BRITISH COLUMBIA

3.5 Geometric Road Design

The purpose of road design is to produce specifications for road construction by determining the optimum road geometry that will accommodate the design vehicle configuration for load and alignment, traffic volume and provide for user safety, while minimizing the cost of construction, transportation, maintenance, and deactivation during the expected life of the road.

Road design is an art that takes the survey information and essentially connects the field data to produce the desired road profile showing the grade, alignment, designed cross sections, excavation and embankment volumes, location and size of drainage structures, turnouts, and surfacing requirements. The optimum road design reduces impacts on other resources by minimizing clearing widths and excavations and specifying proper drainage structures. Also consider the equipment anticipated for use during construction, since the equipment type impacts material movement distances and balance points. Incorporate construction techniques such as rolling grades, full and partial benching, end haul, road width, cut and fill slope angles, and horizontal and vertical control angles with consideration given to climatic, terrain and soil conditions.

Geometric road design (see Geometric Road Design Requirements) includes plans, profiles, cross-sections, and mass haul diagrams showing the optimum balance of waste, borrow, and endhaul volumes. Generate the designs from the route selection process and the location survey. From the location survey information, design a road centreline (L-Line) for vertical and horizontal alignment, calculate earthwork quantities, and produce a mass haul diagram to show the optimum placement of excavated material.

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Road standard drawings

Figure 3-5: Dwg. No. 13-757 - Sample Right-of-Way Through Private Land (PDF)

Figure 3-6: Dwg. No. 13-758 - Sample Plan & Profile (PDF)

Figure 3-7: Dwg. No. 13-759 - Sample River Crossing Plan 1 of 2 (PDF)

Figure 3-8: Dwg. No. 13-759 - Sample River Crossing Profile & Cross-Section 2 of 2 (PDF)

Figure 3-9: Dwg. No. 13-760 - Sample Railway Crossing for Existing Road (PDF)

Figure 3-10: Dwg. No. 13-761 - Sample Pipeline Crossing (PDF)

Figure 3-11: Dwg. No. 13-762 - Sample Powerline Crossing (PDF)

Figure 3-12: Dwg. No. 13-763 - Sample Structure of Compliance with Navigable Waters (PDF)

Figure 3-13: Dwg. No. 13-768 - Sample Highway Junction (PDF)

3.5.1 Design Planning Considerations

In order to meet the ever-increasing demand for access, be apprised of any multi- user needs: for example, oil and gas exploration, mining, power project, recreational, and public uses. These factors may influence the design widths, alignment, and grades beyond those required for forest access during harvesting. Use additional and/or larger turnouts if heavy traffic is anticipated or there is potential for high recreational use of the road. Restrict utilities to only one side of the road to ensure that the road right-of-way has room to expand and be upgraded in the future.

Road maintenance can also be a significant factor to be recognized during road design. For example, access to retaining and catchment walls and spillways may be required once the road is built and, if the structures are inaccessible, this may increase the chance of being overlooked during inspections which may increase the cost of maintenance.

Allow adequate room for equipment operation including snow removal and logging equipment. Large equipment or operations often require additional road width and in the case of snow removal, for example, a place to relocate snow and ice away from the roadway without damaging surrounding forest resources caused by trapping and diverting meltwater on sensitive slopes and not damaging signs, fences, and bridge guardrails.

When designing a road prism that includes excavation into side slopes or the placement of loads on the fill slopes, consider the nature of the soil and ground conditions, so that slope stability can be maintained. In addition to the immediate factors related to the slope, consider the road in the context of the overall area.

Ensure that the road is designed in the location identified by the layout and, where no exception has been provided in accordance with FPPR, the design places the road beyond the riparian management areas for each stream.

