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CORDUROY FOR FOREST ROADS

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Figure 1 - Rata used for corduroy in an indigenous forest located on the West Coast of the South Island

ABSTRACT

Using corduroy for road or landing construction on weak soils reduces the need for often expensive aggregate. The road can be used immediately after construction, does not require specialist techniques, and the company can be confident that road failure is unlikely.

Corduroying involves laying a mat of brush or logs on top of the subgrade. Aggregate is then spread to form the road or landing. Where there is an abundance of slash and undergrowth, the brush mat is commonly used at an approximate cost of \$0.60/m^2. This is cheaper than using pulp logs from the landing at an approximate cost of \$7/m^2. However, these costs are offset by the amount of aggregate required. The brush mat requires an average aggregate depth of 0.4m to fill the voids and provide sufficient support, while the logs require only 0.1m of covering aggregate. If the cost to supply and place aggregate is \$20/m^3 then the total cost for a long road section is \$8/m^2 for the brush mat corduroy and \$9/m^2 (includes lost pulp revenue) using log corduroy. Costs can be considerably higher for repairing short road sections.

Bearing capacity analysis has been used to develop equations for designing log corduroy roads over very soft soils. Design charts have been produced which estimate the depth of covering aggregate required to prevent bearing failure of the soil. The depth of aggregate required without corduroy was also calculated. In this way, the amount of aggregate saved can be estimated and cost comparisons made. The decision to use log corduroy should not be based on cost alone. For very weak soils (shear strength < 15 kPa) it is not possible to construct a road using aggregate alone, due to the overlying weight of the aggregate and load.

Corduroy, as a method of road construction, has a place in modern roading practice. It provides the forest manager with another stabilisation option that, in many cases, can be applied to problem areas and is not limited by soil types, weather, or consolidation time.

INTRODUCTION

Corduroy roading has been used in New Zealand since commercial logging of the indigenous resource began (Figure 1). It found great use in Westland, Northland and Southland, where the presence of extremely wet and weak soils meant that some form of support for animals and machines was required.

Corduroy involves layering brush, mill slabs or logs directly over the weak soil, with aggregate placed on top. The corduroy acts as a structural and separation layer, and reduces the amount of aggregate required to maintain the road's load carrying capacity. Traditionally, corduroy construction has required a great deal of wood and time. It takes up considerable machine and labour time, and often uses wood that could otherwise be sold. However, corduroy may be the only cost-effective option for constructing roads over very weak and wet soils.

Corduroy roading has been used in overseas forestry operations for exactly the same reasons that it is used in New Zealand. Its main application has been in the swamp and peat areas of Germany, Scandinavia, and North America, where it has been successful as a method of "floating" the road over soft ground. Much is written on this method as a roading management option [McFarlane, Paterson and Dohaney, 1968. Reissinger, 1972. and Saunders, 1992]. However, there is little quantitative data on the costs and construction.

This report sets out the reasons for using corduroy, how corduroy works, and develops equations for design of log corduroy roads.

WHY CORDUROY?

There can be many reasons why corduroy should be used :

- Corduroy is a well-proven method of road construction over very weak and saturated soils (that is, low lying swamps and soft clays).

- Specialist techniques and equipment are not required for construction.

- A corduroy road can be used immediately after construction.

- Aggregate depth is reduced, since corduroy reduces the ground pressure on the soil by distributing the load over a larger area.

- A corduroy road can remain serviceable for many years.

- The road builder can be confident that road failure is unlikely.
- Corduroy is not limited by soil types, weather, or consolidation time.
- A corduroy road is often built on top of existing vegetation, minimising exposed earth that could erode.
- Aggregate and/or corduroy material can be recovered on roads that have been abandoned.

CORDUROY TYPES

Brush Corduroy

Brush corduroy involves the spreading of brush (undergrowth and slash) on top of the subgrade, to form a brush mat. Next, aggregate is placed on top to form the road as illustrated in Figure 2. This method is lowest in cost, provided there is sufficient supply of undergrowth and slash. However, an aggregate thickness of 300 to 400mm is still required on top of the brush mat, which increases the cost. This is because the voids in the brush require filling and only marginal reinforcement is provided. The brush corduroy provides a separation layer and improves drainage.

Log Corduroy

Log corduroy is where pulp logs are placed side-by-side on top of the subgrade, at right angles to the direction of travel. Aggregate is spread over the logs to form the road as illustrated in Figure 3.

