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Contents

Preliminary evaluation of stump strength for the design of temporary forest roads

Abstract

Historically, forest roads on the B.C. coast have on occasion been constructed using stumps and log cribs to retain the road fill on steep slopes. However, experience has shown that failures in road fill may occur after several years, often due to root strength deterioration. To ensure slope stability is maintained when building forest roads, a design process needs to be developed when utilizing logs and stumps to retain the road fill. To do this, more information is needed, specifically load carrying capacity and failure characteristics of old-growth stumps on coastal B.C. terrain. This report presents the results of the trials conducted in order to determine the strength of typical old-growth Douglas-fir stumps.

Keywords

Road fill, Stump rotation, Lateral displacement, Creep, Stump load, Ultimate load, Block purchase, Coastal British Columbia, Road construction, Slope stability.

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Introduction

Prior to the introduction of the Forest Practices Code of B.C. (FPC) in 1995, on occasion forest roads were constructed using stumps and log cribs to retain the road fill on steep slopes (Figure 1). This technique is less expensive than excavating a full-bench cut and endhauling the waste material. However, experience has shown that road fill failures may occur after 5 to 20 years, often due to root strength deterioration. The rate of root strength deterioration depends on many factors including stump size, stump species, soil type, moisture levels, and slope.

Figure 1. Stump and log crib retaining road fill.

Therefore the assessment of stump strength in the context of these site-specific factors is critical to the assessment of existing temporary roads and the design of new ones.

Currently, the FPC Forest Road Regulation (BCMOF 1998) permits the use of logs and stumps to retain the road fill if the technique is prescribed as a "measure to maintain slope stability" and the road will be permanently deactivated within five years of construction.[1] Such measures must be prepared by a "qualified registered professional".[2] A strict interpretation of the road regulation may lead these professionals to prepare a geotechnical design for the road fill retention structure. Although the process requirements of the FPC will be streamlined in the near future to be more "results based", professionals will still have responsibility

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[1] See the Forest Practices Code Forest Road Regulation for a full explanation and exceptions to the rule.

[2] "Qualified registered professional" is defined in the Forest Road Regulation. Professional can include a registered professional forester, a professional engineer or a professional geoscientist.

for maintaining slope stability when building forest roads. To develop a design process for these fill retaining structures, more information is needed, specifically, knowledge about the load carrying capacity and failure characteristics of old-growth stumps. Some insight into stump strength is available in previous studies (Pyles et al. 1991; Smith and McMahon 1995; Peters and Biller 1986). However, these studies are not directly applicable because they were done for smaller second-growth stumps located in gentle terrain. Despite this, the studies provide a good basis for developing a test methodology for assessing the strength of old-growth stumps.

Weyerhaeuser Company Limited's B.C. Coastal Group, in conjunction with EBA Engineering Consultants Ltd., began investigating geotechnical design criteria for temporary roads in steep terrain. The Forest Engineering Research Institute of Canada (FERIC) was asked to determine the strength of typical old-growth Douglas-fir stumps used for log and stump retaining structures. Pull-out tests of stumps were completed at Weyerhaeuser's Nanaimo Woodlands Operation.

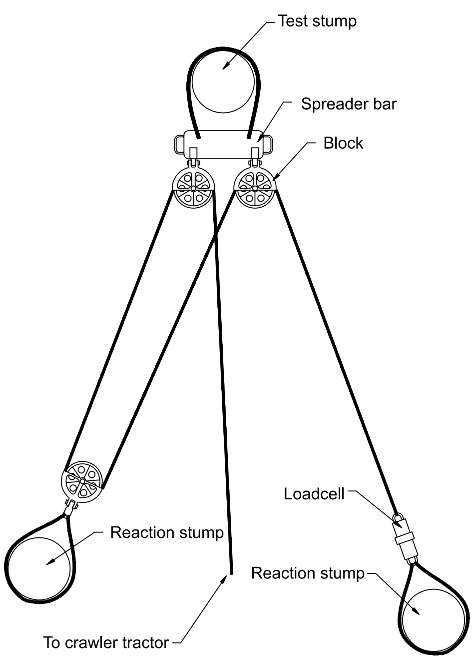

Figure 2. Rigging arrangement for stump pull tests, showing four-part block purchase arrangement.

Objective

The objective of the tests was to determine the strength and lateral displacement relationship for old-growth Douglas-fir stumps with a range of diameters.

