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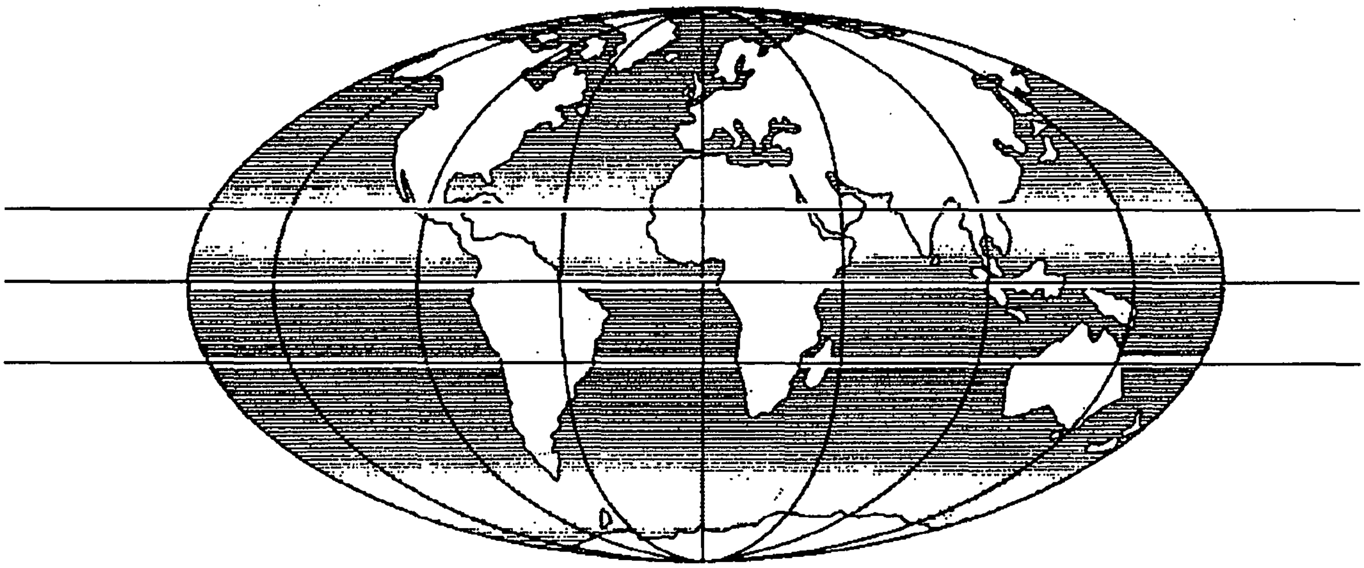
by C J Lawrance



Overseas Centre
Transport Research Laboratory
Crowthorne Berkshire United Kingdom

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LOW COST ENGINEERING AND VEGETATIVE MEASURES FOR STABILISING ROADSIDE SLOPES IN NEPAL

C J LAWRANCE
Overseas Centre, Transport Research Laboratory, Crowthorne, Berkshire, UK

1. INTRODUCTION

Roads are regarded as being necessary to promote development in third world countries, as they always have been. Recently however, donor agencies have begun to take much greater account of the physical impact that a new road can have upon the terrain, and hence upon the lives of those who live within the road corridor. In 1984, the Overseas Development Administration set up a major maintenance project on UK-funded roads constructed in Eastern Nepal, under the management of the UK consultants Roughton International. ODA was concerned at the large number of shallow failures affecting slopes above and below its own (and others') roads in Nepal, and commissioned TRL to examine the possibilities for 'low cost' engineering measures for slope protection that could be incorporated into the Nepalese Department of Roads' maintenance routines.

TRL's brief turned out to be very wide. From the outset it was evident that vegetation would need to be included in the study, mainly because plants are best suited to the retardation of very shallow failures extending over large areas, of which there are many in Nepal. However, very little information was available about suitable plant species, about weathering processes or slope failure mechanisms, or about the effectiveness in Nepal of low cost engineering measures used in Europe and North America. Moreover, it was found that experimental trials could not be set up in the normal way, because the slopes are so variable in hydrology and in the depth and consistency of the regolith, that it was impossible to set up experimental plots with appropriate duplication and controls that would give statistically valid data.