The logs provide substantial reinforcement, so an aggregate depth of 50 to 100mm is usually all that is required. Cost for the log corduroy is higher than the brush mat as approximately 80m^3 of saleable pulp wood is used per 100m of road constructed. However, the higher cost of the log corduroy is offset by the reduction in aggregate needed. The logs provide reinforcement and a separation layer.

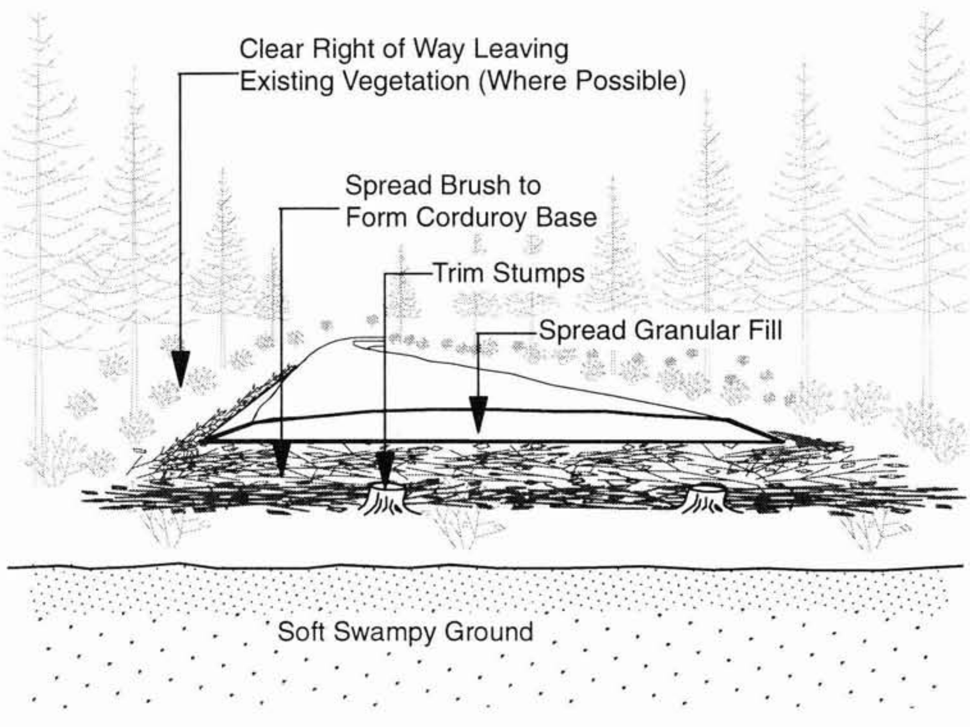

Figure 2 - Corduroy construction using a brush mat.

HOW DOES CORDUROY WORK?

Corduroy is essentially the forerunner to modern geotextiles (and geogrids) (Koerner, 1986) and performs much the same functions. These are:

Separation

A layer of brush, branches or logs between a weak subgrade and the quality aggregate serves to stop intermixing of the two. This ensures that the load bearing functions of the base-course are performed, without contamination from the weaker subgrade. Intrusion of the subgrade into the base-course creates a slippery surface on the aggregate, which will reduce particle interlock (bearing capacity). Consequently, ruts can form and the road surface will be slippery and muddy.

Reinforcement

The effect of corduroy laid across the subgrade is to spread the load. The load is redistributed over the whole length of the log, effectively increasing the load bearing area. Figure 6 shows how log corduroy distributes the load. The aggregate savings have been quantified in the next section. Reinforcement is greater with log corduroy than with brush corduroy as the log acts as a rigid platform.

Absorption of Shock

The shock impact from a loaded vehicle is absorbed by movement and deformation in the corduroy. By lowering the shock transmitted to a road, there is a reduction in cracking.

Improved Drainage

The brush corduroy provides a permeable layer between the base-course and the subgrade. Water on the road surface percolates through the base-course and then flows along the corduroy plane, as shown in Figure 7.

