On Capillary Path Systems In Steep Mountain Areas

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ABSTRACT

This paper describes a high-density path network in a steep mountain area which supports intensive, high quality forestry in Osaka, Japan. The network, which may be likened to a capillary vessel system, makes it possible to: undertake intensive treatment of forests; effect a selective harvest of small, scattered product volumes; change the harvesting method from cable logging (which requires greater worker skill and results in high costs) to one in which products are removed from the stump area by grapple boom cranes located on roads. This network consists of a series of 2.0m wide paths which run parallel to the contour lines and a steep (but very solid) main road (2.5m wide) connecting the paths. The former are branch lines (rib paths) used primarily for extraction and the latter (which is paved with concrete) is the main line (backbone) used for access to the branch lines. In this network, the maximum gradient is 30%, the maximum height of embankment is 1.4 m, the minimum turning radius is 6 m, road density is 222.94 m/ha, correction-factor of shape V = 1.421, correction factor of real skidding distance T = 1.215, and the development percentage is 77.9%. Data shows that the correction factors approach 1.0 as the road density is increased, even in mountainous landforms of the type described.

Key Words: *Capillary Road Network, Steep Slope, Mountain Area, Intensive Forestry, Land Slide Protection*

INTRODUCTION

During the past two decades, Ohasi Forestry (Ohasi) has successfully conducted intensive forestry in its steep mountain land, utilizing a high-density path network of over 200m/ha. This paper describes the road network and what must be done and avoided in planning and constructing such a road network in steep mountainous areas which are readily affected by erosion.

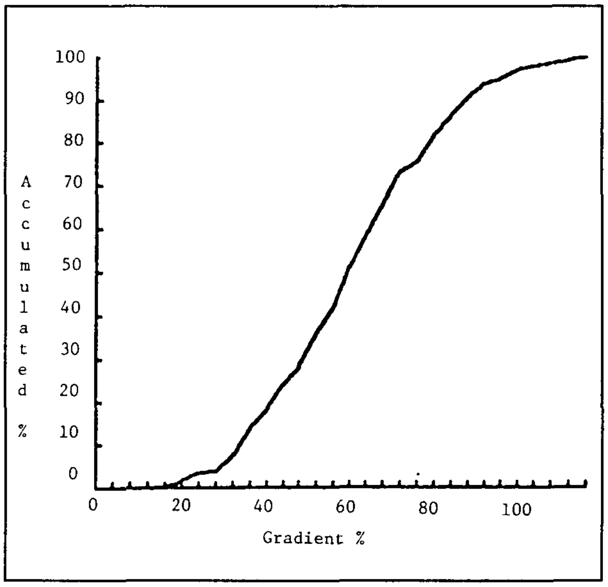

Figure 1. Accumulated frequency of gradients of the Ohasi Forest.

Figure 1 shows the accumulated frequency of gradient in the Ohasi forest and figure 2 is a map of the network. The area is 81.5 ha, the total length of existing paths is 18 170 m resulting in a density of 222.94 m/ha. Adding planned paths (another 1 318 m) results in a density of 239.12 m/ha. Naturally, it is very expensive to construct and maintain such a high- density network in mountainous areas. For example, in nearby areas it was revealed that road construction costs are US$ 127 (19 262)/m for main lines and US$ 24 (3 673)/m for branch lines, with road maintenance costs at US$ 0.47 (71.52)/m/year. Nevertheless, Ohasi finds that the reduced costs in other areas more than offset the expense of a high- density road network. This kind of forest management is one of the new approaches which some Japanese forest owners have developed as a reaction to the difficult business situation with which they are faced.

