

To avoid areas more susceptible to failure, slight changes in clearcut boundary locations can often be made:

ON CONVEX SLOPES, most open slope landslides occur in or near zones of change in slope angle. The slope break can range from sharp to gradual, but most landslides occur where the increase in gradient is 20% or more. With sharp slope breaks, the edge of the slope break is the most common initiation point. With more gradual slope changes, the landslides tend to initiate below the slope break.

ON CONCAVE SLOPES, landslides usually initiate just above the slope break, where seepage is common.

These subtle changes in slope shape are often only apparent after deflection lines are run. Locating the falling boundary inside these trigger points can reduce the incidence of sliding.

3.1.8 Windthrow Boundaries

Landslides along clearcut boundaries are sometimes triggered as a direct result of exposure of standing timber to storm winds. Windthrow-initiated landslides may be reduced by locating windfirm boundaries on stable soils. These boundaries must be run parallel to storm winds. They should not be located on shallow organic soils or on slopes in excess of 40 degrees. Boundaries should not be located along gully head walls. They should be located well above or a good distance below gully head walls, on stable soil (refer Section 3.2.3, Gully Management).

3.2 PREVENTION

Preventative measures are necessary to compensate for changes brought about in slope stability by road construction or clearcutting. Road construction can increase landslide risk by:

OVERSTEEPENING the slope with bermed side cast material
OVERLOADING slopes by adding sidecast material
ALTERING drainage by blocking or redirecting surface or subsurface drainage
REMOVING MATERIAL from the toe of the slope

Yarding operations contribute to slope instability by:

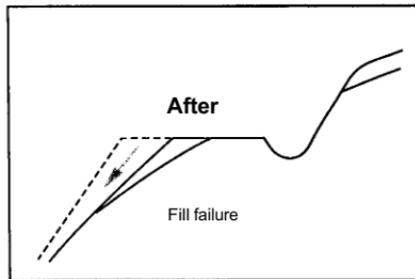
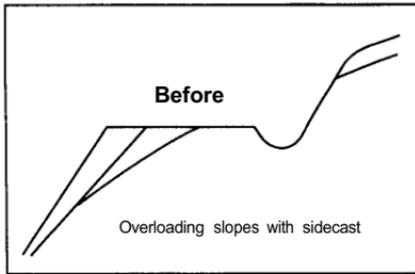
OVERLOADING gullies with debris and soil
INCREASING surface erosion rates which in time may lead to landslides
DISRUPTING drainage

The preventative measures described in this section should be routine operating procedures on all slopes in excess of 60%, and may be necessary on some soil types at even lesser slope angles. Refer back to the “slope stability model” (Chapter 1) to see how changes in the driving and resisting forces can reduce the Factor of Safety to less than 1, often changing a formally stable slope to a potentially unstable site. By implementing the procedures outlined in this section, one can keep the changes in hill slope stability to a minimum.

3.2.1 Road Construction Techniques

Sidecast

Overloading and oversteepening already steep slopes with sidecast material during road construction is the single largest cause of landslides.



Sidecast failures are usually associated with ground slopes steeper than 70%. They are most common on:

- convex slopes
- mid- to upper-slopes
- colluvial soils

Slight regional differences in critical slope angles for different terrain types occur, but 70% is a good "rule of thumb." However, care should be taken to recognize those soil types where the failure angle can be much less, as shown in the table on page 110.

Geographic area	Morainal soils	Colluvial soils	Broken rock
SE Vancouver Island	80% (dry) 65% (wet)	75%	78%
NE Vancouver Island	70% (dry) 65% (wet)	75%	78%
Queen Charlotte Islands	70% (dry) 45% (wet)	70%	75%
Vancouver Island West Coast	70% (dry) 50% (wet)	75%	78% range: 68-100%
Cascades	75% (dry) 65% (wet)	75%	80%

Critical gradients of hillside on which sidecast failures typically occur

To avoid surface ravelling on "sliverfills", 55-60% is maximum ground slope for stable sidecasting. Side slope failures on lesser slopes occur mainly where breakdowns in the road drainage redirect ditch water onto fill slopes. The main contributing factors are:

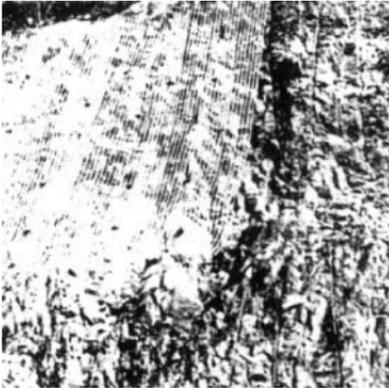
- lack of ditches
- blockage in ditches or culverts by logging debris or cut bank failures
- culverts too far apart or poorly located
- culverts that are too small

Incorporating logs into the fill material only stabilizes the slope in the short term. After 5-7 years, the logs rot and the sidecast failure rate increases drastically. It is not possible to "seal off" a buried stump and prevent rot.

Controlled blasting

Heavy blasting during road construction or quarry excavation is a common cause of landslides. Debris avalanches can be triggered on nearby slopes by ground motion from large blasts, especially during wet conditions. On large cuts, excessive blasting is often used to throw the rock down the slope, often overloading the soil and initiating a debris slide. As well, the rock face itself can be made unstable through heavy blasts that increase rock shattering.

“**Presplitting**” or “smooth wall blasting” minimizes rock shattering and rock overbreak, and controls the volume and travel distance of blown rock. On unstable sites, excavated rock can be end hauled to more stable disposal sites. A clean rock face needing minimal scaling is created, which is less susceptible to weathering or water percolation and improves long-term stability.



A presplit rock face with partial wire mesh protection

The techniques for controlled blasting cannot be standardized because of the importance of the local rock type, and are beyond the scope of this manual. Basically, however, light charges with millisecond delays are used in closely spaced holes along the fracture face. The cumulative shock from the millisecond blast is less than the shock resulting from an instantaneous blast using the same amount of explosive. The full cut is excavated in a number of separate blasts. The cost of presplitting is little more

than controlled blasting, but the extra expense is easily recovered in reduced scaling and maintenance costs.

Recent research has found that the shock wave from blasting is transmitted into wet soils very effectively. In dry soils, there is much less transmission of the energy. This suggests that the potential for initiating a landslide in soil in the vicinity of a blast is much higher in winter than in summer.

Road length reduction

Studies have shown direct correlations between the number of landslides and the total road mileage in an area. Reducing the total road length, and particularly, reducing the road length on steep slopes, will reduce the opportunities for landslides.

Section 3.1.4 describes advantages and disadvantages of various yarding methods and their associated road systems. Reductions in amounts of unstable hillslope construction can, in some situations, be reduced by up to 50% using longline or helicopter yarding systems.

Steep road gradients also provide an efficient means of reducing total road mileage and may be a more cost-effective alternative than full bench, end-haul construction in reducing slide volumes. Steep grades have three advantages in that they reduce:

- amount of road constructed across steep slopes;
- total road mileage;
- road maintenance costs, as a greater percentage of the road is on low maintenance ridge tops.

Disadvantages are road surface drainage problems and increased water erosion. Better ditching, crown surfaces, and frequent culvert spacing are required.

Road width reduction

Most road-related landslides are the result of excessive side-

casting of excavated material. Narrow roads can reduce road surface drainage problems and the amount of excavated material and sidecast dramatically, as shown in the example below.

Road width (full bench)	Hillslope (percent)	Excavated volume (m ³ /m)
5.5m	50	31
7.3m	50	47
5.5m	70	69
7.3m	70	107

Excavated soil volume with various road widths and hillslopes; assumes a 1:1 cut slope and a 0.5 meter ditch.

In the 50 and 70 percent slope examples, there is approximately a 35% decrease in the volume of sidecast material with the narrower road. Cut bank stability is also less affected by the smaller cut. This is particularly important where excavations cut through soft, inclined sedimentary rock or clay soils.

