling can also result in landslides if disposal sites are not well chosen. Natural benches with shallow soils, saddles, and broad gully sides are suitable. All proposed fill sites must be field examined, especially those near gullies, before construction. Dump sites that are underlain by thick duff layers will often fail at surprisingly low angles once the organic material decomposes and becomes saturated. End-haul material that contains a lot of slash or logs will become progressively more unstable as the wood rots.

There are some situations, however, in which full-benching and end-hauling should not be used:

**UNSTABLE ROCK**, especially soft sedimentary rock, is not suitable for full-bench cuts. The large excavation required for full-benching removes toe support and can result in a landslide initiating above the road.

**DEEP SOFT CLAY SOILS**, such as lacustrine or marine soils, are also not suitable for full benches and may induce rotational failures.
EXCESSIVE LOADING of clay or silt soils at an end haul dump site could cause a bearing capacity failure in the subsoil.

Balanced benching or backcasting are more suitable techniques for soft clay or rock materials.

**Cut bank stability**

The optimum cut slope ratio is a matter of tradeoffs:

<table>
<thead>
<tr>
<th>Advantages of steep cut bank</th>
<th>Disadvantages of steep cut bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Less right-of-way</td>
<td>1. Difficult to revegetate</td>
</tr>
<tr>
<td>2. Less excavated material</td>
<td>2. Prone to ravel and ditch plugging</td>
</tr>
<tr>
<td>3. Less sidecast</td>
<td>3. Prone to tension cracks</td>
</tr>
<tr>
<td>4. Shorter slope exposed to erosion</td>
<td>4. Slightly more risk of a rotational failure</td>
</tr>
</tbody>
</table>

Steep cut bank slopes are usually preferable to gently sloping cut banks on temporary roads that will be permanently deactivated after hauling. The disadvantages of steep cut banks can be reduced if high banks are avoided. The maximum cut slope angle and the maximum bank height at that angle is a function of the soil strength and drainage. As soil material type is a good indicator of expected soil strength, it is possible to prescribe typical cut slope ratios for each soil type.
Cut slope ratios

When two different materials are present, one on top of another, the cut slope ratio should be varied, where possible, to take advantage of steeper slopes.

Cut bank stability is not affected by the slope angle of the natural hillslope, provided the soil is free draining. That is, a 3 m high, 0.5:1.0 cut bank is just as stable on a 45% hillslope as it is on a 70% hillslope.

Excavation of cut bank material can, in some instances, cause rotational failures above the road, if toe support is removed. Large
rotational failures are most common in deep, poorly consolidated materials such as marine or lacustrine soils or in soft rock. Care should be taken that there are no signs of instability immediately upslope of the road right-of-way.

A rotational slump in lacustrine soils caused by removal of toe support

### 3.2.2 Road Drainage

Most road-related failures are usually the result of excessive sidecast or problems in the road drainage network. Failures in the road drainage system can lead to saturation of the subgrade of the road or the sidecast material, which reduces effective soil strength and increases the risk of a slope failure. If the ditch flow breaches the road, it can quickly saturate or erode the fill slope, causing a possible slope failure.

Drainage construction practices that are conducive to landslides include:
LACK of ditches, or inadequately sized or poorly maintained ditches

CULVERTS that are spaced too far apart, are poorly located, are not maintained, or are undersized

PROBLEMS associated with discharge points of culverts and ditches

Ditches

Well-constructed and maintained ditches are a real key to long-term stability of a road. Backhoe construction is superior to cat construction in that the ditch can be cut out of the subgrade rather than gouged out of the cut slope. Excavation from the cut slope usually results in an over steepened cut section that subsequently slumps into the ditch. Backhoes can also use the excavated ditch material in the ballast rather than sidecasting it.

The full flow water surface for roadway ditches should be at least 30 cm below the roadway subgrade, plus an allowance for anticipated sediment deposition. This position will prevent ditch water from entering the ballast material, removing the fines and destroying the effectiveness of the ballast. A deep ditch also allows rapid drainage of the subgrade, which reduces the build-up of high water pressures and helps maintain high soil strength. Where ditches are formed from ballast rather than cut into the subgrade, the water can pond in the ditch, saturating rather than draining the subgrade.

The gradient of ditches is largely determined by the gradient of the road. It should be a minimum 1.5%, to ensure a minimum full-flow velocity of 1 m/sec to permit sediment transport (self-cleaning).
Flat-bottomed ditches are hydraulically superior and less subject to scour than V-shaped ditches. A minimum width of 1 m is recommended.