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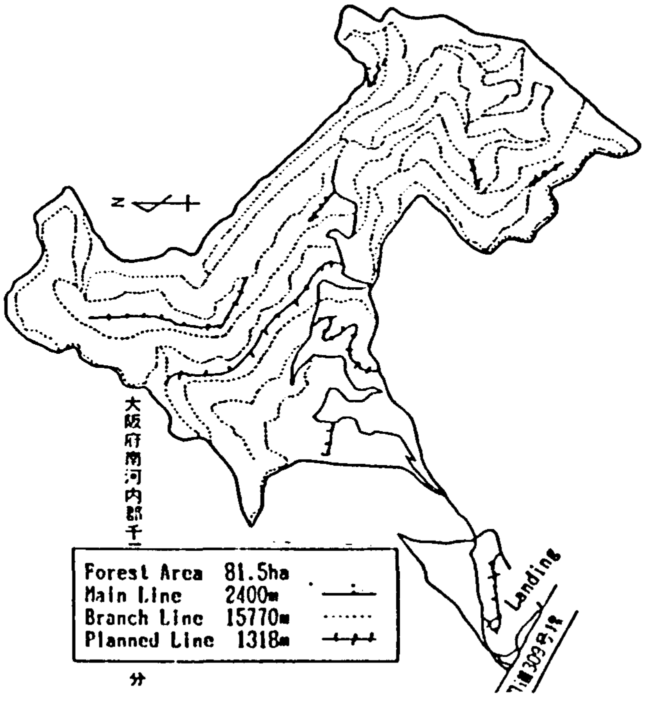

Figure 2. Capillary Path Network in Ohasi Forest.

In figure 2, a solid line represents the main line (back bone line) climbing from the public road at the bottom with a relatively steep maximum gradient of 30%. The main function of the road, which is concrete-paved and 2.5 m wide, is access. Broken lines represent the 2.0 m wide branch lines (rib paths) which are laid laterally from the main road at regular intervals. The relatively level, "contour-hugging" nature of these paths facilitates the operations that must be conducted upon them.

LAYOUT AND STRUCTURE OF A CAPILLARY PATH NETWORK ON STEEP SLOPES

There are two fundamental rules that must be followed in the planning and construction of any road network in steep mountain areas:

1) avoid the risk of slope collapse;
2) minimize the overall cost of construction and maintenance of the network, silvicultural treatment, and harvesting.

The first rule, that the possibility of causing the mountainside to collapse be eliminated, is absolutely important, although it must be understood that road construction is apt to cause such failures. If this risk cannot be avoided in a particular situation then, as a rule, the road network should not be built.

In order to comply with these rules, Ohasi has adopted the following principles:

1) Forest roads are considered to have two distinct functions: to act as main (backbone) lines for access or as branch (rib) lines on which working operations occur. For operations which occur on or from roads, level roads are preferable. As well, level roads allow the construction of wide, saucer-shaped ditches and road surfaces that are resistant to erosion.

In order to access the "rib" paths from the public road, the critical "backbone" road should take the most direct route up the mountain and be resistant to mountainside collapses (caused by heavy rains). In fact, the road's immunity to collapse has higher priority than its ease of utilization and the more direct the route it takes, the easier it will be to construct and maintain. For a man's body, damage to the backbone is catastrophic, and in a similar way the integrity of the "backbone" road is crucial to the Ohasi road network. The quality of "rib" lines (so named because of the way they branch off the main backbone road) are not as crucial, just as damage to ribs is not as serious to a man's body. This idea of separating functions makes it easy to maintain the total road network system at a lower cost.

2) In order to choose the most direct route possible for the backbone road, it is necessary to allow the incline to be so great that only four-wheel drive vehicles can be utilized for wood transport. If the maximum allowable incline of the road is restricted to 10%, for example, a great deal of road must be utilized simply for climbing the grade and the number of dangerous (and susceptible-to-failure) 180 degree turns must be increased. Therefore the maximum allowable incline should be as great as possible, thereby shortening the total length of road and reducing the number of less-resistant sections (usually directly under hair-pin curves).