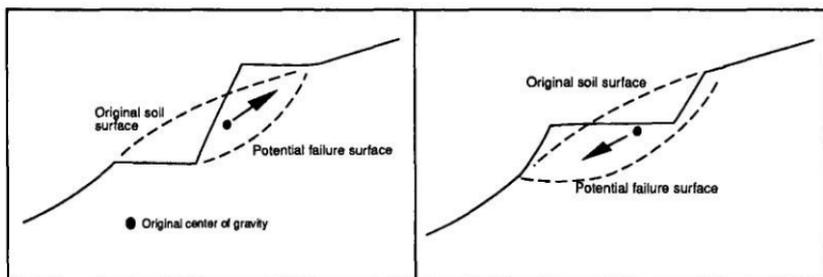
Use of cuts and fills

On most slopes it is difficult to predict exactly where a slide may occur. In these circumstances, the general road construction guidelines outlined in the previous section should be followed.

When the boundaries of an incipient slide are apparent (tension cracks, depressional areas, tilted trees, etc.), the best action is to avoid crossing the area. When this is impossible, knowledge of the boundaries of the incipient slide can be used to advantage. In some cases, correct location of cuts and fills across the landslide can have little effect on the slide stability or may even increase the stability.

The following guidelines are mostly applicable to rotational slides, where the head, toe and side boundaries are apparent.

1. In general, the toe of an actual or potential landslide should be loaded and its head unloaded.
2. Landslides should not be crossed in the middle zone. Both cuts and fills carried out in intermediate positions on the slide can have a conflicting effect on stability. It is therefore best to avoid cuts or fills in intermediate positions and to locate them at the head and extreme toe of the slide, respectively.



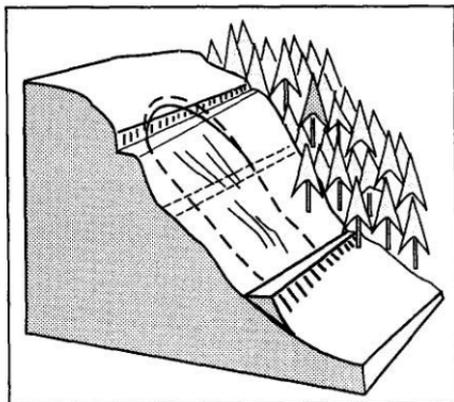
Loading the head and/or unloading the toe shifts the center of gravity upward and increases the potential for slumping.

Loading the toe and/or unloading the head shifts the centre of gravity downward and decreases the potential for slumping.

3. Roads built at the head of the slide should be full-benched and the material end-hauled. No sidecasting should take place.
4. Roads built across the toe of the slide should be built, as much as possible, with end-hauled fill material and cuts made as small as possible. Fill construction is possible only where slope angles decrease downslope, otherwise there is a danger of fill slope failure.

Corrective fills at the toe of the slide are generally preferable to corrective cuts at its head for several reasons:

1. The increase in the "Factor of Safety" is greater with fills.
2. Fill stability improves with time, whereas cut slope stability decreases with time. Cuts in clay soils may take years before failing.
3. In complex slides with more than one potential failure surface, toe loading will protect against all failures, but a cut may destabilize some failure surfaces.



Either:

- Ensure full-bench construction at the head of the slide.

Or:

- Fill construction at toe.

Never :

- Cross middle of the slide.

Backhoe construction

Backhoes have distinct advantages over bulldozers or excavators for road construction on steep slopes. They can:

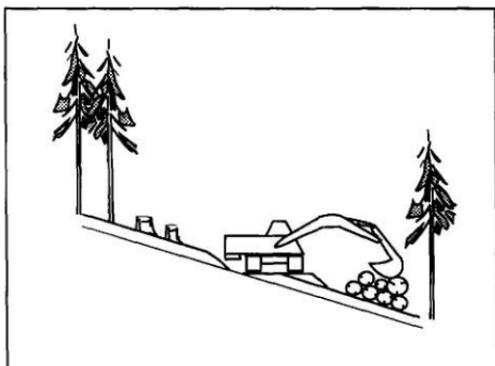
SORT MATERIALS

DECREASE GROUND DISTURBANCE, especially in wet soils

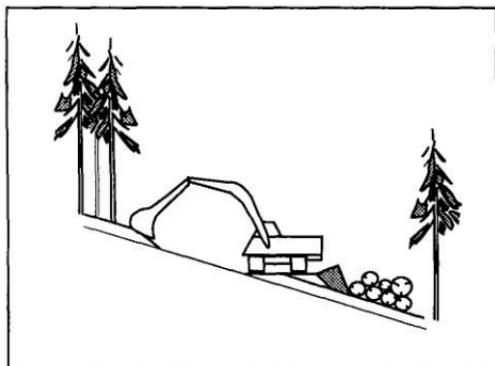
SELECTIVELY HANDLE material and logs because of long reach and mobility

