Alternatives to Full Bench/End-Haul Construction for Resource Roads on Steep Slopes

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Michael P. Wise, P.Eng. [1],
Bruce R. Dagg, P.Eng. [2], & Raveen R. Singh, E.I.T. [2]

Abstract
As a requirement of the Forest Practices Code of British Columbia (FPC), geotechnical engineers and geoscientists are often required to evaluate the stability of proposed forestry roads located on steep slopes. In coastal British Columbia, these slopes often range in gradient from 60 percent to as much as 100 percent (31 to 45 degrees). Full bench / end-haul construction is typically recommended for portions of roads which traverse these steep slopes, but in some cases the method is either inappropriate or overly conservative. Often alternatives to full bench/end-haul construction exist, and involve minimizing the excavation into unstable slopes, reducing the volume of end-haul material, and/or supporting the roadfill. Site considerations are important in selecting alternatives to full bench/end-haul. This paper presents the site considerations which are important for selecting these alternatives and discusses four case studies where these alternatives have been successfully constructed.

Key words: forest roads, slope stability

Background
Full bench and conventional (also known as "half bench" or "partial bench") forest road construction are carried out on slopes for access to timber resources. Full bench /end-haul construction is typically carried out on steep slopes where a moderate to high landslide hazard is expected if conventional road construction were carried out. Full bench excavation is carried out to ensure the running surface of the road is founded on undisturbed (native) soil materials or bedrock (Figure 1). The excavated material is then removed from the site by end-hauling, instead of placing or sidecasting material below the road. This prevents the surcharging of the soil below the road, which could result in the initiation of a landslide. The end-haul material is transported to a waste site (or "spoil area"). In low landslide hazard areas, conventional construction (Figure 2) involves the placement or sidecasting of excavated material on the slopes immediately below the road grade to create a fillslope which becomes part of the running width of the road, making end-haul unnecessary. Conventional construction is the most common method of road construction in the coastal terrain of British Columbia.

The Forest Road Regulations in the FPC require that a road design incorporate "measures to maintain slope stability ... that may include limitations on sidecasting." Often, this is interpreted as a requirement to end-haul all of the excavated material regardless of the type and surface roughness of the underlying bedrock, the gradation of the excavated soil, and existing downslope stability conditions. As an FPC requirement, full bench / end-haul construction is commonly recommended by a geotechnical engineer or geoscientist during a terrain stability field assessment for a proposed forestry road. This recommendation usually gives specific stations along the road corridor for full bench/end-haul construction, with comments made about the location of the waste site for the end-haul material.

However, in many cases full bench / end-haul road construction is not necessarily the most appropriate recommendation. Potential problems associated with full bench / end-haul construction include dramatically increasing the frequency and severity of cutslope failures in some types of soil conditions and excessive costs associated with end-hauling of the material significant distances to a stable waste site. High roadcuts can also have a significant impact on the hillslope hydrology system, as more groundwater is intercepted and brought to the surface (Horel, 1996). Furthermore, it is often difficult to rehabilitate road sections which have been constructed using full bench/end-haul since most of the productive soil has been moved to the waste site.

[1] Forest Resource Advisory Team, International Forest Products, Vancouver.
[2] SRK - Robinson, Inc., Burnaby

Site Considerations

Several site considerations are important in the assessment of road stability on steep slopes and the recommendation of full bench / end-haul or possible alternatives. These considerations include the slope geometry, the site geology, road design, and climatic factors.

Slope geometry can play a significant role in determining alternatives to full bench/end-haul construction. For slopes which are irregular in profile, the road location can be altered to minimize the amount of steep slopes which are traversed by the road. Relocation of road sections will usually require changes in road grade, which may only have a small effect on the use of the road, particularly if the change in grade is favourable (steeper in the direction of travel for loaded logging trucks). In some cases, deflection is a concern and relocation of the road may not be possible if it may result in significant ground disturbance during timber harvesting activities. Geotechnical engineers and geoscientists should discuss possible alternate road locations during a terrain stability assessment, to minimize the amount of full bench/end-haul for a proposed forestry road.