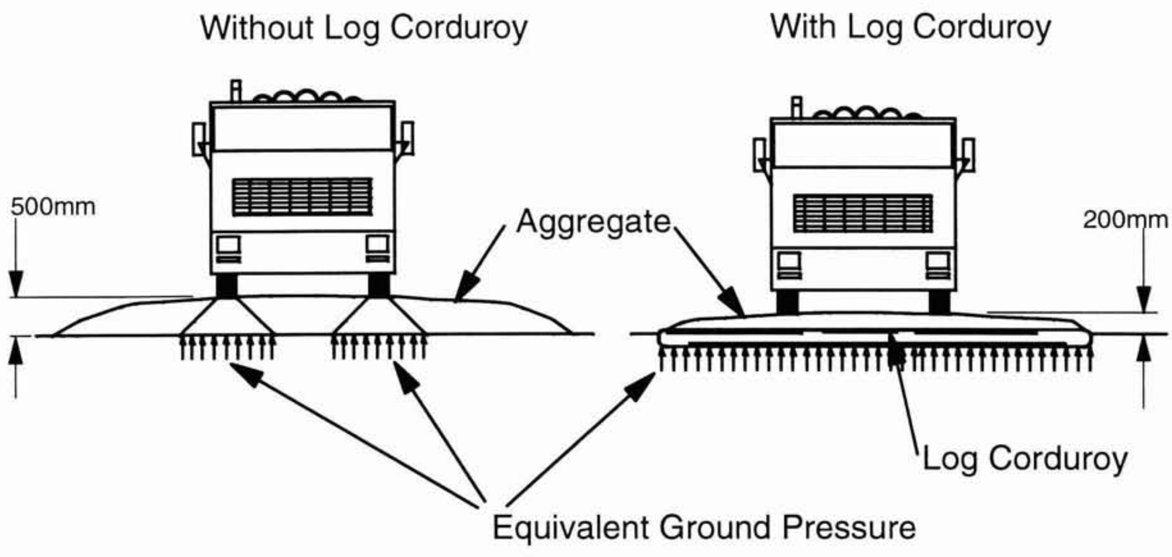

Figure 6 - Reinforcement using log corduroy

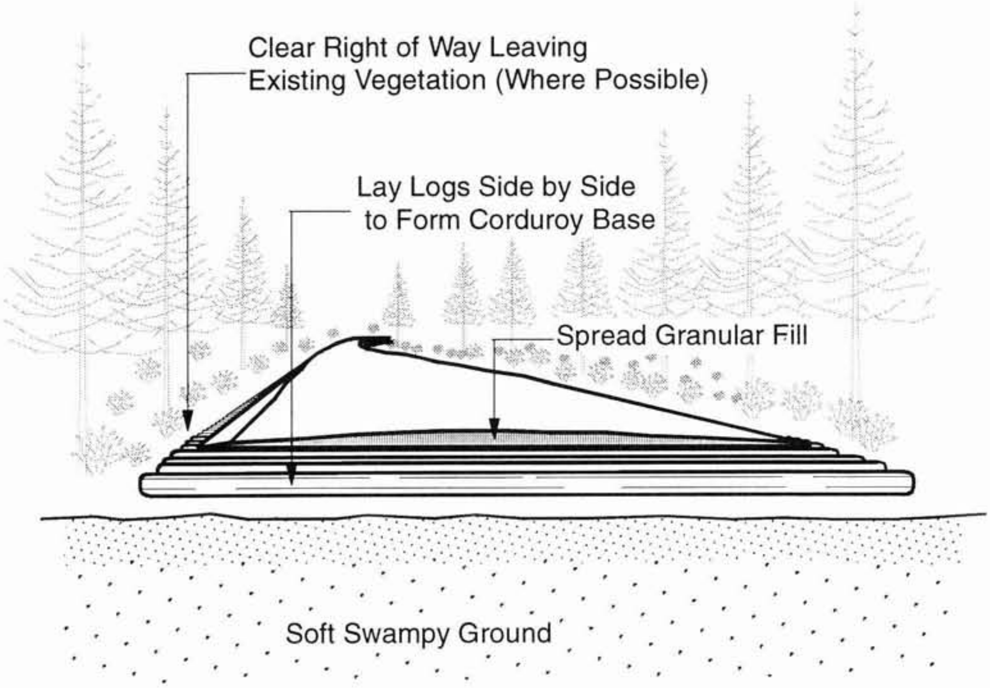

Figure 3 - Corduroy road construction using logs

Mill Slabs

Mill slabs are off-cuts from a timber mill. They used to be readily available from mills milling native timber. They are placed side-by-side on top of the subgrade, across the direction of travel. Aggregate is then spread over the mill slabs to form the road, as shown in Figure 4. The mill slabs provide some reinforcement, so 200mm of aggregate is usually all that is required. If a timber mill is nearby, the cost for the mill slabs is cheaper than using pulp wood.