Incorporate other information in the design, including prescriptions and assessments that relate to the road location and design. These may include professional designs such as deep or steep excavations, retaining walls, designs for stream crossings, bridge design and alignments, designs included in or based on terrain stability assessments, and specialized designs in rock cuts. For example, if a proposed road will cross areas with a moderate or high likelihood of landslides as determined by a TSFA, incorporate measures to maintain slope stability into the geometric road design. Also, ensure that a road design on the Coast incorporates any protective measures prepared by an appropriately qualified professional as part of a gully process or fan stability assessment.

As a result, be aware of the intended use of the road, the timing of such use, construction techniques and other surrounding design considerations as well as the following road design criteria.

3.5.2 Road Design Criteria

Consider the following factors in the road design:

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Clearing width

Keep the clearing widths as narrow as possible, to minimize impacts on other resources, but wide enough to accommodate:

- the road prism;
- user safety;
- decking of right-of-way timber;
- turnouts;
- subgrade drainage;
- subgrade stability;
- waste areas and endhaul areas;
- pits and quarries;
- landings;
- slash disposal;
- equipment operation;
- snow removal;
- fencing and other structures; and
- standing timber root protection, especially on cut banks.

Move to a disposal site organic debris, rock, or other excess material that cannot be placed in the road prism and within the clearing width because of terrain stability or other factors. Ensure such areas are of suitable size to accommodate the estimated volume of waste material and identify the areas in the road design.

Calculate clearing widths on a station-by-station basis as part of a geometric road design. In situations where geometric road design is not required, use other methods as shown on page 179 in the Forest Road Engineering Guidebook (PDF, 7.8MB).

Road alignment

Road design incorporates horizontal and vertical road alignments that provide for equipment use and for user safety. This involves establishing:

- appropriate travel speeds;
- appropriate maximum road grades;
- suitable stopping and sight distances;
- junctions with existing roads;
- road widths;
- turnouts; and
- appropriate traffic control devices.

Designed travel speeds often vary along forest roads due to terrain conditions or changing road standards. The cycle time or distance from the logging area to the dump or processing area may be an important economic factor to consider in establishing an overall design speed. In other cases, topography and terrain may dictate alignment, with little impact from other factors. In general, base the safe vehicle speed for a road on:

- horizontal and vertical alignment of the road;
- vehicle size and configuration;
- road width; and
- sight distance and traffic volume.

Use the the following table to determine appropriate travel speeds and stopping and sight distance requirements along the road.

- Table 3-2 Summary of alignment controls for forest roads (PDF)

Maximum road grades

Ensure that the following design conditions are considered in developing maximum road grades:

- road surface;
- anticipated vehicle types;
- vehicle speed;
- length of pitch;
- curve radius; and
- specific terrain hazards to negotiate.

Subgrade widths

Forest roads widths are categorized as either single or double lane roads based on subgrade width. Roads less than 8m in subgrade width are classified as single lane roads. Double lane roads do not require turnouts. Where road surfacing is not used, the stabilized road width is the width of the road subgrade.

Curve widenings

Design minimum subgrade widths for roads on curves or design widenings in accordance with the following table and the following notes:

Table 3-3 Curve Widenings

Radius of Curve in metres (m)	Minimum Subgrade Width in metres (m)
180	4.3

90	5.3
60	5.8
45	6.0
35	6.5
25	7.5
20	8.0
15	9.0

Double-lane all blind curves or provide adequate traffic control devices. Allow extra width to accommodate for side tracking of truck-trailer units. Note that the subgrade widths in the table do not make accommodation for the overhang of long logs or any slippage of the truck or trailer because of poor road conditions.

Apply the widening to the inside of the curve unless the curve has a 60m long taper section on each end. For widening on the inside, provide a minimum 20m section on each end of the curve. Apply the full widening at the beginning of the curve (B.C.) and end of the curve (E.C.).

Turnouts

A turnout is a short auxiliary lane of sufficient width to provide space for safe passage of industrial vehicles. They are used on single lane roads and located in suitable numbers to accommodate user safety. Design them such that the running surface of the turnout is 4m in width, in addition to the stabilized road width.