Surficial and bedrock geology of the area plays a critical role in determining the most appropriate road construction recommendations for a site. In some situations, excavation of a full bench into glaciolacustrine, glaciofluvial, or blocky colluvial (talus) slopes can destabilize the area upslope of the road corridor and lead to large retrogressive failures of the cutslope. In other situations, some excavated material can be placed on the slope immediately downslope of the road with only a marginal increase in landslide hazard. This is often the case for roads located in strata with no obvious potential failure plane, such as a colluvium/till contact or colluvium/bedrock contact. Significant roughness of a bedrock slope may also provide adequate friction to support roadfill material, either on a temporary or permanent basis.In evaluating alternatives for full bench/end-haul construction, the local and regional climatic factors should also be considered. The geotechnical practitioner should be aware of the amount of precipitation which the area normally receives during the winter months. For wetter areas, it may be necessary to ensure that only coarse rock and large organics are placed on the outside shoulder of the road, or to limit sidecasting altogether. The management of water along the road corridor is also an important consideration for evaluating alternatives to full bench/end-haul construction, and in wet areas it may be necessary to recommend end-hauling of all excavated material.

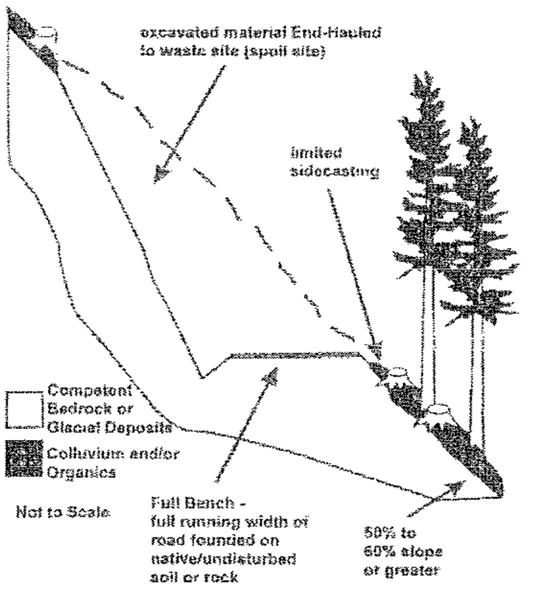

Figure 1. Full bench / end-haul construction (FPC Forest Road Engineering Guidebook, BC Ministry of Forests and Ministry of Environment, 1995)

The intended use and design life of the proposed road play an important role in determining the most appropriate method of construction on steep slopes. For permanent (mainline) roads, which will be needed continuously for over 10 years following construction, it may not be prudent to place material on the outside shoulder of the road since the likelihood of a fillslope failure greatly increases with time. However, most roads (branch and spur) will only be needed for a limited period of time following harvesting activities before they are permanently deactivated, so the likelihood of fillslope

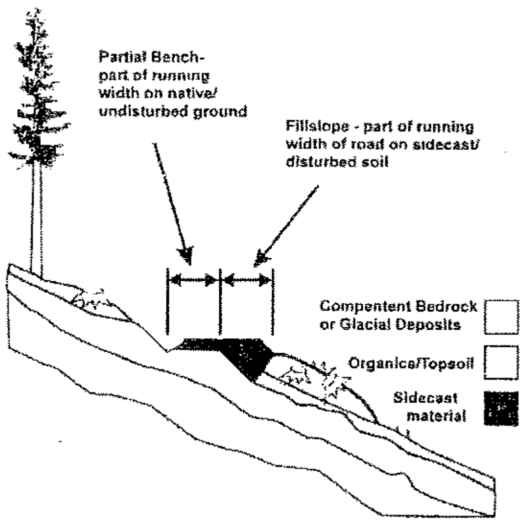

Figure 2. Conventional forest road construction (FPC Forest Road Engineering Guidebook, BC Ministry of Forests and Ministry of Environment, 1995)

failures is substantially less. For these temporary roads, it may be more cost effective to use conventional construction and place suitable material on the outer shoulder of the road and pull back this material during deactivation, soon after harvesting. The intended use of the road is also an important factor in determining alternatives to full bench/end-haul. A road which is needed for hauling will require additional width and fewer, gentler grade changes than a road which is needed for 4x4 access only.