The approach adopted, therefore, was to make regular observations of a large number of sites on which a wide range of techniques and species were implemented, on the assumption that the relative success of these would, in time, indicate those that tended to be most positive. The best circumstances in which to make observations is in heavy rain, when a site is put under stress. Visits to Nepal were therefore made annually in the late monsoon, in the years 1987-1992. On several occasions, sites were watched in the process of destruction by a storm. Much was learned about slope processes and the response of stabilisation measures to heavy runoff at these times.

Our tasks were basically twofold:

- identify 'low cost' engineering techniques suitable for reducing shallow failures on

slopes.
- define a role for vegetation in slope protection in Nepal.

Note that the brief for vegetation concerned its engineering function alone; it did not include any element of aesthetics or amenity. Later, the needs of local people in their utilisation of forest products was given greater recognition and incorporated into new planting schemes.

2. FIRST-ATTEMPT FAILURES

Slope surface protection systems developed in the West fall into two broad categories:
- Surface coverings (eg. mulch, brush matting, jute netting and similar mats).
- Horizontal linear systems (eg. wattle fences, brush layering, fascines).

As a starting point for experimentation in the absence of any guidelines for subtropical conditions, TRL constructed wattle fences (Figure 1) and slope mulches made from local hessian sacking laid upon a trimmed, seeded, slope (Figure 2). The wattle fences were expected to reduce the rate of flow of water over the surface, hold back particles of soil washed down the slope, and form a haven for seedlings. The loosely woven hessian sacking was expected to form a sun shade for seedlings, reduce raindrop energy, prevent the movement of material over the slope surface and ultimately rot down and provide a little organic goodness to the soil.

Figure 1. Woven wattle bamboo fences

The results were a complete failure, for both methods. In the case of the wattle fences, the soil behind the fence became so wet that the fence was either pushed over or the soil liquefied and flowed out from underneath (Figure 3). Fences that survived were found to last only one or two seasons before rotting or being eaten by termites; they simply did not last long enough to allow vegetation to become established. The hessian lay upon the ground like wet blotting paper, suppressing germination and preventing healthy drying out of the soil surface. The soil beneath would sometimes liquefy, causing the cover to bag and tear (Figure 4). These forms of failure were found to be common in horizontal systems and slope covering systems, and demonstrated the need for a much more careful appraisal of slope degradation processes and of the way in which slope stabilisation measures function in this extreme environment.