Make the overall turnout length a minimum 30m, including a 7.5m taper at each end. Increase the turnout length to accommodate longer truck configurations, where the turnout length may increase to as much as 50m. Figure 3-2 illustrates examples of turnout configurations (PDF).

Slope stability considerations

If a proposed road will cross areas with a moderate or high likelihood of landslides, a conventional cut and fill road construction technique may not be an adequate type of measure to maintain slope stability, and alternative measures incorporated into the geometric road design may be needed to prevent road-induced slope failures and landslides.

Examples of types of measures include:

- road relocation;
- site specific road construction techniques;
- methods to cross gullies and fish streams
- cut and fill slope angles;
- location and design of waste areas and endhaul areas;
- drainage control or installation of subsurface drainage; and
- road maintenance (including upgrading and modification), and deactivation strategies.

Examples of different road construction techniques that may be used in conjunction with appropriate deactivation measures, include:

- bench construction with no endhaul;
- oversteepened fills for single season use of the road;
- use of wood for fill support for short term roads;
- oversteepened cuts with modified drainage control to manage minor sloughing;
- bench construction with endhaul and replacement of finer material with coarse rock fill;
- full bench construction with 100% endhaul;
- retaining wall structures to support cut or fill slopes; and
- engineered fills that incorporate special requirements for compaction of the fill and reinforcement of the fill with geosynthetics.

Fill slope & cut slope angles

Design stable cut slopes, road fills, borrow pits, quarries, and waste areas in a manner that will not contribute directly or indirectly to slope failures or landslides over the expected design life.

- Table 3-4 General guidelines for cut and fill slope angles for use in forest road design (PDF)

Fill slopes

The stability of a fill slope depends on several variables, including the forces that tend to cause instability (gravitational and water pressure forces), and the forces that tend to oppose instability (e.g., shear strength resistance of the soil or rock materials expressed as an internal friction angle or cohesion). The stability of fill slope can be increased by incorporating various design and construction techniques.

Design fill slopes at or less than the “angle of repose.” The term “angle of repose” should be used in the context of loose, cohesionless soils only (e.g., non- plastic silt, sand, sand and gravel). Flatter side slopes in all types of soil will reduce the gravitational forces that tend to cause slope instability. For a fill slope in cohesionless material, the angle of repose is about the same as the minimum value of that material’s angle of internal friction. Steeper fill slopes are more likely to cause a road-induced slope failure or landslide than flatter fill slopes.

Compact the fill materials to increase the density and shearing resistance of the soil. The angle of internal friction depends primarily on the relative density (loose versus dense), the particle shape (round versus angular), and the gradation (uniformly graded versus well graded). For relatively loose cohesionless soils, the minimum value of the angle of internal friction will range from about 27 degrees (2H : 1V) for rounded uniform soil grains to 37 degrees (1⅓H : 1V) for angular, well-graded soil grains. For relatively dense cohesionless soils, the maximum value of the angle of internal friction will range from about 35 degrees (1.5H : 1V) for rounded uniform soil grains to 45 degrees (1H : 1V) for angular, well-graded soil grains.

Note: Fill slopes that are constructed at or less than the angle of repose (minimum angle of internal friction) will not necessarily remain stable if partial or full saturation of the fill occurs. Such saturation can result from surface and subsurface water flows during spring melt or after heavy periods of rainfall.

Expect that poorly drained fill materials will be prone to a greater likelihood of slope failure or sloughing than well-drained fill materials. Additionally, the slopes of poorly drained fills at locations of significant zones of ground water seepage may experience larger and greater frequency of slope failures or sloughing problems. The significance of observed seepage zones might dictate the application of special drainage measures to reduce the likelihood of slope failure during construction and the intensity of maintenance activities over the operating life of the road. As a general rule, without special drainage measures, design the side slopes of poorly drained fills (e.g., fills composed of silty soils) at angles that are flatter than the angle of repose to minimize the likelihood of slope failures.