Ditch maintenance is critical to preventing road failures. Ditches should be inspected after any heavy runoff and pulled if necessary. Relatively minor blockages can lead to spectacular erosion and landslides. Slash that could block culverts should be removed.

**Outsloping**

In some situations it is very difficult to keep a ditch open. If a cut bank is continually sloughing, or if regular ditch maintenance is not possible, it may be preferrable to outslope the road 3-4%, or place outsloped swales at grade breaks. Unmaintained ditches can pond drainage to over-saturate the soil, causing failure. With outsloping, water ponding is prevented and excessive pore-pressure development at any one point is avoided.

![Diagram of outsloping road](image)

**Culvert management**

Culverts are directly or indirectly responsible for a large number of landslides and gully washouts. Problems include:
**SPACING AND LOCATION**

Improper spacing causes concentration of water at a single point, quickly saturating the hillslope.

**Place culverts in every natural gully, seep-ageway, and stream (seasonal and continuous).** Put culverts in all dips of the road that will not drain naturally.

**Install additional crossdrain culverts** to drain ditches and minimize erosion; maximum 150 m apart on grades over 10% and 230 m apart on grades under 10%.

**Install additional culverts** at road junctions to avoid concentrating drainage in a single ditch system. Do not divert drainage from one watershed into another!

**Avoid** culvert discharges onto a deep soil or fractured rock that shows any signs of instability. Extend the ditchline to a natural channel.

---

**CULVERT SIZE**

**Undersized culverts** can cause water ponding and fill-slope saturation.

**Culverts must be able to pass the 50-year flood** on mainlines and the 25-year flood on secondary roads.

**Metal culverts** must be a minimum of 50 cm and wooden culverts no smaller than 100 x 50 cm.
CULVERT MAINTENANCE
Blocked culverts can cause ponding, saturation of the fill-slope, and breaching of the road. Blocked culverts are more often a problem than are undersized culverts and must be regularly cleaned. Trash racks can reduce maintenance in chronic debris streams.

OUTFALL
Cascading outfall can erode and undermine the fill-slope.
An apron of coarse rock or riprap installed over the fill-slope can prevent erosion and undercutting. Cull logs or stumps are also useful.
Sloping half-round culverts or neoprene "socks" reduce outfall velocity, although the socks can become flattened in snow areas.

INTAKE
Catch basins constructed at and immediately upstream of culvert openings will reduce turbulence. A basin should be 75-100 cm wider than the ditch and three ditch widths long.
Boulders in the basin will reduce velocity.
Mitred (45°) inlets are less prone to damage and have greater capacity.

STEEP DITCH CULVERTS (>10% GRADIENT)
Maximum spacing = 150 m.
Skew culvert to reduce turbulence and erosion. Angle of intercept between culvert and ditch should be 30° from perpendicular and angled downslope.
Place boulders at and upstream of culvert entrance to slow water velocity.
Culvert gradient should not exceed 10%. Use a larger pipe than normal at 10% and flume down the hill.
Install a ditch block.
Permeable fills

Embankments built against toe slopes to stabilize a hillslope can impede groundwater flow. Similarly, roads may interfere with natural groundwater paths when a thin permeable soil cover is removed and the road built up onto the rock or impermeable till underneath.

Poor subgrade drainage will also reduce the load-bearing capacity dramatically. Poorly drained, well-graded subgrade will support 50% less weight than well drained soils. In these situations, a drainage path under the embankment for groundwater flow should be constructed. To do so, excavate below the subgrade and use a permeable fill-blanket for the bottom few feet of the embankment. Excavating into the underlying soil "keys" the toe load into the slope as well as ensuring drainage is below the critical failure surface. Use this type of drainage for cut and fill and backcast road construction.

For full-bench road construction requiring a permeable fill subgrade, or where supplies of coarse aggregate are limited, trenches can be cut through the subgrade and backfilled with
gravel (Squamish culverts). The trenches should be about 1 m² in cross section and spaced at 5- to 10- m intervals.

A more permanent variant is the “French Drain.” After trenches are excavated, geocloth fabric is laid. The backfill gravel is placed onto fabric and then fabric is folded over top of the drain material. The next step is to backfill and then build a running surface.

