ROLE OF BIOENGINEERING IN MOUNTAIN ROAD MAINTENANCE: OBSERVATIONS FROM NEPAL

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ABSTRACT

Nepalese road network expanded rapidly in the last two decades and is increasing every day. Different types of instabilities are caused in mountain road slopes depending upon the type of material and the environment. Alignment selection, spoil management, drainage systems, and the type of protection measures considered during construction stage play vital role in maintenance stage of the roads. The environment friendly road construction was introduced during 1980s on rural roads and gradually adapted on strategic roads. The concept is labour based construction, reduced geometry and balanced cut and fill. Similarly, suitable bio-engineering techniques in conjunction with small scale civil engineering structures are used to stabilize road side slopes. This concept emphasizes on preventive measures and begins from the planning stage of the road promoting sustainable maintenance. The most significant aspect in mountain road maintenance lies in the use of scale of vegetation cover. The roadside bio-engineering is not just used for slope protection but also incorporates productive plants to become a part of the neighbouring agricultural system. This paper examines how to cope with roadside erosion and landslides through the use of bio-engineering which ultimately contributes to the sustainability of mountain roads.

Key words: Roads, landslides, bio-engineering, community, maintenance, sustainability

1. INTRODUCTION AND BACKGROUND

Roads have been constructed in Nepal over the past 50 years since the opening of the first road link to Kathmandu from India in 1956. Most of the roads were constructed from donor's assistance. Now the Strategic Road Network (SRN) has reached to a length of more than 10,000 kilometers. The SRN is a fundamental contributor to the improvement of accessibility in the remote areas of Nepal and allows the development of local networks within individual districts. A considerable expansion of the local rural road network has occurred over the past 10 years with a large number of local participation.

Department of Roads is carrying out systematic network-wide surveys of traffic and road condition since 1993. The scope of these surveys has been roughness, surface distress and traffic volume. In addition to these, there is a record about the year of construction, reconstruction and resurfacing of pavements. The SDI and traffic data has been used to prioritise periodic maintenance works.

1.1. Geotechnical Environment

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. The 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.

1.2. Alignment Selection and Mass Balance

Department of Roads has developed its own design guidelines as well as specifications for the construction and maintenance of the road networks throughout the country. Good alignment selection is a crucial first step in minimising slope instability in mountain terrain. Road alignments in the high landscape tend to be more stable than alignments low down the landscape. This is because of the landslides coming down from the above and the river scours away at the base of the slope. These include the avoidable crossing of areas of large-scale slope instability and will mean that the roads are costly and barely sustainable. The Green Roads concept introduced by the German Development Agency GTZ for village-level roads (GTZ/SDC, 1999) is sound for lower order roads (labour-based construction, minimal geometry, balanced cut and fill, bio-engineering, etc), but the attempts to translate this into bigger roads have led to a number of compromises.

The approach to construction, quality of works and sources of materials are all elements where drawbacks are frequently found that can lead to both short and long term environmental damage caused by a road. The biggest damage is almost always caused by poor disposal of spoil on steep slopes, since this can extend considerable distances below a road and give rise to high sediment levels in gullies for many kilometres downstream. Management of the earthworks masses is difficult and requires very careful site supervision, but is probably the most important factor in achieving an environmentally sound road. In order to ensure good practices on site, the approach to construction must be thought through carefully beforehand, and the sequential stages worked through carefully.

1.3. Drainage Management

In the mountains, steep slopes crossed by roads 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. Drainage of the slopes adjacent to roads is critical to prevent instability. It is now clear that failure to address slope drainage can lead to large scale mass movements as a result of heavy rain storms. This type of disaster can be averted for relatively low cost if a good slope drainage system is installed. Disposal of runoff generated during storms along roads is essential to protect road surface as well as side slopes. Water in road generally comes from 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.

Groundwater seepage lead 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.

2. ROAD MAINTENANCE SYSTEM

The Department of Roads has introduced planned maintenance system since 1993. This approach makes the best use of available resources and provides a high level of management control over maintenance operations. The aim is to provide an agreed level of serviceability such that total road transport costs are kept to a minimum. Routine and recurrent maintenance consists of many different tasks frequently necessary to maintain the function of the road, such as, pothole repairs, cleaning drains, sealing cracks, cutting vegetation, etc. Periodic maintenance consists of predictable and more costly measures of a less frequent nature designed to avoid road degradation, such as, resurfacing, overlays, etc. Intelligent management, the timeliness of interventions and the adequacy of technical solutions are critical. Routine maintenance is carried out by the length worker system and Contractors are used for implementing periodic maintenance and rehabilitation of roads. Department of Roads has defined the categories of maintenance and related activities as on road and road side support maintenance.

2.1. On Road Maintenance

It is work on the carriageway, side drains and cross drainage structures. Routine Maintenance is required continually on every road as a result of environmental degradation. Recurrent Maintenance is required at varying intervals throughout the year depending mostly on the volume of traffic. Similarly, Periodic Maintenance is required at intervals of several years. Emergency Maintenance is needed to deal with emergencies for immediate action when a road is threatened or closed.

2.2. Roadside Support Maintenance

It is remedial and preventive works to improve slope stability and water management. Routine maintenance is cleaning off-road drains, repairing roadside support structures, repairing slope support structures. Preventative maintenance is trimming slopes, slope netting, masonry walls, gabion walls and revetments for slope, prop walls, check dams, river training works, bio-engineering and planting out to support slopes. Other use of bio-engineering is to improve the appearance of the slope. Emergency maintenance is covering cracks in slides and urgent protection measures such as river training works to minimise the threat of further damage to the road or its structures.

3. BIO-ENGINEERING INTERVENTIONS

Road construction causes adverse environmental consequences. The only cost effective way to protect slopes against erosion and shallow landslides is through the use of bio-engineering. Bio-engineering is the use of living plants for engineering purposes. Plants are carefully selected for the functions it can serve in protecting roadside slopes. It is usually used in combination with civil engineering structures to offer more effective solution because the materials and skills are all locally available.

- Bio-engineering is used to protect the slopes against erosion.
- Bio-engineering reduces shallow planar sliding.
- Bio-engineering is also used to improve surface drainage and reduce slumping.

Bio-engineering is most effective and economic solutions to address shallow-seated problems. The use of bio-engineering techniques may cost more in the short term but in the long term, there should be additional benefits from reduced maintenance costs.

The strength of a structure at various stages of its life can be related to its maximum strength. Figure 1 shows how this is different for bio-engineering and civil engineering structures: vegetation takes a few years to reach maximum strength. As the relative strength of civil engineering structures decrease, the relative strength of plant structures increases.

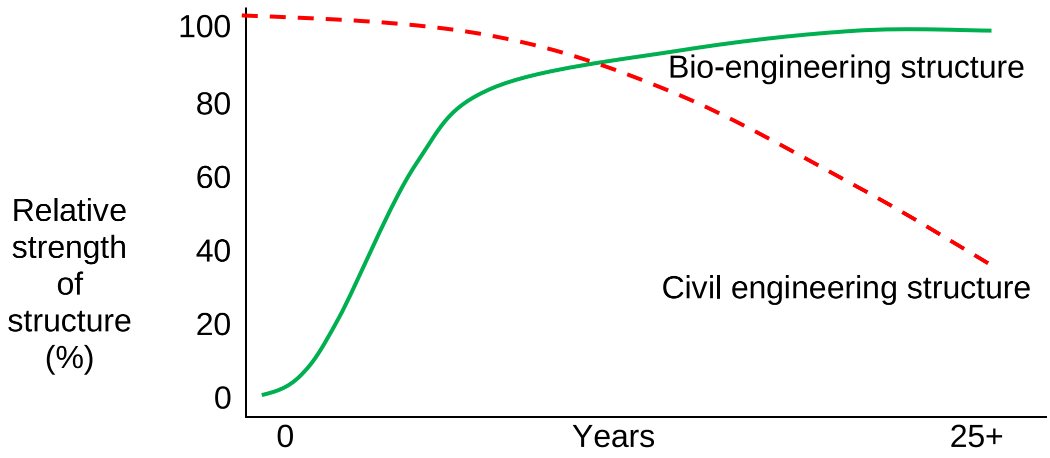

Figure 1 - Life span of small civil engineering and bio-engineering structures

This covers a range of techniques that can be combined with civil engineering structures to enhance drainage and slope stability. 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.

3.1. Selection of Bio-engineering Techniques

Selection of proper bio-engineering measures for slope stabilisation is not simple. Most landslides have more than one cause of mechanism of failure operating at different points on the slope. 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. 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. The main techniques used are summarised in Table 1.

Table 1 - Common bio-engineering techniques and structural functions

TECHNIQUES	STRUCTURAL FUNCTIONS
Horizontal grass planting	They protect the slope with their roots, provide surface cover, reduce the speed of runoff, catch debris and armour.
Vertical grass planting	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.
Diagonal grass planting	They armour the slope with their roots and by providing a surface cover. They have limited functions of catching debris and draining surface water.
Random grass planting	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	This technique is often used in conjunction with mulching and jute netting to aid establishment.
Turfing	A technique commonly used on gentle embankment slopes. Its only function is armouring.
Shrub and tree planting	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. The main engineering functions are to reinforce and, later, to anchor.
Large bamboo planting	Large bamboos can reinforce and support a slope. They can reduce movement of material and stabilise slopes.
Brush layering	They form a strong barrier, preventing the development of rills, and trap material moving down the slope. The main functions are to catch, to armour and to reinforce the slope.
Palisades	These form a strong barrier and trap material moving down the slope. The main functions are to catch, to armour and to reinforce the slope.
Live check dams	These form a strong barrier and trap material moving downwards. The main functions are to catch debris, and to armour and reinforce the gully floor.
Fascines	The bundles of live branches are laid in shallow trenches to put out roots and shoots forming a line of vegetation. The functions are to catch, to armour and to reinforce the slope.
Vegetated stone pitching	Slopes are strengthened by a combination of dry stone wall and vegetation planted in the gaps between the stones. This technique provides a very strong form of armouring.
Jute netting	▪ Protection of the surface, armouring against erosion and catching small debris; ▪ Allowing seeds to hold and germinate; ▪ Improvement of the microclimate by holding moisture and increasing infiltration; ▪ As it decays, it acts as a mulch for the vegetation established.

Emphasis has been given towards techniques which improve slope drainage, since the problems of high infiltration and low cohesion are found in the materials.The widespread prevalence of subsistence agriculture means that there is a heavy degree of reliance on all natural resources, and almost all plants provide some benefits to neighbouring cultivators. Without surface protection, erosion can be rapid and severe, affecting slopes considerable distances above and below roads.

If the environmental damage repair is taken further, then bio-engineering offers a great deal more than just protection against erosion. The right combinations of plants can help to restore agricultural systems or forests, and thereby mitigate some of the damage caused by the construction or presence of a road. As Howell (1999) showed, bio-engineering sites can be managed in such a way as to become productive plantations or parts of well managed farm units.

Figure 2 - Same site after bio-engineering combination of jute netting, brush layering and grass seeding

Bio-engineering work by fulfilling the engineering functions required for the protection and stabilisation of slopes. The plants must provide one or more functions of catching debris, armouring the surface, reinforcing the soil, anchoring the surface layer, supporting the slope or draining the material. Plants used in combination provide much greater effects than single plants (Figure 2). If a line of grasses is planted across a slope, together they form a continuous line to catch debris, and a line of reinforcement. The contour line of grass will also increase the infiltration capacity of the soil. Drainage function can be achieved using grass lines by angling the lines across the slope. It is important to ensure that the slope is armoured against erosion. Grasses are best plants to achieve this. But grasses mostly require full sunlight in which to grow; so to sustain a good cover of grasses it is necessary to keep the shrub or tree canopy as thin as possible. On the other hand, without the shrubs and trees, the deeper reinforcing and armouring functions required on many sites would not be provided.

Bio-engineering techniques developed in Nepal are simple and labour intensive. The skills required are simple as they 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.

3.2. Selection of Bio-engineering Species

The ability of a particular plant to grow in a certain site is determined by the suitability of the species to that site. Plants should become well-established in the season of planting so that they are able to survive the dry months until the next monsoon. Many bio-engineering sites have extremely poor and stony soils, which drain rapidly. The species should be robust enough to fulfil the bio-engineering function. Vegetation growth depends upon the temperature and moisture conditions for which the species is adapted. Species used for bio-engineering have a tolerance for site conditions and grow on almost any site, depending on its characteristics. Water is the main factor for plant growth in the warmer months. The use of pioneer species for bio-engineering on bare roadside slopes helps to allow a vegetation community to establish, through the development of shade and better soil. The factors contributing to the final choice of species are:

- The species that will address the specific problems for bio-engineering techniques.
- Types of appropriate propagation techniques.
- Suitable species for the environmental conditions on site.
- Performance of the required functions on site and also useful to local farmers.
- Availability of species at the right place, at the right time and in the right quantities.

Local species are generally better suited to conditions there than species from another area. This means that the choice should normally be a species found in the area where the bio-engineering is being implemented. Many of the recommended bio-engineering plants are pioneer species, which means that they are naturally adapted to grow and survive on poor sites with extremes of sunlight, heat, drought and low nutrition levels. The main points related to the establishment of stable natural vegetation are:

- Use of fast-growing species for rapid establishment.
- Establishment of a stable, easily maintained plant community.
- Development of a vegetation cover that will reduce erosion.
- Development of a canopy, shades the soil and improves rooting conditions.

Many roadside bio-engineering sites are in inhabited areas. Local farmers may be able to make use of the plants grown on the sites. Wherever possible, the choice of species should be made with the consideration that products are of potential use to local people.

4. LESSONS

Numbers of technical and institutional lessons have been learned during the bio-engineering development in the road sector of Nepal.

Followings are the technical lessons learnt during the process:

- 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.

Some institutional lessons have been learned. 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.

5. CONCLUSIONS

A large number of factors contribute to make a road sustainable. Making a road environmentally sound also depends on good initial planning. Carefully aligned roads have fewer areas of instability and require less maintenance in the longer term. 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. From the experience of road maintenance in Nepal, it is clear that 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. Attempts to save money in maintenance may lead to more costly results because of the damage that is caused and the need for more costly additional engineering works. The use of bio-engineering has improved the roadside environment reducing maintenance costs and has also shown to be reliable and cost effective for slope protection and landslide management in the road sector of Nepal.

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