Cut slopes

In the design of cut slopes, consider and address factors such as:

- the desired performance of the cut slopes;
- types of cut slope materials;
- overall terrain stability;
- engineering properties of soils;
- seepage conditions; and
- maintenance.

In general, cut slopes will remain stable at slightly steeper angles than fill slopes constructed from like soil materials. The reason for this is the undisturbed soil materials in a cut are often in a denser state than similar type materials placed in a fill; and may contain sources of cohesive strength that further increases the shearing resistance of the soil.

Cut slopes designed at too flat an angle can be uneconomical in steep ground because of the large volumes of excavation. Steeper cut slopes may be more economical to construct in terms of reduced volumes of excavation. However, they can also be more costly from an operational standpoint because they require more maintenance due to sloughing and slumping.

For most forest roads, design cut slope angles to favour steeper angles to:

- reduce the length of cut slopes;
- minimize visible site disturbance; and
- reduce excavation costs;

provided that a somewhat higher level of road maintenance and likelihood of slope destabilization is acceptable for the site.

In the latter case, prepare and implement a maintenance schedule that addresses the erosional processes acting on the exposed cut slope face (such as splash, sheet, rill, and gully erosion) and reduces the threat to:

- drainage systems (as a result of cut bank slope failure redirecting ditchwater flows onto potentially unstable fill or natural slopes);
- user safety; and
- risk of damage to the environment.

Consider designing flatter cut and fill slopes, or using retaining wall structures to support cut slopes or fill slopes, in cases where slope stability problems are expected to be difficult to manage with maintenance measures alone.

3.5.3 Swell & Shrinkage of Materials

The volume of natural in-place material usually expands (swells) or contracts (shrinks) after it is excavated and reworked. Figure 3-3 illustrates how the volume of a material can change during excavation, handling, placement, and compaction in a fill. Soil and rock volumes can be expressed in different ways, depending on whether they are measured in the **bank**, or measured in **loose** or **compacted** conditions.

Bank volume (sometimes referred to as **excavation volume**) is the volume of material in its natural, or in-place, condition.

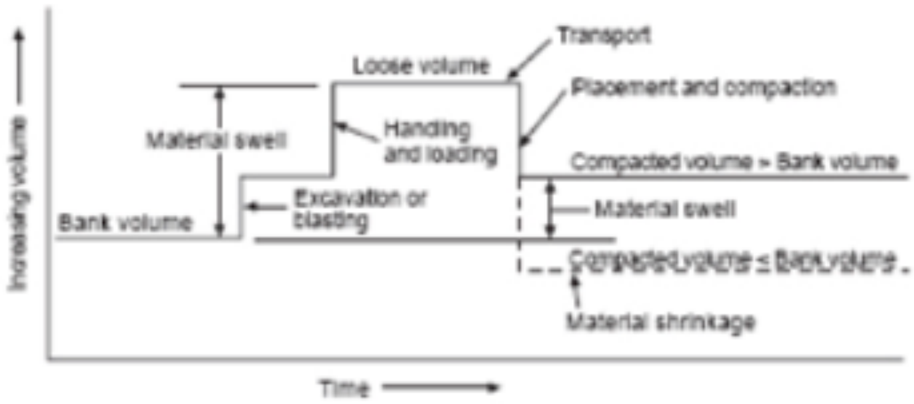
Loose volume (sometimes referred to as **trucked volume**) is the volume of material in a loose, broken, blasted, or otherwise disturbed state that has been excavated and stockpiled or loaded into trucks and hauled (handled). As shown in Figure 3-3, both soil and rock increase in volume (swell) when they are excavated and handled. This occurs because air voids are created in the material during these processes.

Compacted volume (sometimes referred to as **embankment volume**) is the measured volume of material after it has been placed in a fill and compacted. As shown in Figure 3-3, when loose material is placed and compacted, a reduction in volume occurs. The amount of this decrease may be greater or less than the increase in volume due to excavation, depending on several factors explained below. If the compacted volume is greater than the bank volume, the volume increase is called **swell**. If the compacted volume is less than the bank volume, the volume reduction is called **shrinkage**.

