ROOT-WOOD STRENGTH DETERIORATION IN RADIATA PINE AFTER CLEARFELLING

COLIN O'LOUGHLIN and ALEX WATSON

Forest Research Institute, New Zealand Forest Service, Christchurch

(Received for publication 10 October 1979)

ABSTRACT

The tensile wood strength (kPa) of small roots of **Pinus radiata** D.Don (radiata pine) sampled from living trees and from stumps cut 3, 9, 14, and 29 months prior to sampling, was examined. Mean live root-wood strength was 17 600 kPa which is considerably less than the wood strengths of similar-sized roots from other species studied overseas. Mean root-wood tensile strength declined in an exponential manner after felling of the parent trees. Calculated time to half strength was only 14 months.

INTRODUCTION

Although *Pinus radiata* D.Don (radiata pine) crops are noted primarily for wood production, they also serve an important soil-protection function in many parts of New Zealand. In this regard, the development rate and extent of the crop's rooting system, the density of roots, the mechanical strength of the roots, and the rate at which root strength is lost after death of the parent trees, are important factors influencing the degree to which trees enhance slope stability. It has been demonstrated that living tree roots can contribute up to 20 kPa to the soil shear strength (O'Loughlin, 1974a; Swanston, 1970; Endo and Tsuruta, 1969; Waldron, 1977; Wu *et al.,* 1979). Many forest soils obtain a large proportion of their resistance to shear from roots, particularly when the soils are partially or completely saturated.

The reduction in strength of tree roots is believed to be an important means by which clearfelling reduces the stability of forested slopes (Bishop and Stevens, 1964; Swanston, 1970; O'Loughlin, 1974a; Ziemer and Swanston, 1977). Detailed studies of landslides by O'Loughlin (1974b), Wu *et al.* (1979), and Burroughs and Thomas (1977) have indicated that the network of smaller roots less than, say, 4 cm diameter is very important to slope stability and that, during landsliding, such roots fail more often in tension than in shear.

No information is available on the mechanical strength of radiata pine roots or the rates at which roots of this species lose their tensile strength after tree felling. Information of this type is required for developing predictive models of slope stability under managed radiata pine crops. The principal objectives of the research outlined in this paper were to determine the tensile strength of wood or small roots less than

N.Z. J. For. Sci. 9(3): 284-93 (1979).

3 cm diameter sampled from living radiata pine trees, and to identify the rate at which root-wood strength declines after felling of the parent trees.

METHODS

Root sampling was carried out at Ashley State Forest (mean annual rainfall 820 mm) approximately 30 km north of Christchurch. Roots were sampled from living 23-year-old radiata pine trees and from radiata pine stumps cut 3, 9, 14, and 29 months prior to sampling. At each root collection area (mature stand and four cutover areas) approximately 10 to 12 previously marked trees or stumps were selected; their roots in the mineral soil horizons between 10 and 100 cm below the surface were carefully excavated with hand shovels, cut, labelled, and sealed in plastic bags. Only roots with diameters less than 3 cm were collected. All sampling sites were underlain by Makerikeri Hill Soils which consist of silt loams to stony silt loams primarily derived from greywacke gravels, silts, and clays (N.Z. Soil Bureau, 1968). Only trees and stumps located on well-drained mid-slope areas were selected for sampling.

In the laboratory straight sections of root were selected from the samples, trimmed to a length of approximately 28 cm, and promptly tested in tension to avoid excessive loss of moisture. Root testing was carried out with a Floor Model 1195 Instron Universal Testing Machine equipped with a 5 kN maximum capacity, reversible, load cell. Type 3D pneumatic-hydraulic clamps with flat, non-serrated, jaw faces were used to grip the root ends. The load speed (cross-arm speed) and chart recorder speed were set at 20 mm/min for all tests. Short segments of plastic tubing were fitted over the root ends to help prevent crushing and slippage. Clamping forces ranged from 1000 kgf (9.8 kN) for larger root samples from living trees to 100 kgf (0.98 kN) for fragile roots in an advanced state of decay. Generally roots were tested within 24 hours of being collected.