3) The territory which is suitable for road location from the viewpoint of its collapse-resistance (the safety zone) is determined and marked on the map beforehand so that at least the main road can be planned within this zone. There is much variety in the topography and resistance to erosion

in mountainous area. Some areas fail easily for no obvious reasons, while others can be considered to be very "tough". It is very important to determine the local characteristics of a mountainside (where sections are fragile or resistant to erosion) before planning roads. Generally speaking, safety zones are in places where slopes are under 35 degrees, on gentle, wide ridges and shelves. On the other hand, danger zones are, for example, cone shaped piles of debris, 0-dimensional valleys (those having a steep concave entrance, and just under a ridge), and thick vertical layers of earth between rock layers. These can often be detected, to some extent, on aerial photographs and topographical maps, thereby facilitating the selection of safe road lines inside areas where the ground is resistant to erosion. Such acceptable zones of safety are generally not very wide.

4) The cross-sectional profile of the capillary path should be such that the height of embankment is under 1.4 m. In fact, it is more important to keep the height of the cut bank low than to maintain the width of the road face to a given size (in this case 2.0-2.5 m) for traffic. Certainly experience shows that the allowable maximum is 1.4m and, if this restriction doesn't allow for adequate road widths, special construction as shown in figure 3 should be considered.

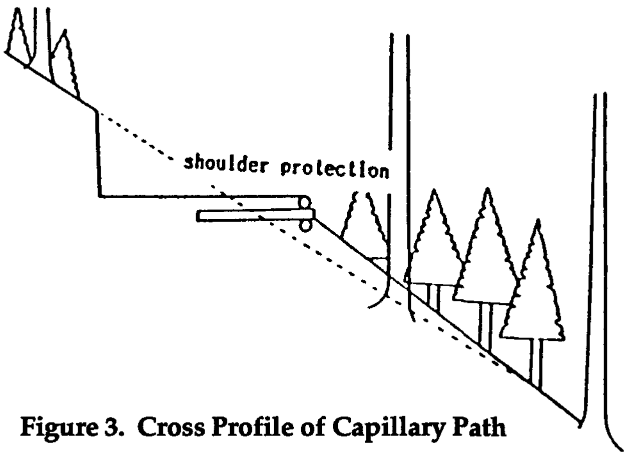

Figure 3. Cross Profile of Capillary Path

Figure 3 represents a typical cross- sectional profile for the capillary path on a steep slope. The cut bank should be vertical with no incline. The earth embankment will, over time, find its natural angle of repose. The log construction in figure 3 (which is filled with crushed rock) is well-drained and strong enough to carry the weight of the log carriers, thereby allowing the narrow path width to be utilized effectively.

5) Water flowing on road surface should only be drained off at slopes and ridges of convex (never concave) shape. In order to accomplish this, roads should be located higher on concave mountainsides and lower on convex ridges. It is very dangerous to concentrate water flows, as water converges naturally in concave slopes or valleys. If a road has a 180 degree turn near a concave slope, failure can easily result. Therefore, water must never be diverted from such concave areas by utilizing the profile-line of the road surface. It is necessary to always drain water on convex slopes and on wide ridges, where the lines of flow diverge and where construction debris and the slope tend to be more stable. Narrow side and cross ditches can be choked so easily that they are not good methods to drain the water safely. Proper design of the road's profile-line is the only reliable way of draining the network.

Allowable maximum gradient

The allowable maximum gradient is 14% for a third class forest road according to Japanese regulations. However, that does not mean that it is very dangerous or impossible to increase the gradient. The upper limit of the gradient at which a vehicle is unable to proceed as a result of slip should be adopted as the factor determining the maximum gradient.

Defining slip ratio S as follows:

$$S = 100\,\frac{V' - V}{V'} \tag{1}$$

where,

V = actual moving speed of vehicle

V′ = theoretical moving speed of vehicle if there is no slip.