Figure 4 - Mill slabs used as corduroy in Tuatapere

Polythene Pipes

Polythene pipes held together by wire rope known as "Columbus Mats" have been used in Germany to fulfil the same job as corduroy. They are strong, lightweight, flexible, easy to handle and reusable (Holtz, 1976). Although the initial cost is three times higher than log corduroy, their cost per use is low as they can be used many times. The Columbus Mat is illustrated in Figure 5.

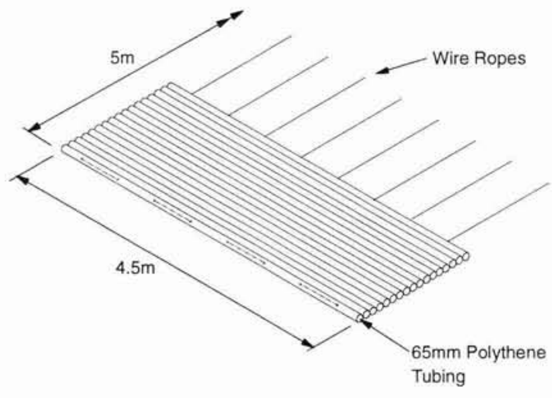

Figure 5 - Columbus mat

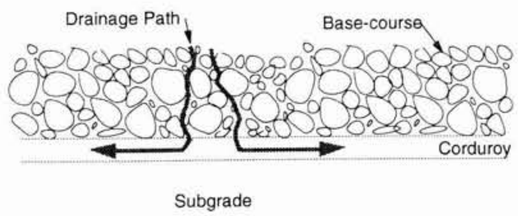

Figure 7 - Flow of water along corduroy plane

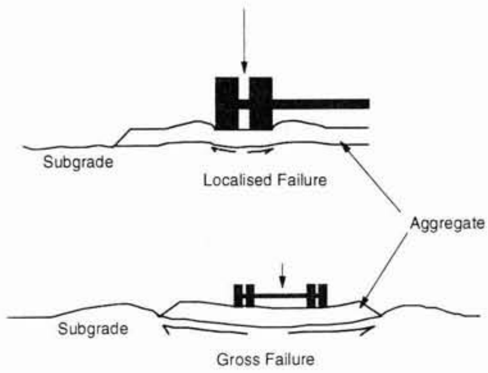

Figure 8 - Two types of subgrade shear failure

DESIGN OF LOG CORDUROY ROADS

There are no readily available pavement design charts for log corduroy roads. However, there has been some design of log corduroy roads using the principles of soil mechanics (Miller and Mills, 1979). This involves designing the road to prevent bearing failure of the soil. There are two general types of bearing failure associated with roads over very soft ground. These both involve shear failure of the subgrade and are illustrated in Figure 8.

The localised failure is independent of fill weight and dependent on wheel load and soil strength. Gross failure occurs when deep fills are used as the combined weight of the fill and axle load exceed the bearing capacity of the soil. This failure covers the width of the road and uplift of the soil along the side of the road will be evident.

Using bearing capacity analysis, the stress at the top of the subgrade (caused by a logging truck and the overlying aggregate) is calculated and then checked to see it does not exceed the ultimate bearing capacity of the soil (including a factor of safety). Miller and Mills (1979) and Hicks and Keller (1979) used this approach for designing roads over very soft soils. Using this approach the equations to determine the depth of fill required were derived. The first equation is for fill only and the second incorporates the use of log corduroy on top of the subgrade.