Methodology

Site description

The site was selected as being representative of conditions on the eastern coast of Vancouver Island, in slope, soil, terrain, and age of stumps (less than 5 years since harvesting). This site, located at the lower elevations of Weyerhaeuser's Nanaimo Woodlands operation, had been harvested in 1998, two years prior to tests. The terrain was concave in shape, with slope gradients ranging from 30 to 45%, and a western aspect. Elevations at the stump locations ranged from 580 to 630 m. Many of the stumps were located on colluvial cones and aprons, and historic alluvial fans. Overburden consisted of well-drained gravely sand, some cobbles, and trace silt, and the soil moisture content at the time of the study ranged from 16-22%. The soil depth was greater than 2 m, with a rooting depth of approximately 1 m.

Stump pulling procedure

Nine old-growth stumps (8 Douglas-fir and 1 western hemlock) were tested with a series of increasing loads until failure was achieved. A crawler tractor and a block purchase system (Figure 2) were used so that sufficient force could be generated at the

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stump. Pulling of the first seven stumps was done with the four-part block purchase arrangement illustrated. A two-part block purchase arrangement was used with the final two stumps, with a single block at the test stump and a single reaction stump. Stumps were pulled downhill and parallel to the slope to simulate the loading in a stump-log retaining structure. In several instances, the load on the stump was backed off prior to stump failure in order to measure the effect of creep.

The load and displacement of the stump were monitored with a datalogger at 4 Hz. The load was measured using a 445 kN (100,000 lb) loadcell installed in the block purchase system as illustrated in Figure 2. The stump load was calculated based on the angles of the lines in the block purchase system, assuming a block efficiency of 97%. It would have been preferable to have measured the stump load directly by placing the loadcell between the stump and the spreader bar. However, the available loadcell did not have enough capacity to achieve this. The stump rotation was measured with an inclinometer mounted on the stump (Figures 3 and 4). The lateral displacement of the stump was measured by two displacement transducers (string pots) mounted at separate referenced locations (e.g., stump or log) and connected by string to a pole mounted on the stump. Measurement of both the rotation angle of the stump and the lateral displacement at a known height allowed the sliding component of stump movement to be differentiated from the rotary movement of the stump. The displacement was then calculated at 30 cm

Figure 3. Instrumented stump showing the inclinometer at the base of the pole.

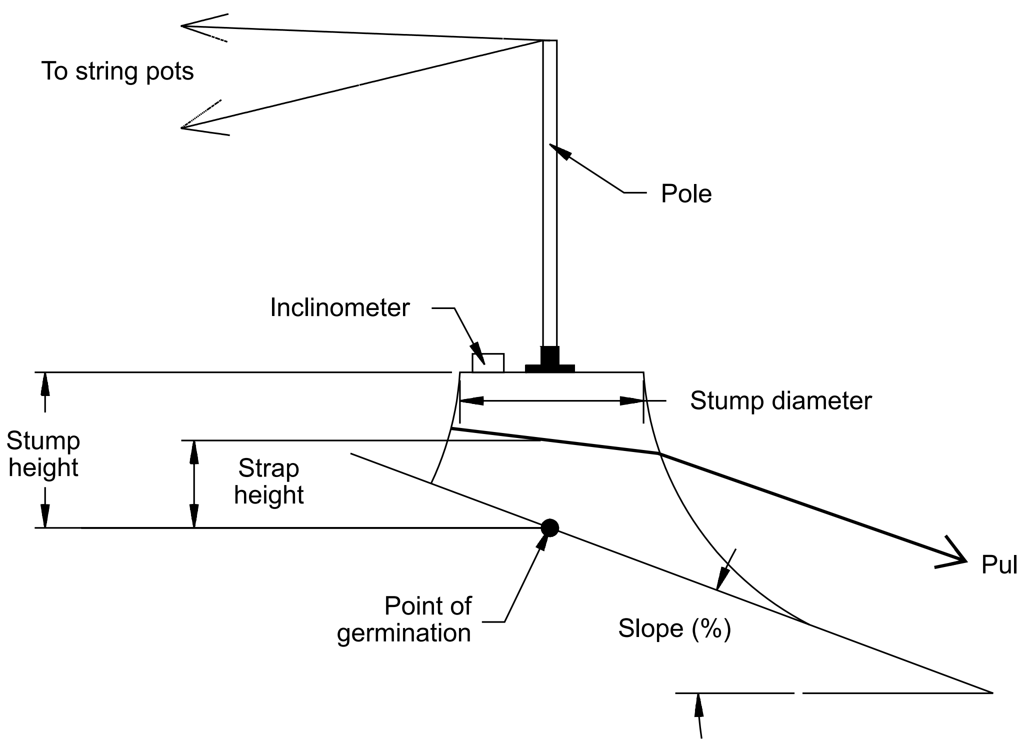

Figure 4. Stump parameters that were measured in the study.

above the estimated point of germination (Figure 4) to facilitate comparison. Stump height, strap height, and stump diameter were measured prior to each test. The diameter at breast height (DBH) (outside bark) was estimated using formulas which account for stump height, stump diameter, and species (Omule and Kozak 1989).