Full bench/end-haul construction can also dramatically increase the road construction costs, to the point that some marginal value stands of timber are not economic to harvest. Recent cost information for coastal British Columbia forest industry indicates that full bench/end-haul construction can increase costs by at least 375% when compared to conventional (half bench) construction. An informal survey of these costs has revealed that the excavation of a full bench rather than a partial bench only adds a small amount of cost to road construction, whereas the end-hauling of the material accounts for the majority of the increased cost of full bench/end-haul construction. The increased cost associated with end-haul relates to the cycle time of the trucks used to haul material, and the linear nature of road construction. Hauling distances of greater than about 400m can dramatically increase costs unless enough turnouts are constructed. Thus, even if a full bench is needed, significant cost savings can be realized by limiting the end-haul distance by placing acceptable material on the outside shoulder of the road or backcasting

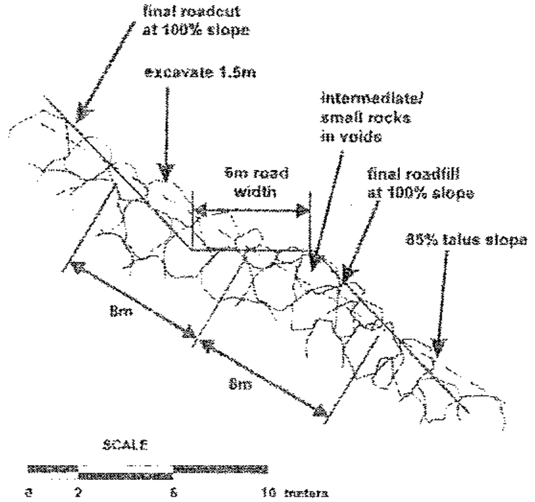

Figure 3. *Road construction through talus slopes, Klinaklini Mainline, Knight Inlet.*

material (raising the road grade) rather than end-hauling over a large distance to a designated waste site.

Case Examples

The following case examples are provided to illustrate alternatives to full bench/end-haul construction on steep slopes. The cases are separated into those in which full bench/end haul is not appropriate due to the presence of unstable slopes, and those in which the volume of end-haul was reduced by using excavated material from nearby road construction as roadfill.

Avoiding Excavation of Unstable Slopes

Case 1: Using Talus Slope Boulders

Deep excavation of talus slopes can cause either frequent rockfalls or large scale debris slides following road construction. In such a situation, it may be possible to minimize the excavation depending on the characteristics of the talus material and the design of the road. Above the Kliniklini River, near Knight Inlet, a mainline forestry road was needed by International Forest Products (Interfor) to access significant amounts of timber. The road crossed about 3km of talus slopes. The slopes in the area range from about 75 to 85 percent, and the angular talus blocks in the area range in size from about 0.5m to as much as 2.5m. The talus in the area is the result of rockfall processes from steep, granitic bluffs above the road. Through much of this area, the road grade is gently rolling with some sections of favourable grade and some sections of adverse grade.

Options for construction at this site included: (i) full bench/end-haul with stabilization of the talus slopes above the road, (ii) relocation of the road; (iii) using imported rockfill to construct a fillslope; and (iv) using a modified form of conventional construction. Due to site considerations, option (iv) was chosen as a cost effective means of constructing the road while maintaining upslope stability.