At the start of each test the length of the root section strained in tension was measured. This length ranged from 18 to 22 cm. Each root was strained in tension at a rate of 20 mm/min until rupture occurred. After the completion of each test the location and form of the break were noted and the mean diameter of the root near the point of rupture was measured with a micrometer. Tests in which breakage occurred at the jaw edges because of crushing and tests where slippage occurred between the jaw faces were not considered for analysis.

Test results were automatically recorded as tensile load *v.* time plots (Fig. 1). The maximum tensile load at the rupture point and the total longitudinal deformation were calculated from these data. Maximum tensile strength (kPa) was calculated by dividing the maximum tensile load by the cross-sectional area of the root at the failure point.

The elastic behaviour of roots in tension was also investigated. The method of Brown *et al.* (1952) was adopted to identify the proportional limit, i.e., that point of the load-time curve which separates the initial straight portion of each curve within the elastic range from the curved portion which lies in the plastic range. The proportional limit was delineated where a line tangent to the curve in the elastic range deviated from the curve (Fig. 1). The modulus of elasticity defined by

$$E = \frac{Tp}{A} \cdot \frac{l}{lp}$$

where E = modulus of elasticity (kPa)
Tp = tensile load at proportional limit (kN)
A = cross-sectional area of root (m^2)
lp = deformation at proportional limit (m)
l = gauge length of root (m)

was determined for roots from living trees and from stumps cut 3 and 9 months before sampling. Roots which had been dead for more than 9 months produced load-time curves without easily determined proportional limits.

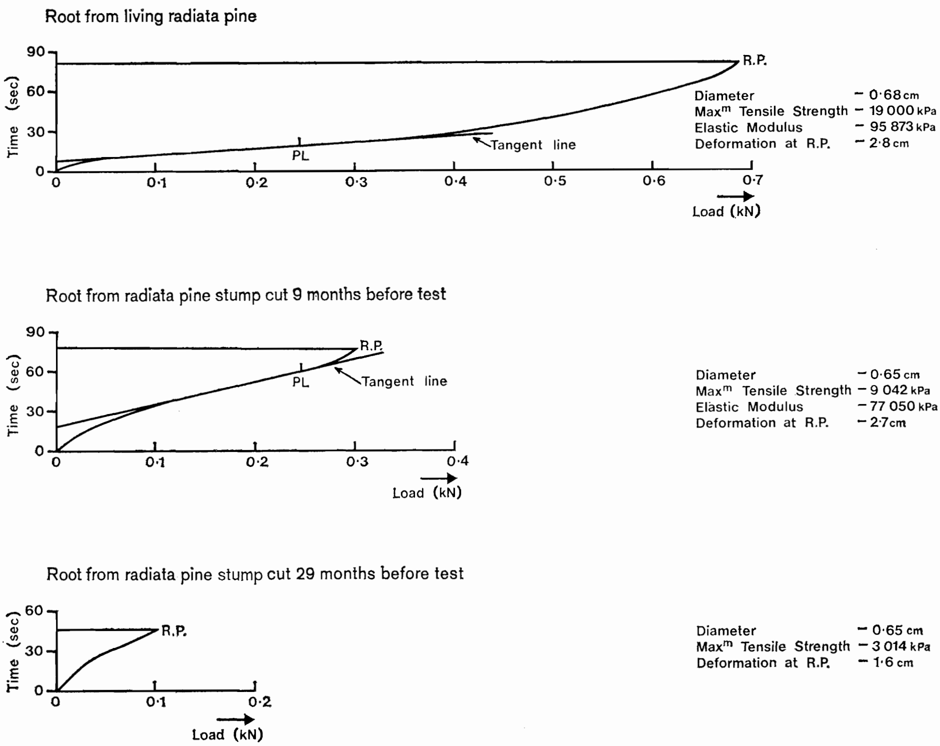

FIG. 1—Load-time curves resulting from tensile wood strength tests on three radiata pine roots at defferent stages of decay. RP = rupture point, PL = proportional limit.

The processing and analysis of the data was carried out on a Burroughs 6700 computer. A total of 845 roots was tested but only 618 tests were considered satisfactory for analysis. Additionally, 58 living *Pseudotsuga menziesii* (Mirb.) Franco (Douglas fir) roots sampled from 35-year-old trees at Ashley State Forest were tested in tension.