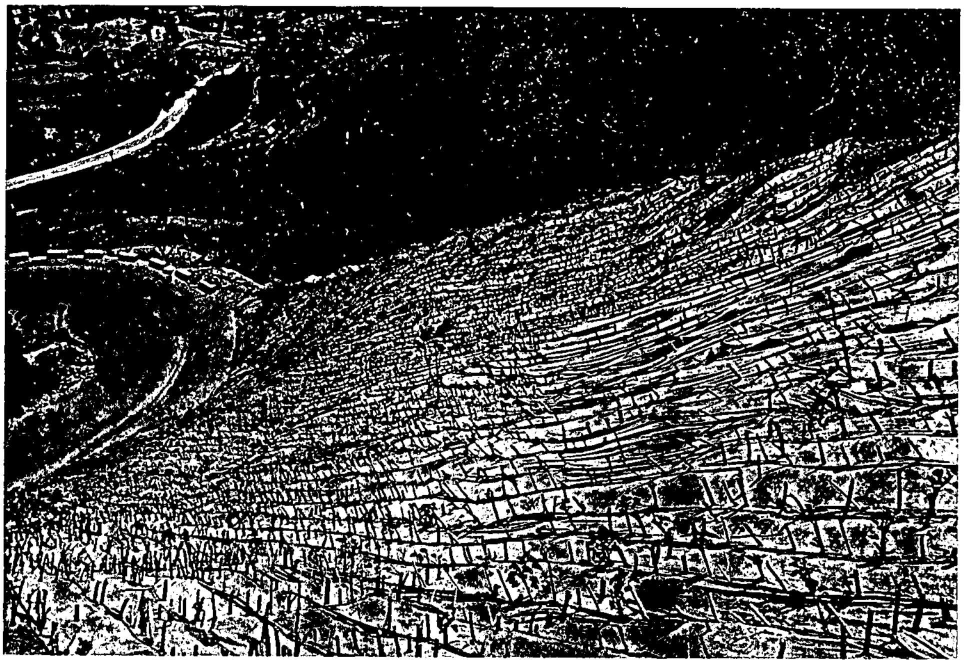

Figure 2. Hessian fabric slope cover and mulch

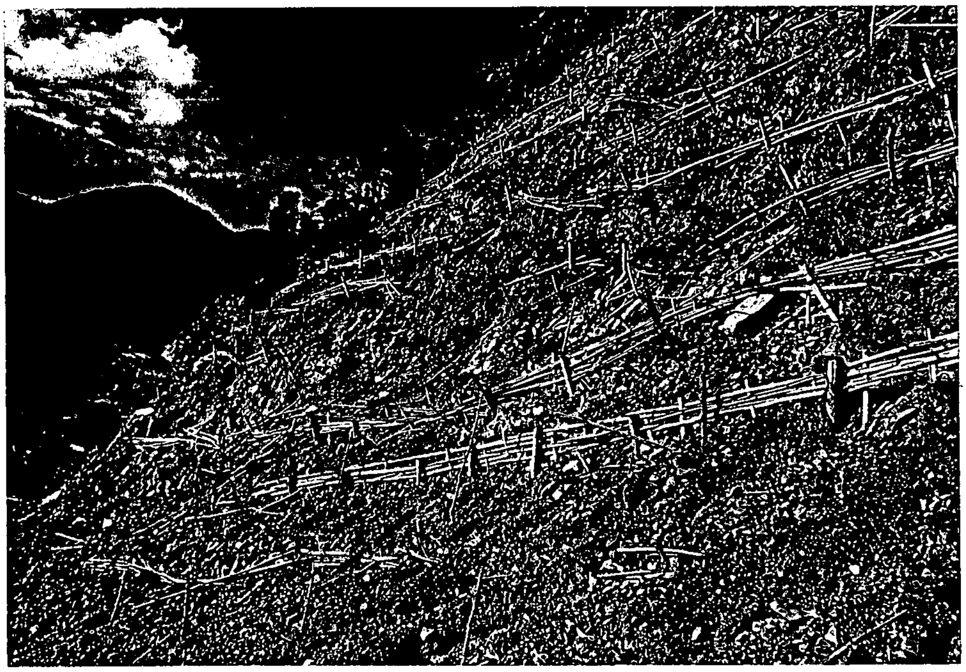

Figure 3. Bamboo fences destroyed by shallow mudflows

3. CLIMATE AND GEOMORPHOLOGY

Eastern Nepal receives 1000-2500mm of rain annually (depending upon orographic factors), most of which falls during the monsoon months of June through to September. Although it can rain continuously for many days, rainy periods usually last for a few hours only, often followed by a spell of intensely hot sunshine. With summer temperatures around 30-35°C, the rocks are subjected to intense chemical weathering which often causes road cuttings to degrade within a few years of being opened up. The rocks of eastern Nepal are metamorphic rocks of