Careful excavation and placement of rock material to avoid destabilizing the slopes above were critical to the success of the road construction. At this site, the stability of the talus slopes is due to the point-to-point contact between the talus blocks. Based on the large size and angularity of the talus blocks, the material is assessed as being stable for short slopes of 100 percent. The method of construction consisted of taking blocks from the upslope side of the road to a depth of about 1.5m and carefully placing them on the downslope side of the road to form a "roadfill". An important feature of the method is the minimal road width due to the elimination of the ditch, which is unnecessary in this situation. Blasting was carried out at some isolated locations to create intermediate sizes for use in the fillslope. Safety was also a concern at the site, and during construction many large boulders above the road were "scaled" using blasting to ensure the safety of the crew below.

Much of the mainline was completed in the fall of 1996, and the remainder will be completed in the spring of 1997. To date, the fillslope has shown no signs of instability and very little, if any, movement has occurred in the talus above the road.

Case 2: Using Engineered Fill / Rockfill

In some cases full bench cuts or even partial cuts on steep slopes can be undesirable in glaciofluvial or glaciolacustrine deposits. In such cases, it may be better to construct the road entirely on engineered fill built up from below the road. This approach has recently been used by Interfor for a 150m section of the Clipper Point Mainline road along Hare Creek, on the east side of Bute Inlet. This section of road crosses a thick deposit of glaciomarine silty sand, on a 65 to 85 percent slope. Extensive ravelling and retrogressive failures of this material were observed in adjacent areas where the creek had undermined the slope, and there was a concern that any excavation into this slope for a road cut would have a similar effect. A break in slope was present at a distance of between 5m and 20m below the road grade, below which the slope decreased to between 30 and 40 percent towards the creek.

Three alternatives for construction of this section of road were identified: (i) construct the road entirely on compacted engineered fill built up from the break in slope below the road; (ii) similar to (i), but use geogrid reinforcement within the fill to permit a reduction in the degree of compaction of the fill; and (iii) use "conventional" full bench/end-haul construction and provide slope stabilization such as gabions, soil nailing, or other methods to support the cutslope as required. At the time it was believed that a vibratory compactor would be available, so option (i) was selected. The fill was to consist of a sand, with lower silt content, excavated from an adjacent section of road where the slope was judged to be more stable.

There were unforeseen delays in starting construction of this road, and consequently by the time the equipment had reached the critical area the vibratory compactor was no longer available. Also, the weather had deteriorated raising a concern that the sand fill could become saturated and unworkable. A senior engineer was mobilized to the site, with compaction testing equipment, to monitor the initial subgrade preparation and fill compaction. It was anticipated that the geotechnical engineer would complete one or two additional site inspections during construction, but that Interfor would perform the majority of the site supervision. As excavation proceeded, it became apparent that the soil conditions in some areas were better than anticipated, and the geotechnical engineer was able to revise the design to permit a partial road cut in places. Also, the contractor had developed a rock quarry for ballast material about 800m from the site. Following discussion, it was determined to be more cost-effective to use excess angular rock hauled from the quarry for fill rather than the locally available sand, since the angular rock could be end-dumped to form a stable fillslope without the need for compaction. The road was successfully constructed in this manner in November and December, 1996 and no instability has been observed to date.

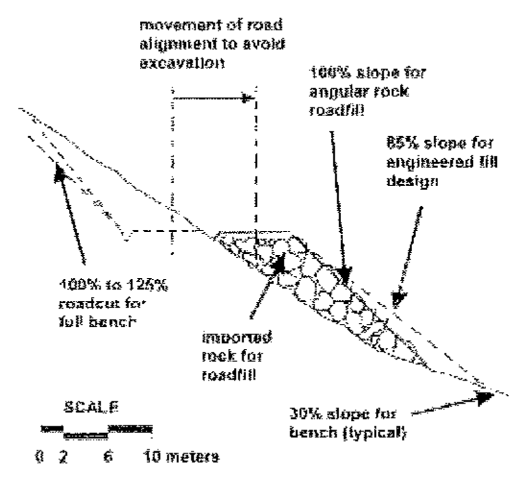

Figure 4. Sketch of road constructed using imported rock fill, Clipper Point Mainline, Bute Inlet

