BIO-ENGINEERING FOR SUSTAINABLE ROAD MAINTENANCE

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ABSTRACT

Roads in Nepal run through mountains and are crossed by major rivers and their tributaries. Different types of instabilities are caused in mountain road slopes depending upon the type of material and the environment. The experience of hill road construction in Nepal shows that the sustainability of road in the mountains depends on proper alignment selection, slope drainage and slope management. Spoil management and the use of slope stabilization measures are other important factors to be considered. Cut slopes on the hill side need to be steep to reduce earthworks and fill slope angle on the valley sides must be safe to sustain the saturated fill materials during monsoon. Road construction causes widespread damage to vegetation and other adverse environmental consequences. The only cost effective way to protect slopes against erosion and shallow landslides is through the use of vegetation.

Bio-engineering offers comprehensive solutions to reduce slope instability problems when combined with appropriate civil engineering measures. A form of bio-engineering is adapted for the unique environmental, economic and institutional conditions in the road sector of Nepal. This concept emphasizes on preventive measures and begins from the planning stage of the road promoting sustainable maintenance. Bio-engineering work by fulfilling the engineering functions required for the protection and stabilisation of slopes. Bio-engineering techniques developed in Nepal are simple and labour intensive. This provides employment to the local communities and they can perform income generation activities through the bio-engineering process.

KEY WORDS: Roads, landslides, bio-engineering, sustainability, community

1. INTRODUCTION

The geology of Nepal is highly mixed and there are several major active faults and thrust running parallel to the length of the country. Nepal is also situated in a geographical zone at very high risk of earthquakes. Climate change is also affecting Nepal negatively and effects will worsen in future. The water flowing from the mountains will impact most heavily through flooding. Down-cutting of rivers and steepening of slopes are common features. The monsoon rains further give rise to weathering rates and saturation during which most of the landslides and erosion take place. The mountains of Nepal do not have simple environment for highway engineering. Every road crosses zones of instability. Geologically volatile slopes bring a complex range of problems. Common problems encountered include steep topography excavation conditions due to the deeply weathered nature of the soils. Intense rainfall lead to high groundwater tables, saturated soils and large quantities of surface runoff during the wet season. Despite these difficulties, it is necessary to establish and sustain roads that serve the inhabitants reliably, providing the transport services that are essential to development.

The construction of roads in Nepal started since 1950 and now the strategic road network has reached to a length of more than 15,000 kilometres. Most of the roads were constructed from donor's experience in the past but now the Department of Roads has developed its own design guidelines as well as specifications and is capable for the construction and maintenance of the road networks throughout the country. Transport sector consumes a considerable part of the overall infrastructure investment in Nepal. A major proportion of the transport sector budget is expended in the improvement and maintenance of roads

2. ROAD ALIGNMENT SELECTION

The experience shows that good alignment selection is a crucial first step in minimising slope instability in Himalayan terrain. Road alignments in the high landscape tend to be more stable than alignments low down the landscape (Figure 1). This is because of the landslides coming down from the above and the river scours away at the base of the slope.
In some projects, road alignments selected are prone to both mountain and valley side failures, and frequently cross unstable terrain when it could have easily be avoided. Such roads display serious errors of judgment in some sections of alignment. These include the avoidable crossing of areas of large-scale slope instability and will mean that the roads are costly and barely sustainable.

3. SPOIL MANAGEMENT

While constructing roads through mountainous terrain, the aim must be to minimise the volume of cut slopes as far as possible. This is achieved by setting the alignment to follow the natural contours. It is also necessary to bench the road into the hillside to achieve a good foundation increasing road side cut slope, which often requires stabilisation in itself. It also gives rise to a problem of spoil disposal (Figure 2). Traditional practice has been to dispose of unwanted material by simply throwing it down the slope. This has given rise to much increased rates of erosion and slope failure at valley side.

Cut slopes cause disturbance to both the terrain and the local vegetation. Attempts to produce a mass balance across the road section are often hampered because in doing so the topographic irregularities may hinder attempts to achieve the geometrical standard of the road alignment. In the past, for example on the Dharan-Dhankuta Road, surplus spoil was moved over considerable distances to designated safe tipping sites. This was certainly effective and made for cheaper maintenance, but was a relatively expensive practice during the construction phase. If the best possible mass balance can be achieved, then a cost effective and sustainable solution generally results. This method gives rise to much lower costs in subsequent maintenance, not only because there are few slopes covered in eroding tipped debris to be stabilised, but also because erosion or mass movement in the debris does not damage or destroy the road during severe storms even many years later. Having monitored similar work on construction of major roads in Nepal in recent years, it can be stated that the combination of good alignment and good mass balancing has led to less damage to the biophysical environment.

4. DRAINAGE MANAGEMENT

Drainage of the slopes adjacent to roads is critical to prevent instability. This is extremely site-specific, but it is now clear that failure to address slope drainage can lead to large scale mass movements as a result of heavy rain storms. Steep slopes crossed by roads in the mountains are of marginal stability even before the road disturbed them. The additional instability caused by construction may result in heavy mass movement during monsoon rain. This type of disaster can be averted for relatively low cost if a good slope drainage system is installed (Figure 2).

FIGURE 1 Carefully selected alignment

FIGURE 2 Spoil and drainage management

Water generally comes from three sources: rainfall, lateral runoff and subsoil water. There is relatively little runoff or seepage from surrounding slopes but even the width of a road's surface can give rise to large volumes of water during heavy rain. Water must be disposed of carefully to prevent erosion from expanding rapidly, undercutting the road and causing large scale collapses. This may necessitate running side drains long distances in order to reach safe gullies into which the water can be discharged. Once gullies are reached, downstream check dams and cascades are often required

Groundwater seepage led to the saturated failure of slopes above and below the road. The remedy is the installation of subsoil slope drains, on the basis that: (a) failure movements are slow, but accelerated by the presence of the road disturbing the slope; (b) the angle of repose of the moving mass is less than the slope angle when wet, but much greater when dry; (c) the removal of pore water by means of subsoil drains will reduce mass weight, increase cohesion and restrict shear; (d) because the margin between stability and creeping movement is so narrow, a low cost, limited response is usually enough to bring the mass into a year-round stable condition; and (e) a retaining structure alone is not adequate, because the saturated angle of repose of most weak debris slopes is very low, and without internal drainage the material will continue to creep, and flow over the retaining structure. Where the failure is above the road, a small gabion breast wall is usually recommended, as this provides the filter for a roadside drain to pick up any seepage water not taken into the subsoil slope drains, and to act as a route for water discharged from the subsoil drains. Surface protection and longer term increase in soil reinforcement is always recommended in addition, through the use of appropriate bio-engineering measures. This is the lowest cost approach to the stabilization of failures of this type, and it has been used successfully in many locations.

5. LANDSLIDE MANAGEMENT

Road construction creates two types of new slopes. Cut slopes on the higher sides of roads, which need to be left at as steep a stable angle as possible to reduce earthworks. Fill slopes on the lower sides, which must be graded to angles that can be sustained when the disturbed material of which they are composed is saturated in the monsoon. Standardised design grades often lead to sections of slope that look acceptable when cut in the dry season, but are simply too steep when they are saturated during the monsoon. These difficulties are compounded by the very large volumes of earthworks that are necessary in steep sidelong ground, and the need for carefully graded, straight cuts without small, over-steep sections. The causes of slope formation in mountains of Nepal are as follows:

- Monsoon rainfall and gravity keep the weathering products moving down the slope.
- Rivers cut down rapidly.
- Sub-tropical weathering attacks rocks.
- Straight planner failure tends to develop.

The standard design grade for cut slopes used by most road projects is 3:1 or 71°, which is too steep for many of the weak residual soils found in many parts of the middle mountains of Nepal. It is better to use a cut grade of 1.5:1 or 56° which can be stabilized in residual soils, but a steeper angle will always lead to a failure within a few years. Unfortunately many design and construction project will not adopt this because of the extra earthworks involved and the consequent immediate increase in construction costs. It has always been necessary to keep project costs within certain limits, and therefore to minimise slope cutting. Also, the use of steeper cut slopes means that there is less land take; and obviously the more land that remains in agriculture, the better it is for the socio-economic environment. But slopes cut at an unsustainable grade will eventually fail and cause damage to an increased area of land, as well as incurring greater costs. Breast walls can be used to increase the steepness of cut slopes in key locations, and this can be particularly important on colluvial slopes where a grade of even 1.5:1 is often too high.

6. BIO-ENGINEERING TECHNIQUES

Bio-engineering is the use of vegetation in accordance with engineering principles to prevent damage to the environment. The roots of vegetation can interrupt shear planes and stop them from instability. Bio-engineering has been introduced for the stabilisation of roadside slopes in Nepal since 1980s. The bio-engineering techniques used in the Nepal road sector are from standard international methods but adapted to local conditions emerged from the research phase (Table 1).

TABLE 1 Bio-engineering Techniques and Structural Functions

Techniques	Design and function
Horizontal grass planting	Grass slips, rooted stem cuttings or seedlings are planted in lines across the slope. They protect the slope with their roots, provide surface cover, reduce the speed of runoff , catch debris and armour.
Vertical grass planting	Grass slips, rooted stem cuttings or seedlings are planted in lines running down the slope. They protect the slope with their roots, provide surface cover, drain surface water. This technique allowes to develop a semi-natural drainage system, gullying in a controlled way.

Techniques	Design and function
Diagonal grass planting	Grass slips, rooted stem cuttings or seedlings are planted in lines running diagonally across the slope. They armour the slope with their roots and by providing a surface cover. They have limited functions of catching debris and draining surface water. This technique offers the best compromise systems.
Random grass planting	Grass slips, rooted stem cuttings or seedlings are planted at random on a slope, to an approximate specified density. They armour, reinforce the slope with their roots and have a limited function of catching debris. This technique is commonly used in conjunction with jute netting, where surface better protection is needed on steep and harsh slopes.
Grass seeding	Grass is sown direct on to the site. It allows easy vegetation coverage of large areas. This technique is often used in conjunction with mulching and jute netting to aid establishment.
Turfing	Turf, consisting of a shallow rooting grass and the soil it is growing in, is placed on the slope. A technique commonly used on gentle embankment slopes. Its only function is armouring.
Shrub and tree planting	Shrubs or trees are planted at regular intervals on the slope. As they grow, they create a dense network of roots in the soil. The main engineering functions are to reinforce, to anchor and to support.
Shrub and tree seeding	Shrubs or trees seeds are applied directly to the site. This technique allows very steep, rocky and unstable slopes to be revegetated where cuttings and seedlings cannot be planted. In direct sowing, seeds are placed individually, whereas the broadcasting involves throwing the seed all over the site. The main engineering functions are to reinforce and, later, to anchor.
Large bamboo planting	Large bamboos are planted by one of two methods: a. the traditional planting or b. to plant rooted culm cuttings from a nursery. Large bamboos can reinforce and support a slope. They can reduce movement of material and stabilise slopes. However, they do not have an anchoring function; also, they can surcharge upper slope areas.
Brush layering	Hardwood cuttings are laid in lines across the slope, usually following the contour. These form a strong barrier, preventing the development of rills, and trap material moving down the slope. The main engineering functions are to catch, to armour and to reinforce the slope.
Palisades	Hardwood cuttings are planted in lines across the slope, usually following the contour. These form a strong barrier and trap material moving down the slope. The main engineering functions are to catch, to armour and to reinforce the slope.
Live check dams	Large hardwood cuttings are planted across a gully. These form a strong barrier and trap material moving downwards. In the longer term, a small step will develop in the floor of the gully. The main engineering functions are to catch debris, and to armour and reinforce the gully floor.
Fascines	The word "fascine" means a bundle of sticks. In this technique, bundles of live branches are laid in shallow trenches to put out roots and shoots forming a strong line of vegetation. It is sometimes called live contour wattling. The engineering functions are to catch, to armour and to reinforce the slope.
Vegetated stone pitching	Slopes are strengthened by a combination of dry stone walling or cobbling, and vegetation planted in the gaps between the stones. This technique provides a very strong form of armouring. It uses vegetation to strengthen a normal stone pitching.
Jute netting	A locally made geotextile of woven jute netting is placed on the slope and has four main functions: (a) Protection of the surface, armouring against erosion and catching small debris; (b) Allowing seeds to hold and germinate; (c) Improvement of the microclimate by holding moisture and increasing infiltration; (d) As it decays, it acts as a mulch for the vegetation established.

Emphasis has been given to techniques which improve slope drainage. Major trials were done on roads such as the Dharan-Dhankuta Road and a number of techniques were identified as the optimum solutions on specific sites. This was made by use of demonstration, awareness-raising, information provision, training, budget programming and provision of technical advice. The use of bio-engineering measures has now become routine in the Nepal road sector. The Department of Roads has Geo-Environmental and Social Unit, whose function is to ensure the use of bio-engineering on a routine basis. The role of the unit is entirely advisory but the Division Road Offices actually carry out the construction and maintenance of the road network. Road construction caused widespread damage to vegetation and other adverse environmental consequences. The only cost effective way to protect slopes against erosion and shallow landslides is through the use of vegetation or bio-engineering (Figure 3). This covers a range of techniques that can be combined with civil engineering structures to enhance drainage and slope stability (Figure 4). In a climate dominated by the monsoon rains, the seasons of works implementation cannot be altered. Failure to undertake bio-engineering works at the right time increases the risk of instability and slope failures in the near future. It is obvious from all previous experience of highway engineering in the mountains of Nepal, that the absence of surface protection leads to a significant loss of investment and maintenance burden.

Most landslides have more than one cause of mechanism of failure operating at different points on the slope. Thus, separate parts of a landslide have to be given different treatments, appropriate to the mechanism of failure. There are many factors which need to be considered carefully before any planning for remedial measures. The most important factors are careful site examination and attention to details. In particular, the use of indigenous large grass species, planted in different configurations, is becoming a simple and yet highly effective means, not only of erosion control, but also of affecting slope hydrology.

FIGURE 3 Jute netting and brush layering

FIGURE 4 Combination of civil and bio-engineering

The skills required for bio-engineering techniques are simple as the farmers use skill in their agricultural farm. The plants are easily available in their locality. The local people can manage and maintain the stability of slope by themselves if the government gives attention towards this. Also, this provides valuable jobs to the local people and they can perform income generation activities through the bioengineering process. Emphasis has been given towards techniques which improve slope drainage, since the problems of high infiltration and low cohesion are found in the materials. Since the effective rooting depth of plant is less than 2 metre, deep seated instability problems are addressed by geotechnical engineering measures and only swallow failures can be treated by bio-engineering technique. Selection of the bio-engineering technique involves the selection of the right means of plant propagation through a consideration of function, propagation and site suitability. The final choice of species and the site characteristics are determined by altitude and moisture. The geomorphological nature of the southern

Himalayas means that there is a natural abundance of pioneer colonising species available throughout the broad altitude ranges crossed by the road network.

7. LESSIONS LEARNT

A large numbers of technical and institutional lessons have been learned during the bio-engineering development in the road sector of Nepal. They are summarised as five main criteria which are needed for soil conservation measures to be really effective.

- Bio-engineering techniques should be strong enough for the purpose for which they are designed.
- Plants must become stronger over time or to remain strong over a significant period;
- Plants should be flexible.
- Plants should be able recover from damage.
- Bio-engineering techniques must be simple and robust enough to users in remote areas with resource constraints.

The main institutional lessons learnt in the process are given below.

- Government regulations in Nepal are relatively strict and trials of uncertain outcome are a difficult and risky undertaking for civil servants. Donor funded suitable projects allow an institution for the experimental works which give the institutions much-needed flexibility to try new ideas.
- Consensus must be developed both within the institution and externally by building ownership feeling.
- There is scope for individuals within the institution to try new things and this encourages change from within the institution itself.

8. CONCLUSION

Making a road sustainable and environmentally sound depends on good initial planning. Carefully aligned roads have fewer areas of instability and require less maintenance in the longer term. Highway engineering in the mountains of Nepal leads to a significant loss of investment and maintenance burden. Special care is required to ensure the stability of slopes and landslide management. It is never possible to avoid unstable areas altogether and all roads have to be prepared to adopt special measures in response for maintenance.

The use of bio-engineering techniques in road sector has shown to be reliable and cost-effective. So the Department of Roads, which is responsible for the construction and maintenance of strategic road networks decided to adopt these techniques. The techniques have improved the condition of roadside slopes reducing maintenance costs. The use of bio-engineering technique has now become routine for the slope stabilisation and landslide management in the hill roads of Nepal.

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