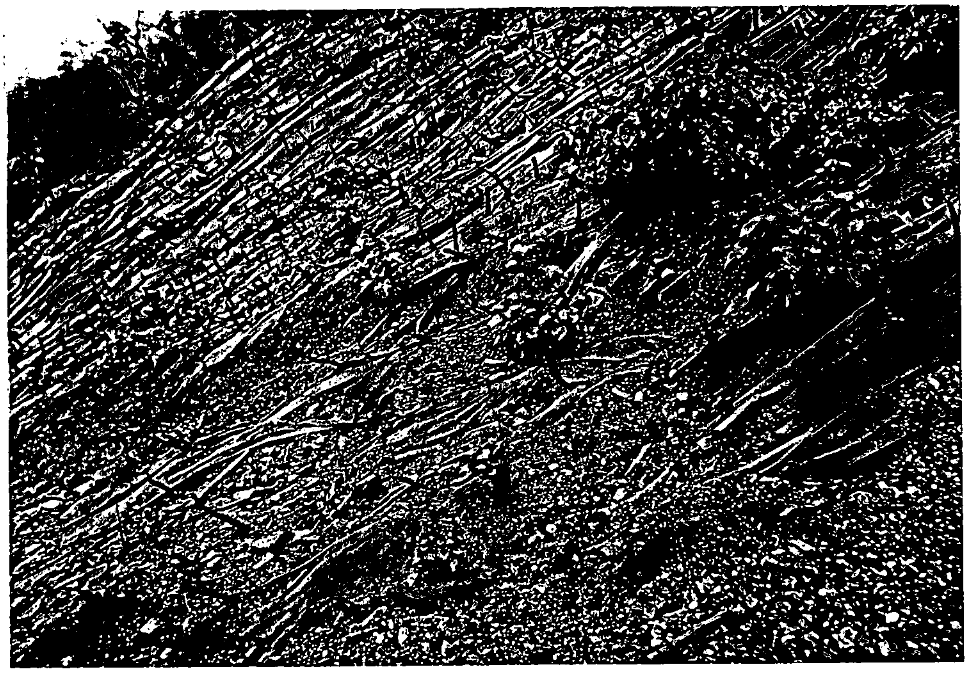

Figure 4. Hessian slope cover damaged by mudflows beneath

varying grade - phyllites, schists and gneisses, with subsidiary unmetamorphosed soft sandstones, siltstones and mudstones. All are highly susceptible to weathering. The downcutting of Himalayan streams causes continual undercutting of the valley sides, with attendant landsliding. This has created a landscape of slopes of 35-40° that are more or less straight from valley to crest, whose factor of safety is not far above 1. They are very sensitive to removal of support by, for instance, a road cutting. The slopes are mantled by 1-3m of more or less *in situ* weathered rock or old landslide debris (it is often difficult to tell them apart in the field). The materials are typically open-textured, of low cohesiveness and very stony.

4. LANDSLIDE APPRAISAL

It is obvious that in a situation where permeable materials are subjected to saturation and short periods of very heavy rain, the hydrological regime of the uppermost few centimetres of the soil greatly affects the stability condition near the surface. Although it has not been possible to measure or predict hydrological conditions in this zone, their importance for slope stabilisation has been taken into account in the drawing up of a simple classification of failure modes and failure depths, that provides a first step towards identifying appropriate mitigation measures (Tables 1 and 2). The point to note is that, with some exceptions, vegetation is applicable only to erosion and failures in debris, as opposed to rock, and where the depth to the failure plane is less than 250mm. If the failure plane is deeper than this, even mature trees become at risk to sliding forces.

Failure mechanism	Definition	Consequence for engineering
Erosion	Removal of debris particles from the surface by water flow	Surface treatments
Shear failure ("Slide")	Mass movement of soil or debris down slope. Includes rotational slumps, translational slides, flows of saturated material and soil falls	A variety of slope support and slope drainage methods, plus surface treatments
Plane failure	Mass movement in rock, whose failure plane is controlled principally by fracture planes within the rock mass	Rock mechanics solutions - propping, pinning or grouting. Propping is most appropriate in Nepal
Collapse ("Disintegration rockfall")	Type of rockfall in which rock fractures play little part in controlling development of the shear plane. In sparsely-jointed, permeable and weatherable rocks (eg sandstone). Rock weakens and eventually fails by shear. Debris consists of mineral particles (eg, sand) containing soft, weathered cobbles	Very difficult to stabilise other than by reducing slope angle to one which will stand when rock is weathered and saturated
Undermining	Type of rock failure that occurs in bedded sequences of soft and hard rocks (eg, sandstone and mudstone). Soft rocks weather back, leaving overhangs of hard rock which break off along a vertical joint plane. Thus face retreats	Prop walls between hard layers, or surface rendering of the soft layers

Table 1. Slope failure mechanisms

Depth to failure plane (mm)	Principal mechanism of failure	Scale of remedial measures
Up to 25	Erosion	Can be stabilised with vegetation alone, assisted by "light" engineering measures
25 - 100	Liquefaction	Can be stabilised by normal engineering methods, plus vegetation
100 - 250	Sliding or plane failure	*Ditto*
250 - 1000	Sliding or plane failure	Heavy engineering needed; expensive. Possible risk of failure.
More than 1000	Sliding or plane failure	Sophisticated engineering required. Major capital investment

Table 2. Depth to failure plane, and scale of remedial measures

The use of timber and jute raised the question of the longevity of low cost engineering measures in a tropical weathering environment (Table 3). When a site is to be planted, it is obviously important to ensure that the material used in mechanical stabilisation will last long enough for the plants to become established and take over. The concept of handover from a mechanical to a vegetative system of stabilisation is itself an essential consideration for design; the engineering function must be the same for both systems. A list of engineering functions was thus drawn up, to help in the landslide appraisal process (Table 4).

Material	Life
Untreated bamboo, jute net, hessian	1 rainy season
Timber (branches up to 50mm diameter), local roofing felt	2 rainy seasons
Bitumen-coated jute net	At least 4 years
Wire horizontal fences (with steel posts)	At least 6 years
Gabion, masonry	At least 20 years (provided that ground water is not corrosive and stone is not weatherable)

Table 3. Life of low cost engineering materials in the tropics

Engineering function	Engineering treatments	Vegetative treatments
REDUCE STRESS	Remove load; reduce slope angle	Not applicable, but weight of vegetation on slope should be minimised
CATCH material moving over surface	Tightly-pegged wire netting; catch wall	Stout grass; broad-based shrubs
ARMOUR slope against rainsplash and erosion	Revetment; surface rendering; jute netting	Grass mat; aerial canopy
SUPPORT slope from below	Toe wall; prop wall; fence	Trees; shrubs; bamboos
ANCHOR slope by pinning through to layer below	Rock anchors; anchored earth (both hardly used in Nepal); cable lashing of boulders	Anchoring effect of individual tree root systems cannot be guaranteed, though this mode of operation is often assumed
REINFORCE soil by increasing its shear strength	Reinforced earth; soil nailing; soil-filled fabric cells. (Not used in Nepal)	Strong, dense rooting system of grasses, shrubs and trees
DRAIN slope by means of sub-surface waterways	Gravel-filled drains	Root systems carry water down into soil - can be a dis-advantage; live fascine drains
LIMIT extent of slope failure should it occur, or of damage to property	Loosely-draped wire mesh (limits hazard but not extent of failure)	Change in rooting depth from shallow to deeper layer can prevent lateral spread of failure
IMPROVE environmental or ecological condition of site	Not applicable	Site and micro-climate of soil improve as vegetation develops

Table 4. Engineering functions of treatments

5. PLANT SPECIES FOR SLOPE STABILISATION

Since there was no indigenous source of supply of seed available on a commercial scale, consideration was given to importing the quantities required. However, importation was rejected on the grounds that:

- costs could be high and would utilise foreign exchange.
- the introduction of exotic species could have an adverse effect on the ecology.
- local people, with their agrarian background, had the potential to develop their own nursery industry. By including farmers in the slope protection programme, both they and the project could benefit.
- importation is against the principle of sustainable development.

As with the bioengineering techniques, expert advice on suitable species was completely lacking. Agriculturalists and foresters in Nepal had no knowledge of the bioengineering characteristics of any of the wild plants found growing within the road corridors that were thought to be potentially useful. They could not even name them; specimens were sent to the Royal Botanic Garden in Scotland for proper identification.

Figure 5. Plants for engineering. *Butea minor*, a deep-rooting shrub, protects drain margins, and *Neyraudia arundinacea*, a clumping grass, prevents erosion

Initially, about thirty species of grasses, shrubs and trees were selected, primarily on the basis of their rooting depth, ease of propagation, speed of growth and ability to colonise poor sites (Figure 5). As a range of plants for all bioengineering purposes, the list had its shortcomings:

- one is a weed which spreads in an unwelcome way into adjacent farmland.
- at least two are colonisers of open ground which are quickly suppressed by invading species.
- no creeping grasses, having a dense, binding root mat, occur locally. (Only clumping grasses are available, although some are very substantial).
- the plants had to be unpalatable to animals, because it was impossible to prevent goats and cows from eating any palatable species that was planted. This situation has since been rectified by employing local farmers as resident guards to protect new sites. This practice has given access to many more species as potential bioengineering candidates.

Questions of ecological compatibility, maintenance and value to the community as a source of forest products, were all deferred in order to pursue engineering effectiveness. These wider issues are now being addressed by current projects in Nepal.

6. PLANTING CONFIGURATION

Deciding upon an ideal planting configuration proved to be the most difficult area of research because, to the variables in the landscape and species is added the need to allow time for the plants to become established; only then can they demonstrate their ability to hold a slope that is coming under stress. The following observations were made regarding plant development:

- the often spectacular rate of growth of the aerial part of a plant belies the much slower development of an extensive root system. At least three seasons must pass before a plant is capable of performing an engineering function. A site containing immature plants can be wiped out by a single heavy storm. Many experiments were lost in this way, hampering progress in research.
- growth rate is appreciably slower than normal on dry, rocky, exposed sites, as most landslide scars and road cuttings are.
- growth is considerably retarded during monsoons in which less rain falls compared to normal monsoons.

Figure 6. Rills formed by a rush of surface water during a storm

As noted above, horizontal systems tend to be affected by liquefaction and undermining. In heavy rain, water pours downslope in rills (Figure 6), carrying all before it. Two forms of improvement were, and still are, sought, in preparation for those occasions when a site is subjected to a downpour. One is to allow excess water to escape, the other is to build an element of 'survivability' into any new site, to minimise the destructive effect of a storm early in life. It was observed that the only plants to escape a deluge tend to be those growing on the ridges between waterways. A theory was conceived, that it might be better to place plants in lines down slope, in order to allow excess runoff to flow between the lines of the seedlings without impacting upon them. It was reasoned that, by allowing rills to develop or even creating them during slope preparation, excess water could be removed more quickly from the slope. This would increase the risk of deepening of the rills, but after the storm, provided the site remained intact, the rills could be stabilised by stone pitching or equivalent, to prevent them from deepening further.

The theory was put to the test by planting about six sites vertically with grasses (Figure 7). It was found that, although water may flow between the lines, the new configuration carries its own disadvantages that prevent the plants from becoming established:

- plants on ridges seem to suffer from drought. Growth is very slow - even after two years they remain small and can be pulled out with one hand alone.
- water sometimes travels preferentially down the line of plants, following the lightly-compacted planting holes and excavating the seedlings as it goes.
- enlargement of the rills causes the ridges to rapidly become undermined, exposing the roots and killing the plants. The plants cannot grow fast enough to protect the ridge from erosion or liquefaction before the ridge is destroyed.

Figure 7. Grasses planted down slope on a prepared ridge and rill surface

Experiments with down slope planting were thus abandoned. However, a variation was tried that does seem to offer some advantages. When plants are placed in closely-planted *diagonal* lines (Figure 8):

- overland flow volume is kept up, while the rate of flow is reduced because the water is intercepted at intervals by the grass lines.
- water impact on the grass line is minimised because the water strikes the line at an angle, and the grass slips support each other.
- water enters the ground along the line of plants, feeding the roots.

The main disadvantage of diagonal lines as presently implemented is that the plants are overcrowded, causing many ultimately to die, which is wasteful of planting material.

7. CONCLUSIONS

If vegetation is to serve a true engineering role, it is essential that the intended engineering function of the vegetation is firmly established and incorporated into the design of the remedial works. This implies that the failure mechanism that the plants are intended to resist is correctly predicted, which requires a careful assessment of soil and water conditions on the

Figure 8. Grasses (*Neyraudia arundinacea*) planted diagonally on a trimmed slope. A line of *Indigofera atroturpurea*, a small leguminous tree, is planted along the toe

slope, and of slope degradation processes. In the tropics, where storms can be very intense, it is important to design an element of 'survivability' into the planting scheme, so that if the site is subjected to heavy runoff in its early life, loss is not total. A design to improve a site's ability to withstand heavy runoff may reduce its capacity to stabilise the slope, but since maximum efficiency in this respect cannot be achieved in less than five years, survival to maturity is at first more important.

The engineering function of the vegetation is also important when a planting scheme is combined with a 'hard' engineering measure, especially if the latter has a life of only a few years. The engineering function of the hard structure must be equivalent to that of the vegetation, and its life span should be sufficient to afford protection to both the site and the planting scheme, until the plants reach maturity and take over the engineering role from the decaying temporary measure.

ACKNOWLEDGEMENTS

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