Limiting End-Haul Distance

Case 3: Using Nearby Rock as Roadfill

In the case histories discussed above, full bench cuts were considered undesirable because of the potential of destabilizing the slope above the road cut. This example describes a different situation, where the rock slope above the road was considered stable. However, the steep slopes created a concern for the stability of a conventional roadfill, and an initial recommendation for full bench/end-haul was made. Subsequently, an opportunity was

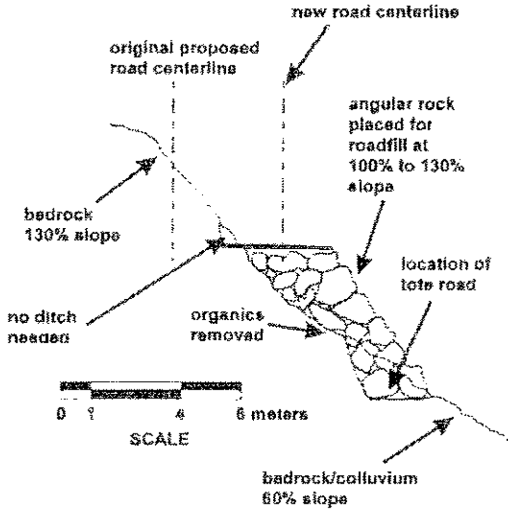

Figure 5. Road constructed using nearby rock fill, Chambers Mainline, Chambers Creek.

identified to both reduce end-haul volumes and reduce the risk of disturbance to a creek during construction, based on the slope geometry.

A mainline forestry road was constructed by West Fraser Timber Ltd. through a deep bedrock depression and across a near-vertical bedrock bluff approximately 40 metres above Chambers Creek, which has high fisheries values. The slopes in the depression ranged from 70 to 85 percent, and consisted of an organic veneer overlying 0.3 to 0.5m of angular rock and sand colluvium, which covered bedrock. The bluff consisted of a moderately competent meta-sedimentary rock with fractures which were of variable orientation, size, and continuity. Developing a full bench cut through this bluff would have required the use of controlled blasting techniques (such as downhole methods) or blasting mats to prevent deposition of flyrock and other debris into the creek below. These techniques are quite expensive, and given the isolated location of the site, were not seen as feasible. Options considered for the site included: (i) relocation of the road; (ii) construction of a full bench cut and end-hauling the material; and (iii) use of nearby rock as roadfill.

Due to site constraints, the third option was selected as the most cost effective method while minimizing the risk to downslope resources. This involved building up the grades through the bedrock depression, using angular rock fill. Since the angular rock has a high angle of repose, a significant increase in the slope of the roadfill could be achieved without compromising stability. The rock was placed in the bedrock depression using an excavator equipped with a hydraulic thumb to lock together the boulders on the outside edge, forming a fill slope with an approximate inclination of 100 percent and a height of 8m (Figure 4). Construction across the bluff required a more detailed design, in order to protect Chambers Creek below. A break in slope existed at the base of the bluff, where it flattened to about 60 percent down to the creek. It was determined that roadfill could be placed below this break, provided that the organics on the slope were removed and the rock was keyed into a bench. An excavator was used to construct a tote road across the slope below the bluffs. From the tote road, the excavator stripped the organics from between the tote road and the base of the bluffs. The organics were end-hauled off site, and then the tote road was then used as a short bench to support rockfill imported from the nearby blast sites. Larger rock was piled on the outside of the tote road, and smaller rock was stacked on the slope to the base of the bedrock face. The 50-metre long section was then capped with a granular ballast. Because the road fill consisted of angular, free-draining rock, and the weak organic layer had been removed, a ditch was not required in this short section.