Graphic plots of force versus lateral displacement were generated for each test. Both the maximum (ultimate) load required to pull the stump from the ground (regardless of displacement), and the maximum load achieved prior to a displacement of 12.5 mm at 30 cm above the point of germination, were summarized along with the DBH estimate.

Results and discussion

Most stumps exhibited an elastic loading relationship up to a critical load level (Figure 5). There are essentially two yield points, evident where the slope of the force displacement line changes. The first yield point typically occurred at 50% of the ultimate load and at a displacement of 1 to 2 mm. The second yield point typically occurred at 85% of ultimate load and at a displacement of 7.5 to 15 mm. The displacement at 12.5 mm generally represents this second yield point. In Figure 5, the stump was pulled a number of times at increasing loads and the load was released after each pull. When the first three low-load pulls were released, the stump returned to a displacement of 2 mm. This low level of displacement represents the creep under elastic loading. However, after the fourth pull, displacement (at zero load) was more substantial and the second yield point was reached, likely because some of the major roots were strained. In Figure 5, the ultimate load occurred at a significant lateral displacement (77 mm). The measured creep for the nine stumps was between 1 and 9 mm.

The majority of the stumps were from trees with estimated DBH from 81 cm to 111 cm, with one stump from a smaller tree at 62 cm DBH (Table 1). Generally stump strength increased with diameter. The ultimate load required to pull the stump out of the ground ranged from a minimum of 308 kN to a maximum of 842 kN (Figure 6). The ultimate load often occurred at significant lateral displacements up to 77 mm, and therefore ultimate load is probably not a

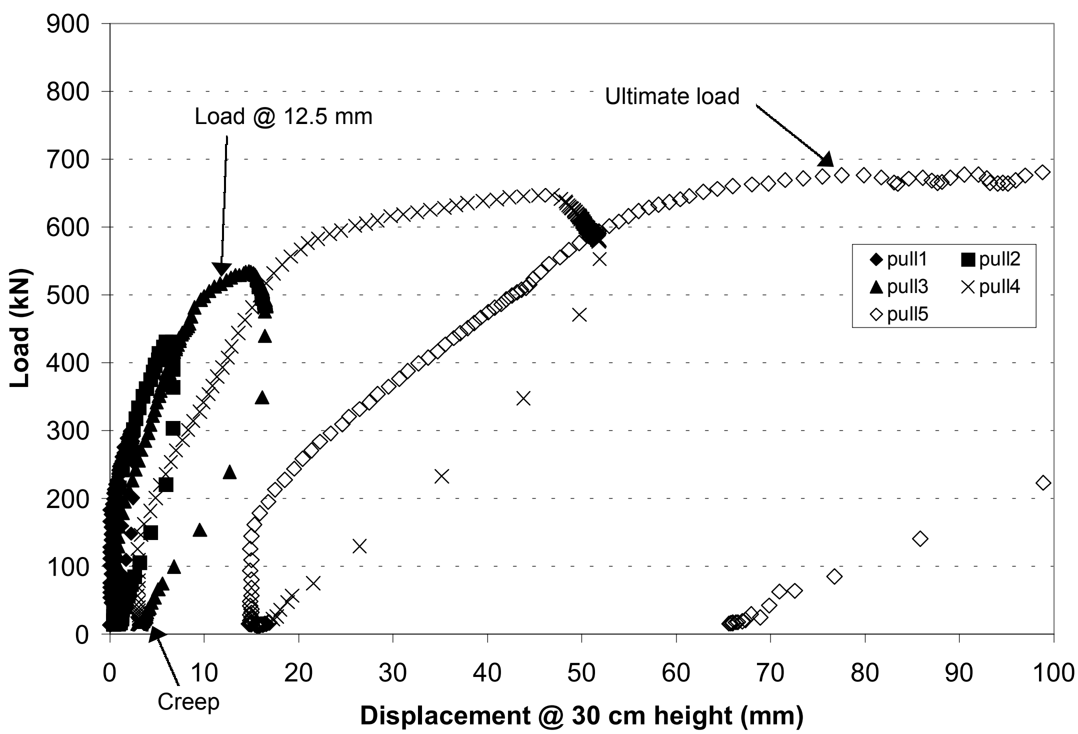

Figure 5. Graphic representation of sample load versus displacement for one stump.