RESULTS

The tensile strength of wood of small radiata pine roots from living trees ranged from 37 500 to 7 700 kPa and averaged 17 600 kPa. After cutting of the parent trees the mean tensile strength of root wood declined rapidly at an approximate average rate of 500 kPa per month (Table 1 and Fig. 2). At 20 months after treefelling the wood of small roots had lost about half of its original tensile strength.

The general condition of the roots sampled from the four classes of cut stumps is summarised in Table 2. On an area where the parent radiata pine trees had been cut 40 months prior to the investigation, most of the roots less than 3 cm diameter had disappeared and roots larger than 5 cm diameter showed advanced decay and often consisted of only empty fragile bark sheaths.

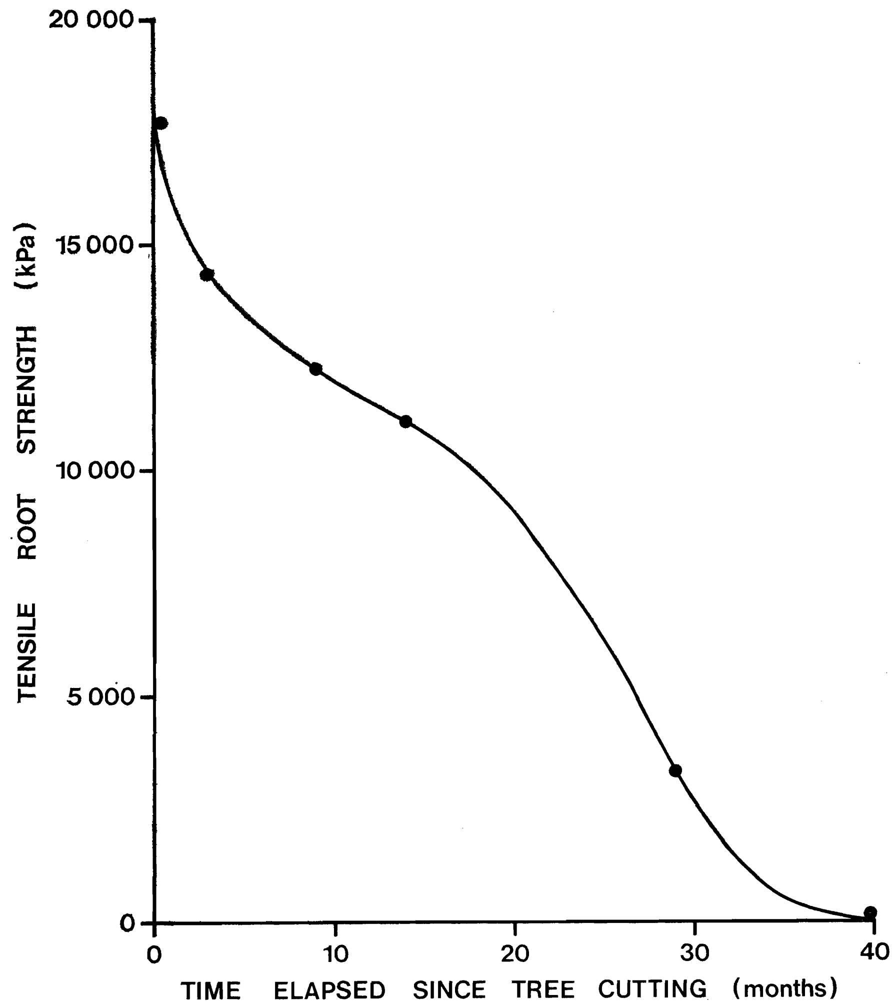

FIG. 2—Curve of mean tensile strength v. time elapsed since tree cutting, for wood of small roots of radiata pine.