Fill only (no log corduroy):

$$c = \frac{(F.O.S)\,q}{5.14}\left[1-\left(\frac{1}{1+(R/z)^2}\right)^{3/2}\right] + \frac{(F.O.S)\,G\,z}{5.14}$$

Fill and log corduroy:

$$c = \frac{(F.O.S)\,L}{5.14 \times l\,w}\left[1-\left(\frac{1}{1+(R/z)^2}\right)^{3/2}\right] + \frac{(F.O.S)\,G\,z}{5.14}$$

where: c = soil shear strength (kPa)
F.O.S = factor of safety
q = tyre pressure (kPa)
L = axle load (kN)
l = length of log corduroy
w = diameter of log corduroy
R = effective load radius (m) $= \frac{1}{2}\sqrt{\frac{2L}{\pi q}}$
z = fill depth (m)
G = in place fill density (kN/m^3)

Using these equations, design charts to estimate the fill depth were produced. Figure 10 uses common aggregate fill, while Figure 11 uses a lightweight pumice fill. The depth of fill with or without log corduroy can be estimated from the design charts. This can then be used to determine the most economic solution. However, on weak soils with a shear strength less than 15 kPa, log corduroy or a lighter fill material has to be used. This is because the weak soil is unable to support the total weight of the aggregate and axle load.

The "shear strength" of a soil can easily be measured in-situ using a "hand vane tester". The equipment consists of a stainless steel vane of four rectangular blades mounted on the end of a high tensile steel road, as illustrated in Figure 9. To make a measurement, the vane is pushed into the soil and the head is turned slowly until the soil shears. The maximum torque required for failure is read from the dial, which is then converted to shear strength (c), using the formula (Craig, 1987):

$$c = \frac{T}{\pi(d^2h/2 + d^3/6)}$$

Where:
T = torque at failure
d = overall vane width, and
h = vane length.

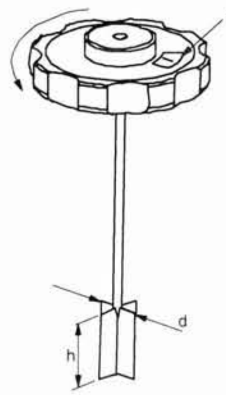

Figure 9 - Hand Vane Tester

Alternatively the shear strength can be estimated from a known subgrade CBR, where shear strength equals 25 times CBR (%) (Uzan et al, 1980; Cited in Lay, 1986).

$$c = 25CBR(\%)$$

CBR (California Bearing Ratio) is commonly used in pavement engineering as a measure of subgrade strength. CBR is measured in the lab or alternatively can be estimated by converting penetration per blow from dynamic cone penetrometer tests to CBR. However the cone penetrometer will give unreliable results on weak soils with a CBR <2 as the penetrometer sinks under its own weight.

Simple field tests as given in Table 1 (Holtorf and Lysne, 1979) can also be used to estimate the soil shear strength.