3.2.3 Gully Management

Gullies are particularly susceptible to failure because of their very steep slopes, concentrated seepage, and disturbed vegetative cover. Logging and road building further increase the level of instability; debris flows often initiate where roads cross steep gully headwalls, or from logged gully sidewalls and headwalls.

Road building and yarding activities in gullies that can destabilize the gully include the following:

**DEEP ROAD CUTS** are often necessary in gullies because of the very steep slope and the deep soils. Sidecasting of the excavated material will over-steepen and overload the lower slope. In soft soils, cutbank failures can also occur.
YARDING can scour gully sidewalls, particularly where cross-gully yarding is practiced. This may destabilize a gully sidewall, initiating a failure or resulting in increased siltation.

LOG BREAKAGE is common during falling along gully sides and during cross-gully yarding. Large amounts of slash can accumulate in the gully bottom. This material increases the volume of any debris flow initiating upslope.

Preventative measures to reduce the incidence of debris flow in gullies can be taken at various stages of harvesting:

Avoidance of unstable gullies

Use the previous sections on site assessment of gully stability to determine the hazard of road building or harvesting. The characteristics of unstable gullies are summarized below:

<table>
<thead>
<tr>
<th>GULLY SIDEWALLS</th>
<th>steeper than 70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>GULLY CHANNEL</td>
<td>steeper than 45%</td>
</tr>
<tr>
<td>DEEP MATERIALS</td>
<td>in gully sidewalls</td>
</tr>
<tr>
<td>WET SOILS</td>
<td>and lots of seepage</td>
</tr>
<tr>
<td>SIDEWALL SLUMPS</td>
<td>and debris slides</td>
</tr>
<tr>
<td>DISTURBED VEGETATION PATTERNS</td>
<td></td>
</tr>
<tr>
<td>COMMON WINDTHROW</td>
<td></td>
</tr>
<tr>
<td>OVERSIZED FANS</td>
<td>at toe of gully</td>
</tr>
</tbody>
</table>
Buffer strips

Buffer strips are areas of intact or selectively cut forest maintained around a gully. Narrow buffer strips around gullies are **only** recommended where the windthrow hazard is not high. Windthrow occurring around an unstable gully will often trigger a landslide and will certainly contribute to the volume of a debris flow. If windthrow is a potential problem either:

- **leave a large area** around the entire gully complex, or
- **harvest the entire gully** and accept the risk of a possible debris flow, or
- **selectively harvest and leave** those trees that are significantly taller than the topographic break, and hence will have no protection from the wind. Extensive thinning of the buffer stand is not recommended, however, as this can open the entire stand to windthrow.

Buffer strips should be at least the width of the tallest tree in the buffer strip to be effective. It is usually possible to cut a narrow corridor through the buffer strip, for limited yarding of trees on the far side of the gully.
**USE DEFLECTION LINES** to establish the road and landing location so that maximum deflection will occur over the sensitive sites.

**ESTABLISH GULLIES** as setting boundaries. Gullies in the middle of the clearcut mean that hundreds of logs are yarded across them. Soil disturbance levels in gullies are directly related to total log traffic over the yarding road.

**ESTABLISH LANDING LOCATIONS** so that yarding will take place away from the gully. Avoid cross-gully yarding as much as possible.

**THE PREFERRED METHOD** of logging gullies is to construct a road above the headwaters and to grapple yard straight up the gully to landings along the top road. In the example on the following page, it is possible to highlead the entire headwater area from landing (1), but only by cross-stream yarding. If the road is developed (2), the same area can be logged but wood is yarded up the gullies to landings (3), (4), and (5).
Falling

Directionally fall along the slopes to minimize the accumulation of wood debris in the gullies.
**Yarding**