TABLE 1—Tensile strength (TS, kPa) and diameter (D, cm) of radiata pine roots and Douglas fir roots sampled from Ashley State Forest

Root class (No. tested)	Mean		Maximum		Minium		Standard Deviation	
	TS	D	TS	D	TS	D	TS	D
Radiata pine								
Living trees (188)	17 617	0.53	37 530	1.39	7 650	0.13	6 320	0.23
Cut 3 months (105)	14 372	0.56	33 310	1.05	2 860	0.20	5 547	0.21
Cut 9 months (134)	12 308	0.62	43 310	1.51	2 890	0.21	6 426	0.22
Cut 14 months (140)	11 038	0.68	30 860	1.45	2 680	0.22	4 666	0.27
Cut 29 months (51)	3 332	0.83	14 260	1.78	290	0.29	3 346	0.32
Douglas fir								
Living trees (58)	27 594	0.41	112 582	1.33	11 138	0.16	15 699	0.21

TABLE 2—Condition of radiata pine roots < 3 cm diameter

Time elapsed since felling	General condition
3 months	Bark in good contact with root-wood. Small areas of fungal discoloration at wood-bark interface.
9 months	Bark peels off wood easily. Wood surface mottled green-grey-brown. Fungi visible at wood-bark interface. Minor insect borings.
14 months	Bark peels off wood readily. Root-wood soft and discoloured grey-brown. Wood surface pitted with numerous insect borings.
29 months	Wood completely decayed within bark sheaths. Residual wood either dry crumbly mass easily powdered or wet gelatinous mass. No roots less than 0.5 cm diameter remain.
40 months	Roots smaller than 3 cm diameter absent.

Regressions of tensile strength (kPa) on root diameter (cm) were not significant in all five classes of roots, indicating that, within each group and within the rather restricted diameter range sampled, diameter did not significantly influence tensile strength.

Differences among pairs of age-class mean tensile strengths were all statistically significant at the 0.01 level except for the difference between 9- and 14-month means (not significant at the 0.05 level) and the difference between the 3- and 9-month means (significant at the 0.05 level but not at the 0.01 level).

The total deformation (Δl) and elasticity modulus (E) data are presented in Table 3. The mean deformation at the rupture point decreased from 2.21 cm for roots sampled from living trees to 1.16 cm for roots collected from stumps cut 29 months prior to sampling. The modulus of elasticity did not show any well-defined trends as roots decayed.

DISCUSSION

The mean wood tensile strengths of living radiata pine roots reported in this study are considerably smaller than the wood strengths of similar-sized living Douglas fir roots from Ashley State Forest, Douglas fir and *Thuja plicata* D.Don (western red cedar) roots from old growth stands in North America (Burroughs and Thomas, 1977; O'Loughlin, 1974b), and living *Populus deltoides* Marsh (poplar), *Betula pendula* Roth. (birch), *Quercus robur* L. (oak), and *Picea abies* (L.) Karst. (spruce) roots from Russia (Turmanina, 1965). Table 4 summarises tree root-wood tensile strength information for a number of species.

The decline of tensile root-wood strength appears, at least in the early stages of decay, to follow a simple negative exponential curve of the form

$$TS_t = TS_0 e^{-bt}$$

where TS_0 = tensile strength of root-wood sampled from live trees

TS_t = tensile strength of root-wood sampled from stumps cut t months previously

b = probability of decay.

TABLE 3—Total deformation (Δl, cm) and modulus of elasticity (E, MPa)

Root class (No. tested)	Mean		Maximum		Minimum		Standard Deviation	
	Δl	E	Δl	E	Δl	E	Δl	E
Living trees (112)	2.21	208.1	5.40	429.0	1.00	93.0	0.69	66.5
Cut 3 months (105)	2.31	156.9	4.60	464.0	0.70	57.0	0.67	78.8
Cut 9 months (134)	1.84	176.1	3.50	629.0	0.70	40.0	0.62	115.1
Cut 14 months (140)	1.94	—	5.90	—	0.70	—	0.80	—
Cut 29 months (51)	1.16	—	2.80	—	0.30	—	0.57	—

TABLE 4—Mean tensile strengths (TS) of root-wood sampled from a range of living conifers and hardwoods