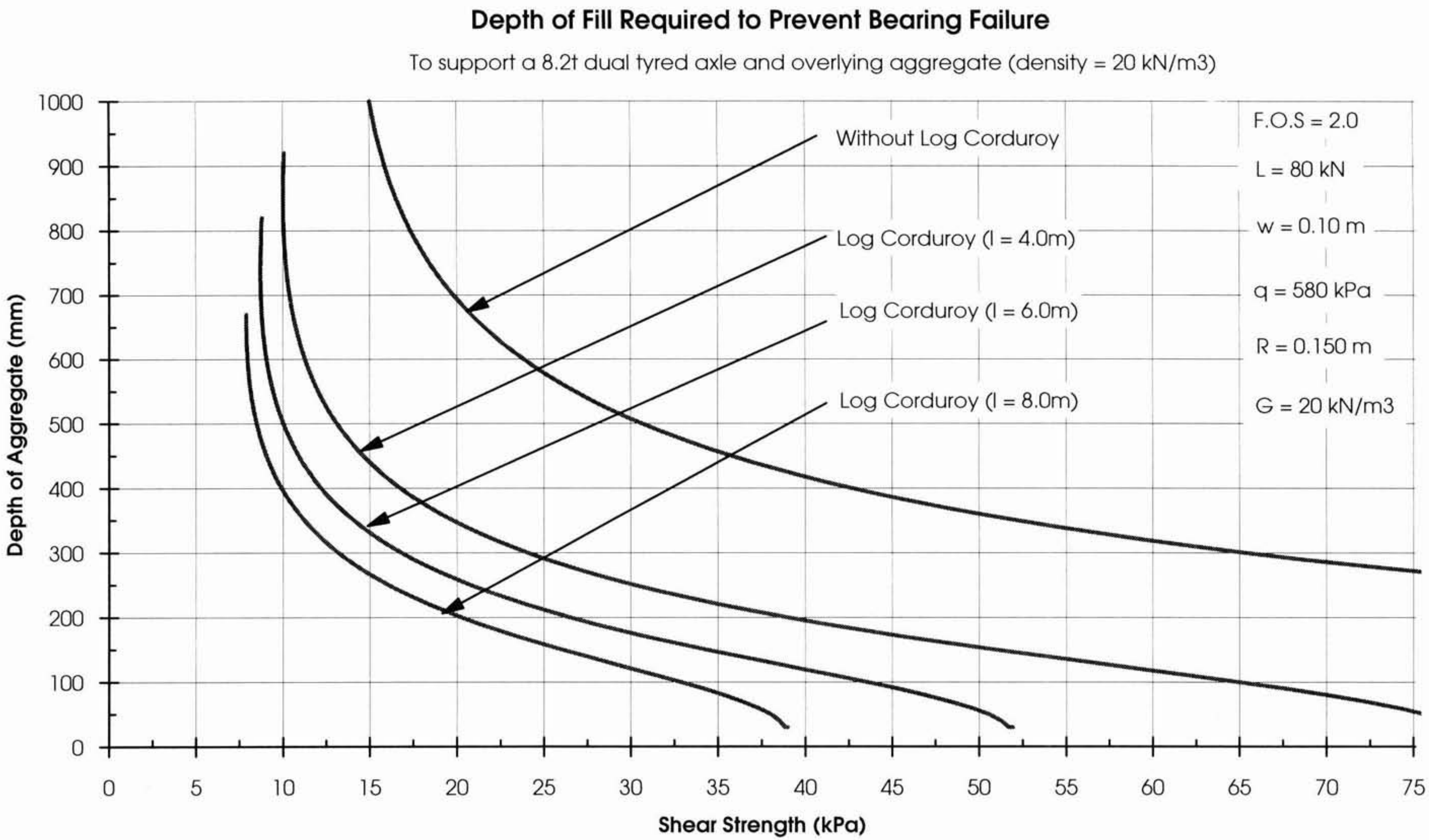

Figure 10 - Depth of fill required to prevent bearing failure using aggregate fill.