Table 1. Summary of test data

Test (no.)	Species	Slope gradient (%)	DBH (cm)	Ultimate load (kN)	Displacement @ ultimate load (mm)	Load @ 12.5 mm displacement (kN)	Creep (mm)	Failure type
1	Douglas-fir	45	111	676	77	525	3.6	Rotational
2	Douglas-fir	45	98	801	35	718	1.8	Rotational
3	Hemlock	45	87	627	36	587	1.1	Rotational
4	Douglas-fir	40	99	565	13	565	NA	Rotational
5	Douglas-fir	40	87	358	13	358	NA	Rotational/Sliding
6	Douglas-fir	40	98	842	60	671	NA	Rotational/Sliding
7	Douglas-fir	40	81	640	47	640	9.1	Rotational/Sliding
8	Douglas-fir	30	86	603 [a]	17	594	0.6	Rotational
9	Douglas-fir	30	62	308	29	295	2.6	Rotational

[a] Ultimate load was not achieved because a two-part block purchase arrangement was used and the crawler tractor's winch capacity was maximized.

suitable parameter to use for the design of road fill retaining structures. A more appropriate design strength may be the load that is achieved prior to a lateral displacement of 12.5 mm (@ 30 cm stump height from the point of germination). Stump #5 had a much lower ultimate strength than others of a similar size—field observations indicated that this stump was likely dead prior to cutting (no bark, weathered appearance). The results with this stump illustrate the loss of root strength over time, and it is not included in the graphs of diameter versus strength (Figures 6 and 7).

The ultimate strength of these stumps was greater than second-growth stumps previously tested in Washington and Oregon (Pyles et al. 1991), where the ultimate strength ranged from 50 to 275 kN and from 150 to 450 kN for Douglas-fir and hemlock stumps, respectively. This difference was likely due to the less-developed root structure found in the smaller second-growth stumps compared to the old-growth stumps evaluated in this trial.

The force required to move the stump 12.5 mm (Figure 7) ranged

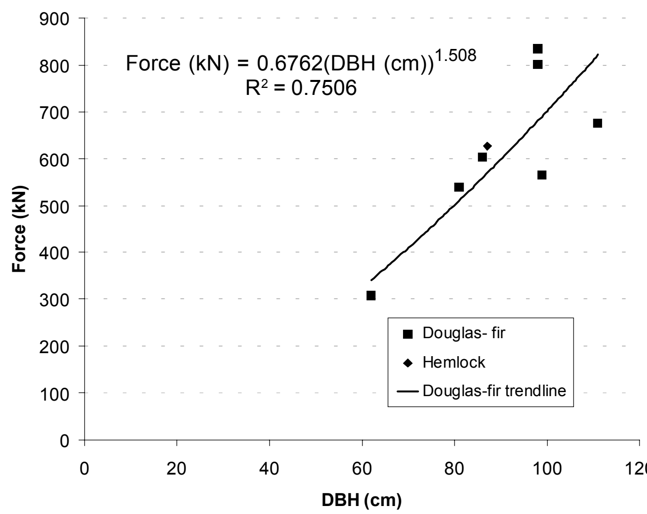

Figure 6. Relationship of ultimate stump strength with estimated DBH.

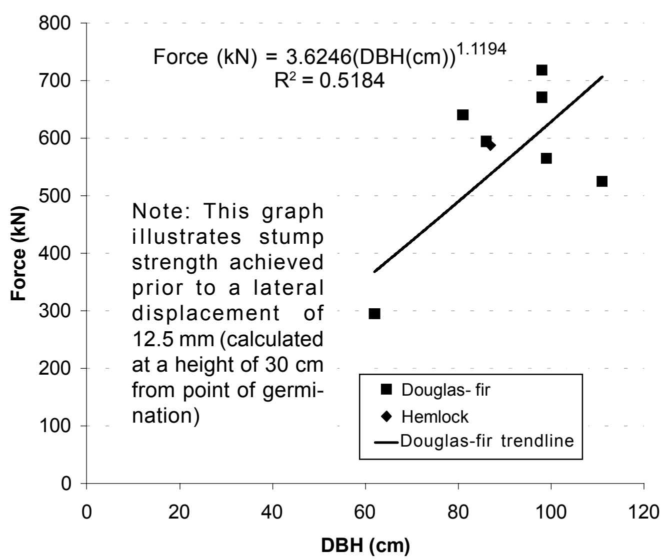

Figure 7. Relationship of stump strength at 12.5 mm lateral displacement with estimated DBH.