	Location	Diameter range (cm)	Mean TS (MPa)	Source
Radiata pine	NZ	0.1-1.8	17.6	O'Loughlin
Douglas fir	BC, Canada	0.1-0.4	61.6	O'Loughlin, 1974b
Douglas fir	Oregon, USA	0.5-1.0	34.0	Burroughs & Thomas, 1977
Douglas fir	NZ	0.1-1.4	27.6	O'Loughlin
Western red cedar	BC, Canada	0.5-0.3	55.9	O'Loughlin, 1974b
Poplar	Russia	0.1-2.0+	38.3	Turmanina, 1965
Birch	Russia	0.1-2.0+	37.4	Turmanina, 1965
Oak	Russia	0.1-2.0+	31.7	Turmanina, 1965
Spruce	Russia	0.1-2.0+	27.2	Turmanina, 1965

It is convenient to express the decline of strength in this form as the term e^{-b}, which is equivalent to the hydrograph recession constant used in hydrology, provides a useful expression of root-wood strength decay rate. Furthermore, the time which elapses until the root-wood strength is reduced to half its initial value (TS_o) can easily be computed:

$$t_{0.5} = \log 0.5/\log e^{-b} \text{ (Martin, 1973)}$$

where $t_{0.5}$ = half strength period.

An exponential loss in strength occurred in radiata pine root wood sampled at Ashley State Forest for the first 30 months after clearfelling (Table 5 and Fig. 3) and in Douglas fir and western red cedar root-wood sampled in North America for the first 60 to 70 months after cutting. The negative exponential relationships shown in Fig. 3 are significant at the 0.01 level. Table 5 shows that the decay constant (e^{-b}) was smallest in radiata pine and the time to half strength was only 14 months compared to 27 months for Douglas fir from British Columbia, 46 months for Douglas fir from Oregon, and 66 months for western red cedar from British Columbia.

TABLE 5—Exponential relationships between root-wood tensile strength and months after clearfelling of parent trees ($y = ae^{-bx}$)

n	a	b	r	e^{-b}	$t_{0 \cdot 5}$	
5	18.974	—0.0560	0.9722	0.954	14.83	Radiata pine (NZ)
6	24.617	—0.0180	0.9616	0.985	46.17	Douglas fir (Oregon)
5	71.196	—0.0305	0.9846	0.975	27.24	Douglas fir (BC)
4	54.589	—0.0125	0.9716	0.990	66.45	Western red cedar (BC)