PRODUCE WELL-CONSTRUCTED DITCHES

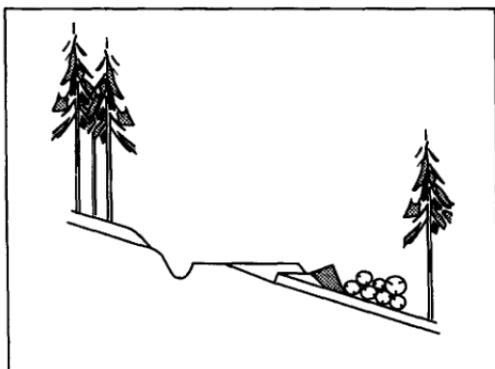
"Clean Up buckets" are recommended to sort materials and leave a smoother, more stable cut bank or ditch line. Balanced cut and fill with the backhoe 3-pass technique excavates the minimum amount of material for a given road width and therefore reduces the volume of sidecast material. In the first pass, log and stump removal take place over a "pioneered" track and logs are stacked crosswise behind. The second pass consists of stripping the overburden from above the "pioneered" track and placing it on the downslope. The logs across the pioneer road are then picked up and placed on and below the wasted overburden. The third pass consists of using the uncovered, unweathered material to construct the bearing surface of the road. Ditch material is also utilized.



First Pass - Log and stump removal



Second Pass - Overburden removal



Third Pass - Completed subgrade

This method minimizes the amount of sidecast material created, and maintains maximum soil strength within the road prism by using only unweathered material.

Compaction

Compaction is the most important aspect of road fill strength. A well-compacted road fill has many times more strength than a loosely placed fill, and should be used in any potentially unstable zone.

Proper compaction depends on soil type, moisture content, and equipment used. Optimum moisture content for various soil types is shown in the following table.

Soil	Optimum moisture
Sand or crushed rock	Bone-dry or saturated. Anything between compacts less.
Clay	Can roll a "worm" 3-6 mm diameter. Smaller, and it is too wet. If it crumbles it is too dry.
Silt	Can't roll to a thread. Can form a ball.

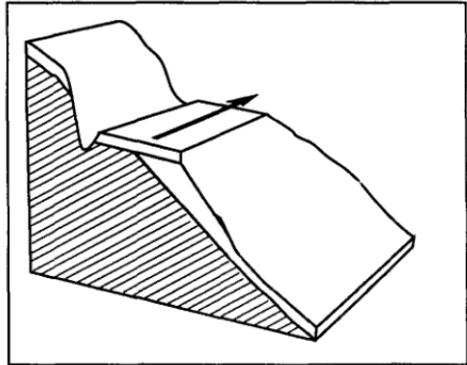
If optimum moisture conditions do not exist, wait for drier weather or sprinkle the fill with water. Aerating with ripper teeth can speed drying. Soil modifiers or cement can aid compaction, especially in silt soils. Place fills in layers of 20-30 cm depending on compactor. Remember bulldozers and loaders are **not** efficient compactors. For logging roads, a grid roller is an inexpensive compactor that works on most soil types.

Road benching techniques

Fill slope failures are the most common type of road-related landslide. Correct handling of fill material during construction of the road bench is the most important fact in the long-term stability of the road. Each of the five methods outlined below and described in the following text is best in specific soil types and should not be attempted in other types of soils. Generally, the methods are listed in order of use for "increasing slope instability." In all instances, care must be taken to ensure that fill does not interfere or block downslope (and subsurface drainage).