from 295 kN for a 62 cm DBH stump to 718 kN for a 98 cm stump. Note that only a portion of the relationship between pulling force and stump DBH is explained by the regression equations[3] shown in Figures 6 and 7. The variability of stump strength is also due in part to variations in soil composition and depth, and root architecture throughout the site. These tests can therefore only provide rough site-specific guidelines for the use of stumps to support road fills on temporary roads. More statistical confidence in these results can only be obtained through further testing. It should also be noted that these tests were conducted under relatively dry soil conditions. If the tests had been conducted when the soil was saturated, the stump strength would likely have been reduced. Therefore the stump strength estimates should be reduced to account for these limitations until more data are available. An appropriate interim design load can be calculated by using the equation in Figure 7, and dividing this by a safety factor (e.g., 1.5). The variability of stump strength and the unknown site influences demonstrate the need for further testing.

The failure mode was predominantly rotational (Figure 8). In three cases some surface sliding also occurred. Creep was minimal in most cases (Table 1); the greatest creep was 9.1 mm for stump #7, primarily due to sliding. The well-developed deep root systems on this site contributed to the high frequency of rotational failures. Only the minor roots would have been severed during the test, so that the entire root wad would have rotated out of the ground. The placement of a fill and crib structure above the stump places a vertical load over the root system which will, in turn, increase the stump's resistance to rotation. Therefore the stump strength would be theoretically increased relative to the measured values, when the stumps are used in a fill and crib structure. The measured stump strengths are influenced by where the force is applied relative to the stump's centre of rotation. The force required to pull the stump from the ground will decrease as the force is applied at a greater distance from the stump's centre of rotation. For the tests conducted, the force was applied on average 36 cm above the point of germination, and the centre of stump rotation was estimated to be 1.26 m below the point of germination. Therefore the stump strength at different heights relative to the point of germination can be adjusted by the following factor:

$$\text{Force adjustment factor} = (1.62)/(H+1.26)$$

where H (in meters) is the distance between the point of germination and where the force is applied.

Weyerhaeuser completed a design for a fill retaining structure in cooperation with EBA Consultants utilizing the stump strength data obtained in the tests (Higman and Patrick 2001). The structure was designed to support a swing yarder, and resulted in an estimated static factor of safety of 1.35. This was based on a Douglas-fir stump with an ultimate strength of 150 kN/m (stump spacing 4 m, stump strength 600 kN for 90 cm diameter stumps) and assuming the soil was well drained. In situations where the fill retaining structure is intended for log hauling purposes only, the stump spacing can be increased because loads are less than with a swing yarder.

Figure 8. Stump failure. Arrow shows the rotational movement of the root wad.

[3] The regression equations use the power relationship for consistency with the previous stump pulling trials in the Pacific Northwest (Pyles et al. 1991).

Conclusions

1. The stump strength evaluation method used for this trial presents a cost-effective means of measuring stump strength to support short-term road fills.
2. The ultimate load required to pull the stump out of the ground ranged from a minimum of 308 kN to a maximum of 842 kN. The ultimate loads often occurred at significant lateral displacements (up to 77 mm).
3. The load achieved prior to a lateral displacement of 12.5 mm may be a more appropriate measure to use in design than the ultimate load. The load at 12.5 mm displacement ranged from 295 kN to 718 kN. The design strength should be reduced by safety factors to account for saturated soil conditions and when using high stumps.
4. The failure mode was predominantly rotational, with some surficial sliding. Creep was minimal in most cases.
5. The stump strength data were utilized to design a log crib fill retaining structure. For the loading of a swing yarder, a static factor of safety of 1.35 was estimated, based on Douglas-fir stumps spaced 4 m apart.
6. These tests provide rough site-specific guidelines for utilizing stumps in combination with log cribs to support road fills. However, due to the variability of the data and limited number of samples, more testing is required under varying site conditions to validate this design process.

Implementation

Companies planning on using this road construction technique for temporary roads should consult with a "qualified registered professional" (e.g., geotechnical engineer), with experience in forest road design and construction prior to starting the project. The professional should consider stump integrity and strength during the initial assessment, using the stump strengths presented in this report as a guide in the design of a temporary fill-retaining structure. Due to the variability in stump strength between sites, consideration should be given to testing stumps representative of those to be used in the prescribed structure (species, diameter, slope, and soil conditions) using the procedure described in this report. FERIC would be available to assist members in this testing upon request.

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