Figure 4 shows the relationship between the slip ratio and gradient as a result of experiments conducted on a road constructed of soil similar to that found in the Ohasi Forestry. The main road in Ohasi Forestry is paved with concrete, which has more friction than soil. Denoting I(%) for gradient of road surface, f for friction coefficient between tire and road surface, and a for the constant, the following formula representing the relationship between gradient(%) and slip ratio(%) was induced theoretically by Deki [2]:

$$I = 100(\mu\ (1 - (1 - \exp(-aS))\ /aS) - 0.1) \tag{2}$$

where,

$\mu = 0.56$

$a = 0.68$

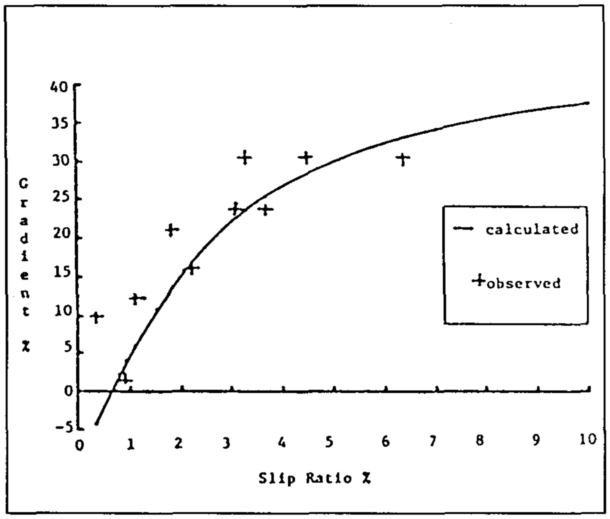

Figure 4. Relation between Gradient and Slip Ratio.

Figure 5 shows the relation between tractive coefficient and slip ratio.

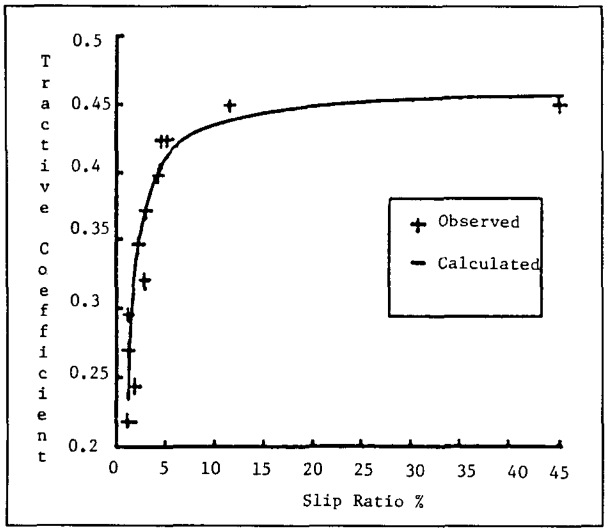

Figure 5. Relation between Tractive Coefficient and Slip Ratio

In these experiments, where a Mitsubishi Minica four-wheel drive wagon pulled another larger vehicle with a wire rope, the tension of the wire rope and slip ratio were measured with an electronic tension meter and a tachometer. Denoting P for tension or pulling power, TC for tractive coefficient, W for the mass of Mitsubishi Minica wagon, and for gradient of road, and defining

$$TC = \frac{P}{W \cos \Theta} \qquad (3)$$

the fitting graphline is represented as:

$$TC = \mu(1-(1-\exp(-bS))/bS)-0.1 \qquad (4)$$
$$(R = 0.912)$$

where,
$W = 0.98$ tonne
$\mu = 0.56$
$b = 2.26$

The results show that the tractive coefficient reaches its maximum value when the slip ratio is 10%. From this result, allowing for a factor of safety, a 5% slip ratio was selected as the allowable maximum limitation. This slip ratio is equivalent to a 30% gradient (from formula (2)). By this reasoning, the allowable maximum gradient was decided to be 30%. Those results should be seen as valid only in an area of Pleozoic strata with a comparatively good mix of soil grains-sizes, and will vary with the quality of soil and moisture conditions.

The problem of erosion of the road surface by water flow in the case of such steep gradients can be overcome by the use of concrete pavement.