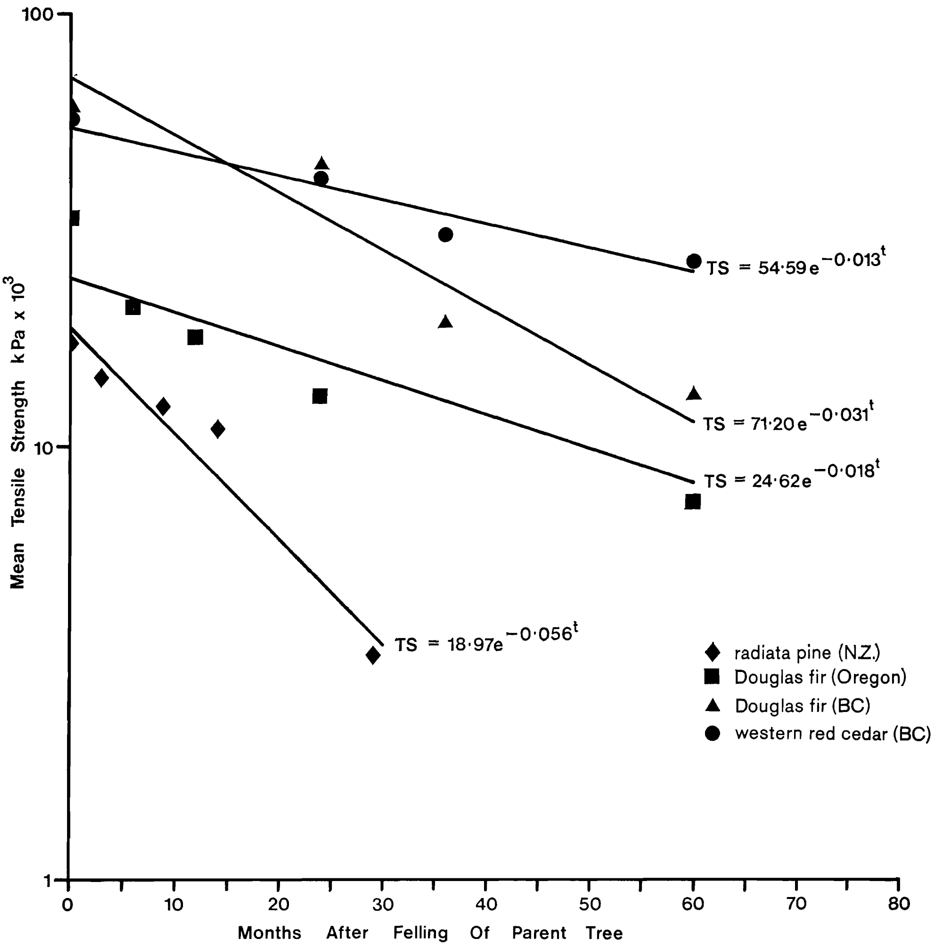

FIG. 3—Negative exponential relationships between mean tensile strength (TS) and time elapsed since tree cutting (t) for wood of small roots of radiata pine, Douglas fir, and western red cedar.

In summary, the wood of small roots of radiata pine trees possesses less tensile strength and loses this strength more rapidly after clearfelling than the wood of small roots of other tree species that have received study overseas. However, this does not imply that radiata pine is an inferior slope stabiliser or soil strengthener compared to other tree species, as root-wood tensile strength is only one of many factors involved in a tree crop's influence on slope stability. The apparent ability of radiata pine to expand its root system rapidly in the first few years after planting is probably the most important slope stabilising attribute of this fast-growing species.

REFERENCES

BISHOP, D. M. and STEVENS, M. E. 1964: Landslides on logged areas in southeast Alaska. **U.S. Forest Service, Northern Forest Experiment Station, Research Paper NOR-1.** 18 p.

BROWN, H. P., PASHIN, A. S. and FORSAITH, C. C. 1952: "Textbook of Wood Technology". Vol. 2. McGraw-Hill,New York.

BURROUGHS, E. R. and THOMAS, B. R. 1977: Declining root strength in Douglas fir after felling as a factor in slope stability. **U.S. Forest Service, Intermountain Forest and Range Experiment Station, Research Paper INT-190.** 27 p.

ENDO, T. and TSURUTA, T. 1969: The effects of tree roots upon the shearing strength of soils. Pp. 167-82 **in** Annual Report of Hokkaido Branch, Forest Experiment Station, Sapporo, Japan. No. 18.

MARTIN, G. N. 1974: Characterisation of simple exponential baseflow recessions. **Journal of Hydrology (NZ) 12(1):** 57-62.

NEW ZEALAND SOIL BUREAU, 1968: General survey of the soils of the South Island. **New Zealand Soil Bureau Bulletin 27.** 404 p.

O'LOUGHLIN, C. 1974a: The effect of timber removal on the stability of forest soils. **Journal of Hydrology (NZ) 13(2):** 121-34.

——— 1974b: A study of tree root strength deterioration following clearfelling. **Canadian Journal of Forest Research 4(1):** 107-13.

SWANSTON, D. N. 1970: Mechanics of debris avalanching in shallow till soils of southeast Alaska. **U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Research Paper PNW-103.** 17 p.

TURMANINA, V. 1965: The strength of tree roots. **Bjulleten Moskovskogo Obscestva Ispytatelej Prirody (Otdel Biologiceskij) 70(5):** 36-45.

WALDRON, L. J. 1977: The shear resistance of root-permeated homogeneous and stratified soil. **Soil Science Society of America Journal 41:** 843-9.

WU, T. H., McKINNELL, W. P. III and SWANSTON, D. N. 1979: Strength of tree roots and landslides on Prince of Wales Island, Alaska. **Canadian Journal of Geotechnical Research 16(1):** 19-33.

ZIEMER, R. R. and SWANSTON, D. N. 1977: Root strength changes after logging in southeast Alaska. **U.S. Forest Service, Pacific Northwest and Range Experiment Station, Research Note PNW-306.** 9 p.