The advantages to utilizing the above method are that amount of end-haul was limited to that required for construction of the tote road and removal of the organics above the tote road. The full bench cut for the tote road was on less steep slopes than the original proposed design, and did not require significant amounts of blasting. Because the tote road was only required to allow the passage of an excavator, its width could be reduced, which further reduced the amount of end-haul. By using the controlled placement of rockfill, a fill slope was constructed without significant amounts of blasting above a sensitive fish-bearing creek. The primary disadvantages of this method are that extra time was required to complete the section, which delayed the progress of bridge building further along the alignment.

Case 4: Using Excavated Material to Raise Road Grade (Backcasting)

Full benching will inevitably be required on slopes which are too steep to support road fill. In areas where the colluvial or organic cover is thin (up to 0.5m), and the bedrock has a uniform surface, the use of backcasting can reduce the amount of end-hauling required by building up the road grade.

Near Boston Bar, B.C., backcasting has been used by J.S. Jones Timber and Canadian Forest Products to significantly reduce end-haul volumes for the construction of the South Ainslie Mainline. Backcasting involves the excavation of a full bench cut into the rock (and thin overburden soils if present) a few metres below the final road grade. The excavated material is then cast back onto the excavated bench behind the advancing equipment to build up the road grade, using a roadfill slope which is steeper than the original ground surface (Chatwin et al, 1994).

Backcasting can only be used when the material is free of organics and contains only a minimal amount of fine-grained soil. The larger, angular rock should is used to build up the outer slope of the fill at the edge of the excavated bench. Proper construction of the outer fill is the critical factor in ensuring stability. Where larger boulders are segregated and carefully placed, slopes of up to 100 percent or more can be attained. Geometric constraints require that the outer slope of the fill be at least as steep as the roadcut, otherwise the width of the road will be less than the initial full bench cut. The finer excavated and blasted material should be used to build up the inside portion of the road prism as required. Where the fill material consists of angular coarse fragments and is generally free-draining, the ditch can be eliminated to maximize road width. Expansion factors for the excavated material usually lead to creating excess material, some of which may require end-hauling.

The use of backcasting will result in less required excavation, less material which would require end-hauling and spoiling, and a reduced cost in road-building in these critical areas. Disadvantages of this roadbuilding method include a slower progress rate due to the double handling of material for the segregation and careful placement of fill. It should also be noted that end-hauling of excess material may still be required, particularly if significant amounts of organics or unsuitable soils are present. When building on steep, planar bedrock surface surfaces, a small bench or 'key' may be required where the toe of the roadfill is to be located. Boulders can be placed in the 'key' to support the toe of the rock fill, in a manner similar to the use of the tote road at Chambers Creek site, described above.

Other Examples

Supporting/Eliminating Roadfill

Some methods can be used to support or eliminate roadfill material, allowing for conventional road construction on steep slopes. Methods to support the roadfill include the use of high stumps and log "cribs", as well as other conventional geotechnical techniques for earth support such as lock blocks.

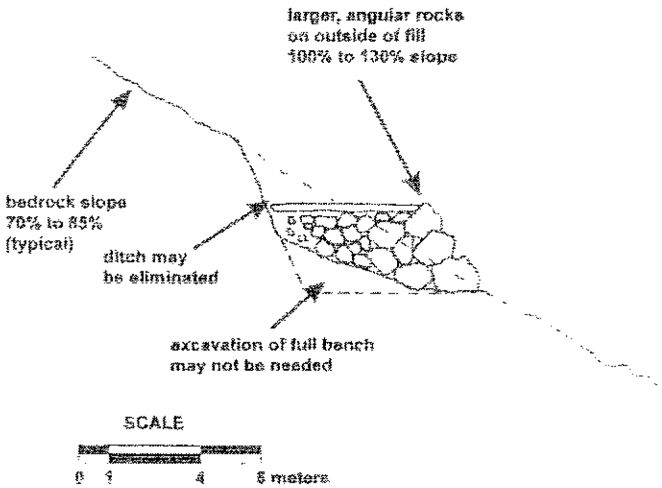

Figure 6. Use of excavated material in backcasting, South Ainslie Main, Boston Bar.