The amount of swell and shrinkage depends on several factors, including:

- soil or rock type;
- natural in-place density;
- moisture content of the loose material at the time of placement and compaction; and
- compactive effort applied to the fill material.

Figure 3-3 Example of material volume variation with time for various stages of road construction (not to scale)



3.5.4 Example Correction Factors

If the objectives of road design are to optimize the balance of excavated, fill, waste, and endhaul volumes and to minimize volume movements, adjust material volumes to compensate for swell and shrinkage. Table 3-5 shows example correction factors for various material types, to convert compacted volume to bank volume for use in road design.

In road design, material volumes are most commonly reported in volumes equivalent to bank volumes, because road construction projects are usually estimated, contracted, and paid based on bank volumes. In this system:

- Cut and volumes are both reported as the volumes they would occupy in the bank.
- The cut volume is the bank volume calculated from the road cross-sections, and therefore no adjustment is required.
- To convert the compacted fill volume back to the bank volume, apply a correction factor for swell and shrinkage. The correction factor is <1 to compensate for swell and >1 to compensate for shrinkage. If no net swell or shrinkage occurred during excavation, handling, placement, and compaction, the correction factor is 1.0.

The correction factors in Table 3-5 do not include any effects due to wastage or loss of material. Consider the need to separately account for other potential material losses that might affect achieving a balanced cut and fill design. Typical important sources of material loss, among others, can include material lost (spilled) in transport from cut to fill and subsidence, compression, or displacement of the prepared subgrade or original ground surface caused by the weight of the overlying embankment.

Table 3-5 Correction factors to convert compacted volume to bank volume for various materials

	Swell or shrinkage	**Material when it was IN THE BANK**
0.75 to 0.85	Swell	**Solid rock.** Assumes drilling and blasting is required, resulting in large fragments and high voids.
0.9 to 1.0	Swell	**Dense soil or rippable rock.** In the case of dense soil (e.g., glacial till) or rippable rock, typical compaction during conventional forest road construction

		will result in swell.
1.0 to 1.15	Shrinkage	**Compact to loose soil.** Lower correction factors are more appropriate for coarse-grained soils (e.g., sand, sandy gravel, or mixtures of gravel, sand, silt, and clay). Higher correction factors are more appropriate for fine-grained soils (e.g., silt and clay). It is more possible to achieve shrinkage during conventional forest road construction if the soil in the bank was in a loose condition. For example, a correction factor of 1.0 (i.e., no shrinkage) may be appropriate for compact sands and gravels, whereas a correction factor of 1.15 may be appropriate for very loose silts.

Notes Table 3-5:

1. The "example correction factors" are applicable to forest road design purposes only. They assume compaction typically achieved during conventional forest road construction, and different correction factors could apply for engineered fills, placed and compacted to achieve the highest material density possible. Because of the variability of natural materials and their conditions in the bank, the potential for material loss during handling, and the range of road construction methods, correction factors are best determined from experience and local knowledge.
2. The example correction factors are based on swell or shrinkage effects due to an increase or decrease in the density of the soil or rock materials, and do not include any effects of potential wastage or loss of material from other sources.

Example

Bank volume = compacted volume x correction factor.

Example: If the compacted volume of shot rock is 12 m3 measured from drawings, how much bank volume needs to be drilled, blasted, and excavated to achieve this volume? Assume a correction factor of 0.75.

Solution: Bank volume = 12 m3 x 0.75 = 9 m3

Surfacing often depends on the material available within an economic haul distance and intended season of use. Rock ballast roads may require minimal surfacing material while other roads require extensive surfacing for year round use. Consider the surfacing depth during the road design process. The depth of surfacing is dependent on the stabilization of the subgrade and the ability to carry design loads.