CHARACTERISTICS OF THE PATH NETWORK AND DISCUSSION

The results of measuring the characteristics of the path network of Ohasi Forest are shown in Table 1. The table shows two cases: the first is the current network alone, while the second includes planned roads. Figure 6 shows the accumulated frequency of actual skidding distances.

Table 1. Characteristics of the Path Network in Ohasi Forest

Article		Today's	Planned
Area	ha	81.5	81.5
Total length of path	m	18170	19488
Mean shortest skidding distance	m	15.93	12.18
Mean actual skidding distance	m	19.36	13.63
Density of path	m/ha	222.94	239.12
Theoretical mean skidding distance	m	11.215	10.455
V:Correction Factor		1.421	1.165
T:Correction Factor		1.215	1.119
Development Ratio %		77.89	79.80

mean value of the shortest length of straight line from every intersection point of a net with 2 cm mesh on a topographical map of 1/2500, to the nearest path. The average skidding distance D_a is also the mean value of the length of the line running perpendicular to the contour lines from each point of the same mesh, tothe nearest path. It seems that in this kind of road network, about 80% of the area falls under 50 m of skidding distance (as shown on figure 6), so even short-distance cable systems could not be used.

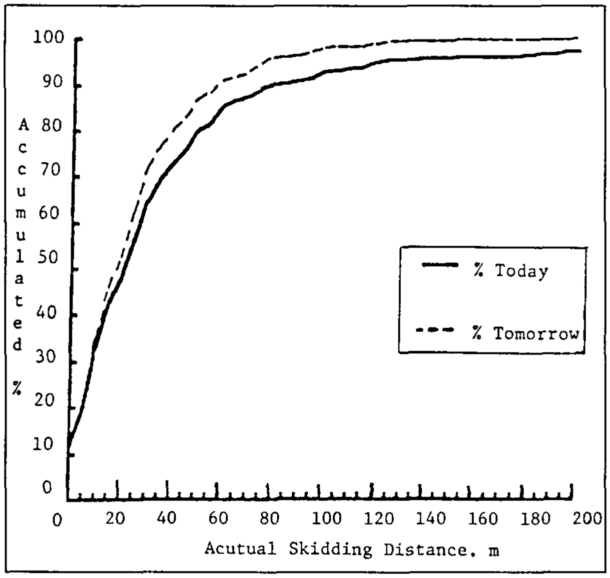

Figure 6. Accumulated Frequency of Actual Skidding Distances in Ohasi Forest

In the actual case of Ohasi Forestry, no cable system is utilized. Harvested wood products are pulled up to the path by winches or simply pushed down by gravity. V and T are the correction factors of Segebaden [4], [5] calculated as follows:

$$V = \frac{D_s}{D_c} , \qquad T = \frac{D_a}{D_s} \qquad (5)$$

where,

D_c denotes theoretical mean skidding distance calculated as

$$D_c = \frac{2500}{d}$$

where, d = density (m/ha) of road

The development ratio of Backmund [1] is a ratio of the points staying under D_c from the nearest path to the total number of mesh points inside of Ohasi Forest. The correction factors were ordinarily reported to be V = 1.4 - 2.0 and T = 1.75 - 2.3 in mountain areas [3]. However in the Ohasi Forest, the average incline is 31.2 degrees (62.3%), V = 1.421 and T = 1.215 for the current network, and V = 1.165 and T = 1.119 adding planned lines. They are near 1.0 in the case of parallel layout, and the thicker the road density is the nearer to 1.0 the correction factors are. This confirms that the correction factors of Segebaden may be used to evaluate road networks even in mountainous area, and that the concept of parallel layout, which was developed for flat land, may be seen as ideal for road networks in mountain areas.

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ACKNOWLEDGEMENT

The authors extend their sincere appreciation to Professor E.W. Robak, Department of Forest Engineering, University of New Brunswick, Canada for his considerable assistance with the translation of this paper.