Temporary bridges can be used to span short bedrock depressions, eliminating the need for roadfill in this short area.

The use of high stumps and log "cribs" was a technique used previously by foresters and road construction crews. The technique involves leaving high stumps along the low side of the road and the placement of logs horizontally on the upslope side of the stumps to retain roadfill material (Figure 7). This method is appropriate for temporary roads which will be deactivated following harvesting, and where the downslope resources would not be significantly affected by a fillslope failure.

Although many landslides are associated with past use of this method of road construction, most of these are due to the failure to deactivate the road following harvesting activities or the incorrect assessment of the overturning strength provided by the high stumps. It is noted that although the Forest Practices Code provides for the use of this method for road construction, there are few guidelines

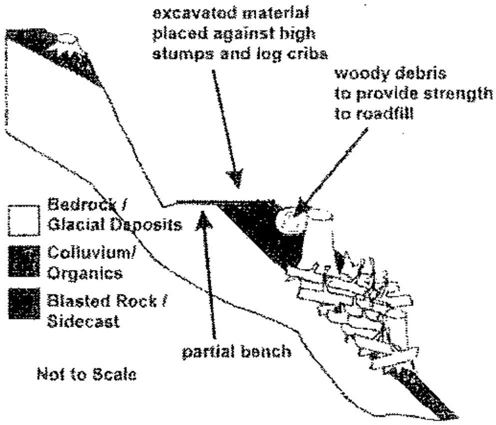

Figure 7. Sketch of high stumps as log cribs for temporary roads in moderate to high landslide areas (FPC Forest Road Engineering Guidebook, BC Ministry of Forests and Ministry of Environment, 1995).

available for the geotechnical design and assessment of road of this type other than the performance of nearby roads constructed in a similar manner. Even though the Windthrow Handbook (Strathers *et al*, 1994) can be used to provide an assessment of the rooting conditions of trees, more quantitative methods have yet to be developed. Presently, there is a joint Forest Renewal B.C. research project with Interfor, the University of British Columbia, and the Ministry of Forests to develop geotechnical criteria for the design of temporary roads using high stumps and log cribs.

Lock blocks and temporary bridges can be used to reduce the amount of full bench/end-haul construction on steep slopes, and both have been used successfully by Interfor's Sechelt Operations. Lock blocks have been used on steep bedrock slopes to retain roadfill material for a temporary road. The blocks were placed on a blasted bedrock ledge and tied back into the bedrock slope for additional support. The use of the lock blocks greatly reduced the need for excavation into the bedrock slope, and consequently the need to end-haul material. Temporary bridges can also be used to move the alignment of the road further out from the slope for crossing steep bedrock depressions, again minimizing the volume of blasted bedrock which must be end-hauled from the site. Due to the remote nature of most forest road construction sites, the transportation costs and construction delays should be considered for either of these methods.

Summary

A number of case examples have described alternatives for full bench/end-haul construction on steep slopes. The selection of alternatives is based on site considerations such as the slope geometry, the surficial geology, as well as the design life and intended use of the proposed road. The high road construction costs associated with excessive full bench/end-haul construction may make stands of marginal quality timber uneconomic to harvest.

Alternatives to full bench/end-haul construction are based on minimizing the excavation into potentially slopes, reducing the amount of material which is end-hauled, and supporting the roadfill to allow for conventional construction on steeper slopes. Case examples are given to illustrate how these alternatives have been used in the construction of forestry roads. A reduction in the amount of full bench/end-haul construction can also be gained by relocating short sections of road, provided there are no significant changes to other forest engineering constraints.

The cost effective development of forest resources in coastal British Columbia is dependent on the most effective means to develop road access. The use of alternate, more cost effective methods for road construction on steep slopes can significantly reduce the existing high costs, and make road access to marginal timber areas economically viable. Additional studies are needed to identify and evaluate alternatives, and provide guidelines for the geotechnical assessment of resource roads on steep slopes.

Acknowledgements

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