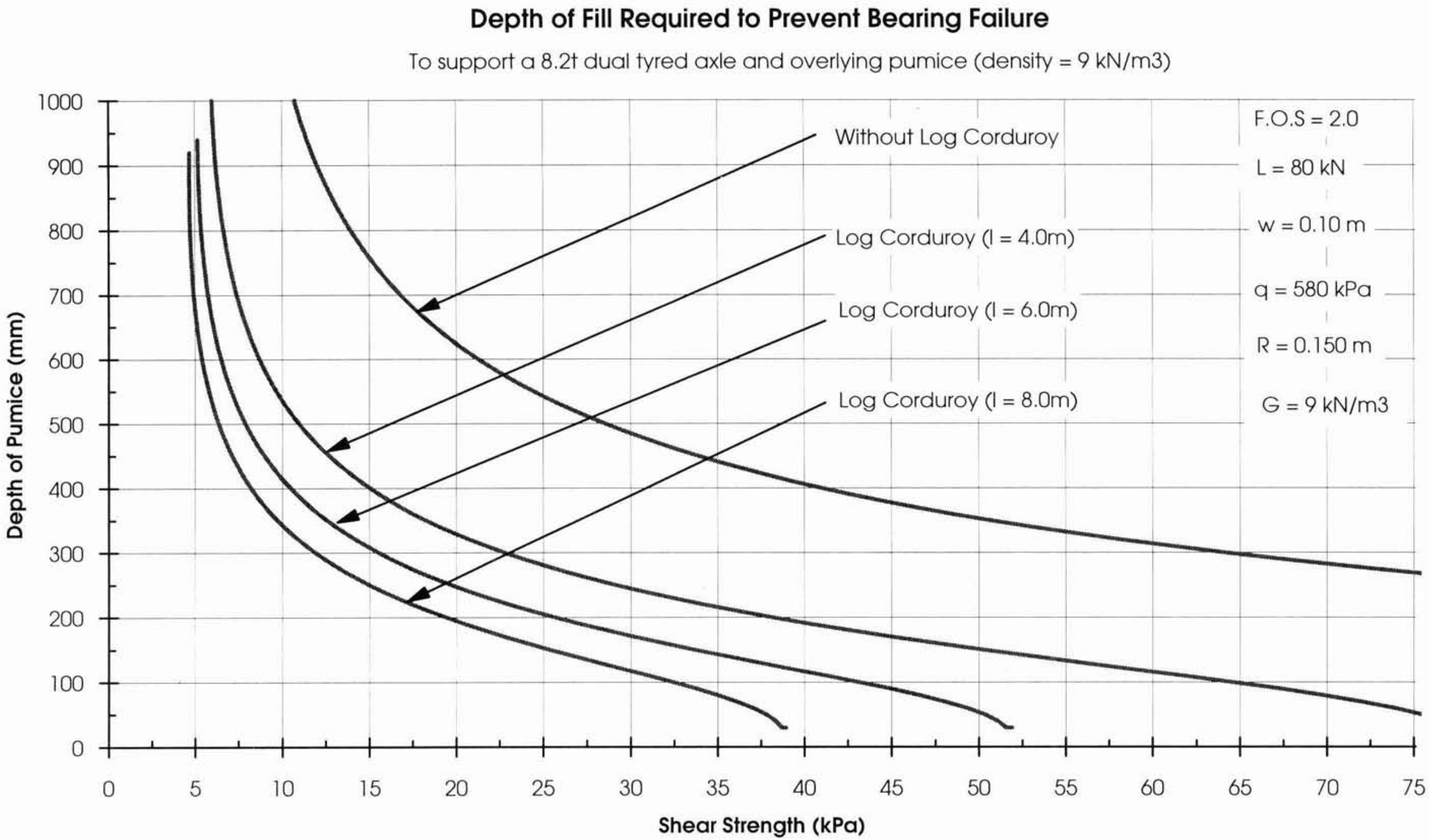

Figure 11 - Depth of fill required to prevent bearing failure, using pumice fill.

Table 1 - Field tests used to estimate the shear strength of a soil

TERM	SHEAR STRENGTH (kPa)	FIELD TEST
Very Soft	0 - 24 kPa	Squeezes between fingers when fist closed.
Soft	24 - 48 kPa	Easily moulded by fingers.
Firm	48 - 96 kPa	Moulded by strong pressure of fingers.
Stiff	96 - 144 kPa	Dented by strong pressure of fingers.
Very Stiff	144 - 192 kPa	Dented only slightly by finger pressure.
Hard	> 192 kPa	Dented only slightly by pencil point.

Figures 10 and 11 should be used as a guide only. The pavement depth is the minimum required to prevent bearing failure under a 8.2 tonne dual tyred axle. The methodology used is based on static loads and does not consider the effect of multiple vehicle passes. Therefore, a factor of safety of 2 or greater is recommended. This accounts for dynamic loads, which fluctuate in magnitude by up to 50% above the static load [OECD, 1988] and variability in soil strength properties.

COST

The cost to construct corduroy roads is dependent on the region, where aggregate costs and availability of corduroy material will vary. In addition, the loss of revenue from using pulp logs will be dependent on whether there is a pulp wood market in the region. In Westland, where a brush mat of native undergrowth is used as corduroy, the cost is relatively cheap at about \$8.60/m^2. This includes \$0.60/m^2 to place the corduroy material plus \$8.00/m^2 for the aggregate (\$20 /m^3), with an average depth of 0.4m.

In other regions, where there is not an abundance of undergrowth or slash, pulp logs have to be used as corduroy. When pulp logs are used, corduroy on average costs \$7/m^2 when placed. This includes paying the logging crew for the pulp wood produced (\$18/m^3) and a loss of revenue that was incurred through not selling the pulp wood (\$8/m^3). However, aggregate saving is substantial, usually requiring a depth of only 50 to 100mm over the logs. The cost for the aggregate is on average \$2 /m^2 (\$20/m^3). Therefore the total cost to construct log corduroy roads is on average \$9/m^2.

A case study in Patunamu Forest showed the cost can be as high as \$24 /m^2 (van der Voort, 1994) for repairing short sections of road (<20 m).

Where aggregate costs are expensive, the use of log corduroy becomes more attractive. This is shown in Figure 12, where the costs were calculated using the aggregate depth requirements from Figure 5. For a high aggregate cost of \$25/m^3, log corduroy construction is cheaper than using aggregate only for shear strengths < 35 kPa.

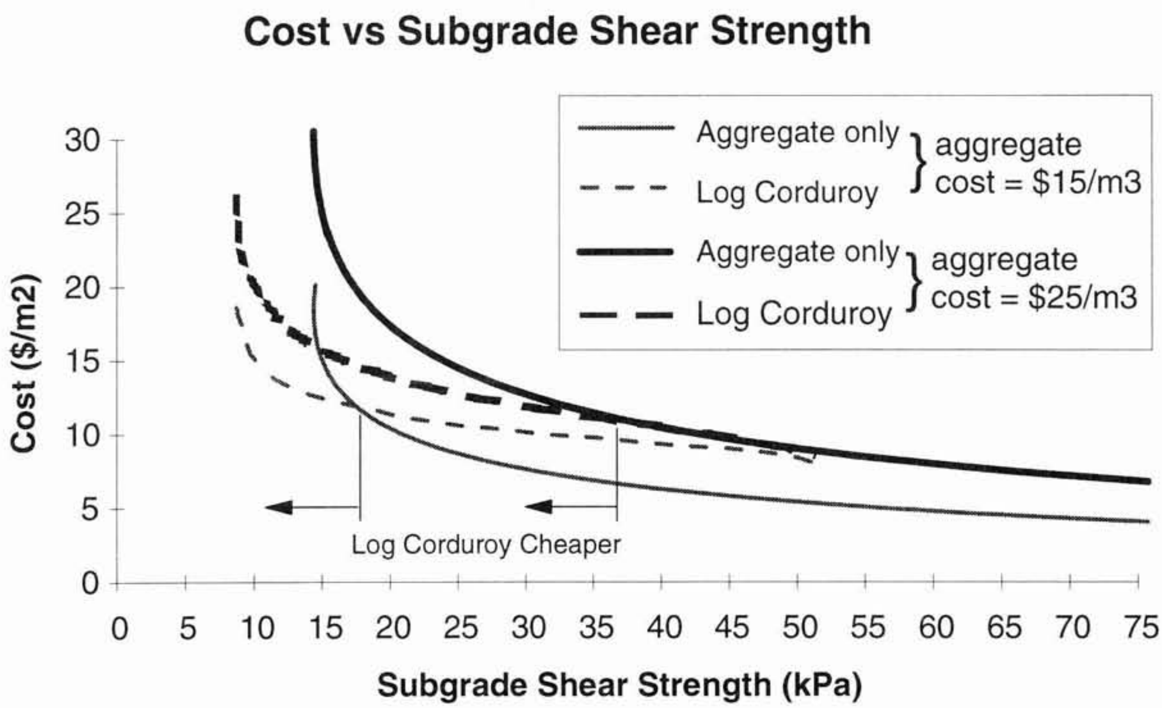

Figure 12 - Costs for log corduroy and aggregate road construction, (for aggregate costs of $\$15/m^3$ and $\$25/m^3$)

On corduroyed roads that have been abandoned, the aggregate can be recovered as there is a clear separation with the corduroy layer. In addition, the log corduroys can be re-covered for reuse or sale. By recycling the materials, costs can be greatly reduced.

CONCLUSION

Corduroy can either be a brush mat, polythene pipes, mill slabs or logs placed side-by-side on top of the subgrade and then covered with aggregate. The brush mat or logs are most commonly used in New Zealand. A brush mat consists of undergrowth and slash spread evenly over the roadway. Pulp logs from a nearby landing are typically used for log corduroy. The prime functions corduroy provides are reinforcement and separation between the subgrade and aggregate. Logs provide substantially more reinforcement than a brush mat and consequently aggregate requirements are reduced.

The cost for laying the brush mat is cheap ($\$0.60/m^2$), as the corduroy material has no other value. However, an average aggregate depth of 400mm is needed to fill the voids and provide adequate support. If the cost to supply and spread aggregate is $\$20/m^3$, then the total cost is $\$8.60/m^2$. The cost to supply and spread pulp logs is approximately $\$7/m^2$, but only 100mm of aggregate is required giving a total cost of $\$9/m^2$. These costs are guides only as corduroy road construction can be as high as $\$24/m^2$ for short road sections.

The use of corduroy is primarily suited to saturated soils with low bearing capacity.

Its overall effect is to distribute the aggregate and vehicle weight over a wider area. Corduroy road construction does not require specialist techniques or equipment and provides a trafficable road in a relatively short time. It is a well-proven method of construction, where the forest owner can be confident that road failure will not occur.

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