<table>
<thead>
<tr>
<th><strong>Avoid yarding sensitive sites in heavy rainfall months.</strong></th>
<th>Yarding disturbance or guyline stress may trigger slides during wet weather.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>For guylines, a minimum stump size</strong></td>
<td>of 0.8 m diameter is needed to reduce the incidence of stump pullout. Avoid securing guylines to any stumps located on soils with high water tables. Multiple stumps can be strung together. <strong>Rockbolts may be an option</strong> in rock-lined gullies, where large trees are rare.</td>
</tr>
<tr>
<td><strong>Use full or partial suspension</strong></td>
<td>whenever possible. Avoid using two chokers hooked end to end.</td>
</tr>
<tr>
<td><strong>Buck oversized logs,</strong></td>
<td>as they are particularly prone to gully disturbance.</td>
</tr>
<tr>
<td><strong>Logs hooked in the centre</strong></td>
<td>are unstable and disturb the soil more than logs hooked at one end.</td>
</tr>
<tr>
<td><strong>Do not pullout logs</strong></td>
<td>imbedded in the channel. They store considerable amounts of sediment and act to stabilize the channel. Also <strong>leave windthrown trees</strong> in the channel.</td>
</tr>
<tr>
<td><strong>On steep landing locations,</strong></td>
<td>clean off debris regularly, but avoid overloading the slopes below with accumulated debris.</td>
</tr>
</tbody>
</table>
**Sacrificial bridges**

Bridges across the channel or fan of a gully prone to debris flows should be designed to have either a very high clearance or to be "sacrificial." Most debris flows occur in a series of sediment pulses. Even relatively light bridges are capable of stopping the smaller pulses, causing an in-filling of the channel and a buildup of material behind the bridge. Subsequent pulses will be diverted out of the channel, possibly into buildings or along roads. The bridge may eventually fail under the increasing load, releasing a large destructive volume of material.

Sacrificial bridges should not be designed to be an obstacle to debris flows. Lightweight bridges with at least 4 m clearance will allow minor flows to pass. The more infrequent, large and rapid flows will destroy them without losing momentum. If the bridge stringers are anchored at one abutment by cables, the stringers will be thrown aside but will not become part of the flow.

**Fords**

Fords are fill or concrete structures built in contact with the creekbed so that vehicles can cross the gully. Examples are the permeable trench drains of coarse cobbles and boulders. Low summer flows seep through the fill; high winter discharges flow over the top. During extreme events or debris flows, the ford will be washed out.

More permanent fords can be made of erosion-resistant concrete dish-shaped structures that will pass both water and debris. Problems can occur with water erosion around the edges of the structure, leaving an impassable elevated ford.
3.2.4 Riprap Revetments

Many valley bottom roads parallel rivers. Where the riverbank sides are steep; or where fill material from the road extends into the river, there is always the danger of material eroding from the toe of the slope. This will reduce the stability of the slope by reducing the resisting forces.

The best method for slope stabilization along rivers is riprapping the toe of the slope. Riprap is relatively easy to construct and is effective on many types of eroding banks. Heavy riprapping keyed into the slope acts as a permeable toe buttress, increasing resistance to failure. Minimum riprap size may be estimated from the largest boulders in the streambed. Where rock of the right size is not available, gabions or wire mesh baskets can be constructed and filled with boulders.

The design recommendations illustrated below and given on the following page should be followed in laying a slope supporting riprap:

![Riprap revetment diagram](image_url)
| **EXCAVATE** into the riverbed to key the riprap into the slope |
| **SLOPES** of the riverbank should be cut to a 1.5:1 slope for increased stability before the rock is placed |
| **EXTEND** the layer 1 m of elevation above the expected high water level |
| **PLACE** riprap, do not just dump it over the bank |
| **INSTALL**, where banks are fine textured, a gravel filter before the riprap |
3.3 STABILIZATION

The previous sections described the forces that tend to cause failure and those that resist failure. All landslide prevention and slope stabilization methods act on one or more of these forces. There are, in fact, only **four basic methods that can be used to improve slope stability:**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNLOADING</td>
<td>the head of the slope</td>
</tr>
<tr>
<td>DRAINING</td>
<td>groundwater</td>
</tr>
<tr>
<td>LOADING</td>
<td>the toe of the slope</td>
</tr>
<tr>
<td>SHIFTING</td>
<td>the position of the potential failure surface</td>
</tr>
</tbody>
</table>

The stability of any slope will be improved if these actions are carried out. To be effective, however, the most important controlling process must be identified, and the appropriate technique applied to a sufficient level to reduce the influence of that process. There is no point, for example, in installing drainage pipe into a slope which has very little groundwater. The treatment must be designed to fit the condition of the specific slope under study.

Slope stabilization either takes place during construction, when a road must cross an unstable slope, or when stability problems develop unexpectedly following construction. Many slope engineering techniques require a detailed analysis of soil properties and a sound knowledge of soil and rock mechanics. **In any high-risk situation, where a landslide may endanger lives or property, the forest engineer must consult with a geotechnical engineer before any stabilizing work is undertaken.**