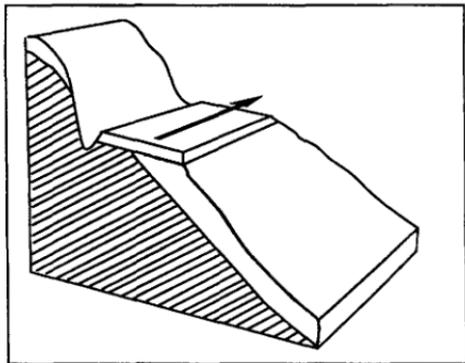
Balanced benching

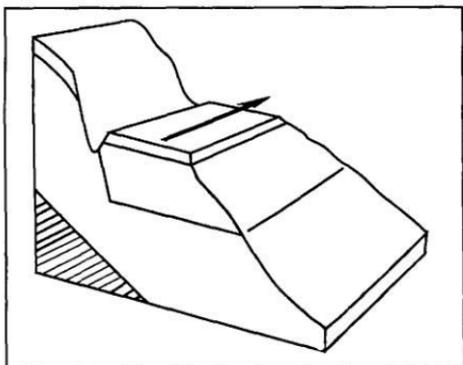
- 3-pass backhoe system
- Balance cut and fill



Sliverfills

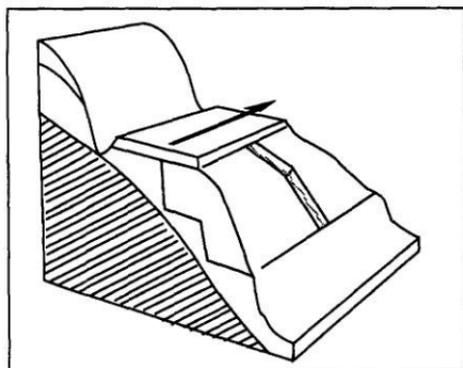
- 3/4 to full-bench construction
- Rubbly material is draped far down hillslope with backhoe
- Use only with rock or coarse colluvium
- Do not use in silts or clays
- Do not place material over organic soils, slash, logs, or brush





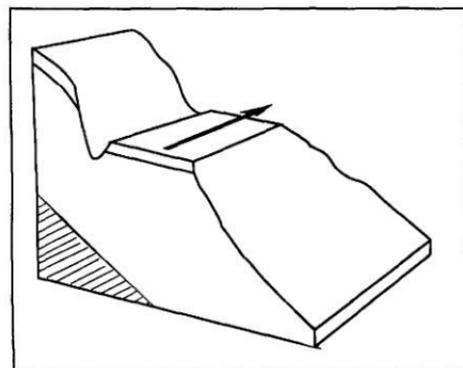
Backcasting

- A wide bench cut 3 m below center line
- Excavated soil backcast on bench behind the backhoe, forming subgrade
- Complete ditch and culvert installation after settling is complete



Multi-benching

- A small bench excavated below grade
- A second, higher bench excavated, with sidecast supported on lower bench
- The road bench then excavated with sidecast supported on the second bench
- Drainage carried over fill slopes in 1/2 culverts or riprap



Full benching/ end hauling

- Bench cut equal to road width
- No fill construction
- Excavated soil hauled to stable dump site or, when suitable, used for road ballast

Sliverfills

Sliverfills are thin fills lying parallel to the underlying hillslope rather than as wedges used in normal cut and fill. Controlled sliverfills are built where three-quarters to full-benched roads are constructed through rock or coarse colluvium and there is nowhere to dispose of the material. Some level of sliver filling will occur whenever fill material is placed on slopes over 60%. The rationale is to avoid creating an oversteepened slope. This is a method of last resort, as the potential for failure is moderately high and there is a large amount of local forest site loss due to the length of the fill slope. This method can also pose a hazard to fallers working below the roads.

Sliverfills can only be used in specific situations. For example, the excavated material must be free draining: broken rock is ideal; silts and clays are completely unsuitable. Also, the angle of the hillslope cannot exceed the angle of repose of the excavated material.

The material is placed or draped down the hillslope and not cast. The 11-m arm on a backhoe can usually control a 15-m long fill. Care must be taken that material does not hang up on the slope behind stumps or boulders, as locally oversteepened areas can fail. Uncontrolled sliverfills can occur where sidecast material becomes unstable and ravel down the hillslope.

Backcasting

Backcasting is a method used where full-benched roads are necessary and the soil is free draining. It uses most of the excavated material to construct a high subgrade, thereby minimizing the amount of sidecast, and eliminating the need to end haul. The method can only be used where the native materials are suitable for subgrade (medium to coarse textured and well drained) and where side slopes are less than about 80%. The operation consists of the following steps: