Development of bioengineering strategies in rural mountain areas

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Abstract Rural mountain areas in the moist tropical and subtropical zones tend to be prone to high erosion risks; to be areas where population expansion and development place high demands on the land; and to lack the very high levels of finances required to develop infrastructure with maximum safety. Bioengineering technology offers such areas a cost effective means of surface erosion control in many situations. But this depends on a systematic and careful assessment of the processes involved. A straight transfer of European and North American techniques is not acceptable. An outline appraisal of the principles involved in the practical establishment of a bioengineering programme is provided. These allow for the development of a responsive and site specific arrangement which makes full use of both established technical information, and indigenous and local resources. A number of examples from East Nepal are used.

INTRODUCTION

Mountain environments which lie within the moist tropical and subtropical zones are exposed to considerable forces of natural and accelerated erosion processes. These are exacerbated by:

- rapid, deep soil weathering under hot, moist conditions;
- high erosivity of tropical and monsoonal rainfall, as a function of intensity, timing and duration;
- tectonic movement and orogenic processes: these result in active down-cutting of river valleys, over-steepening of slopes and high rates of natural slope instability.

Increasing demands on mountain environments to provide resources to meet the requirements of rapidly growing populations (for example, the population of Southeast Asia has doubled in the last 30 years: IUCN, 1992) are placing pressure on the natural systems of surface protection. The removal of forest for the expansion of agricultural land or exploitation of timber resources

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can significantly alter the hydrology of steep slopes and remove the reinforcing effect which live tree roots can exert on the stability of slopes. Changes in land use have been shown to be correlated with increased incidences of slope failure (Gray, 1978).

Further observation and research into the effect of vegetation on slope stability and surface protection has found that the processes of interception of rainfall by the vegetation canopy, evapotranspiration from the vegetation, change in infiltration rates under vegetation and soil root reinforcement can all affect the stability of slopes (Gray & Leiser, 1982; Coppin & Richards, 1990). Depending on the particular environment these influences can be beneficial or adverse to slope stability. The effects of vegetation on the stability of the slope are shown in Fig. 1.

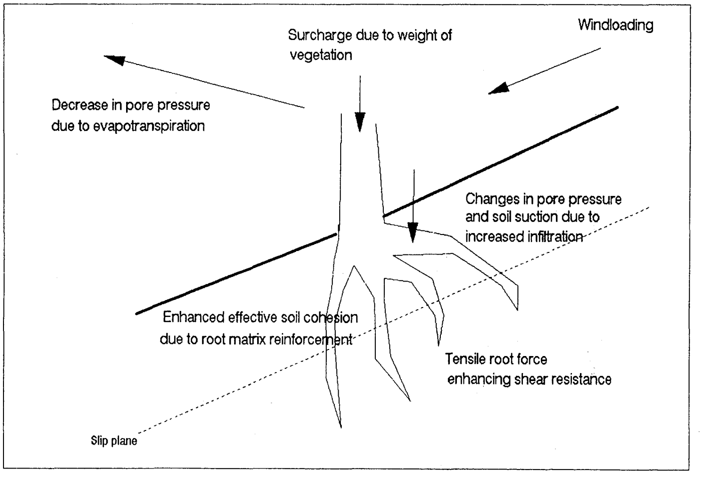

Fig. 1 The effects of vegetation on the stability of a slope.

The disturbance of fragile mountain environments through the construction of roads has all too frequently led to an increase in accelerated erosion, slope instability and in extreme cases, to downstream problems of increased sedimentation (National Planning Commission, 1988). The modification of slopes and their natural protection is acceptable only if adequate measures are taken to ensure that damage is minimized.

Engineering strategies which include the construction of costly civil engineering works for the prevention and repair of slope damage have come under criticism, especially in the more extreme environments of remote tropical steep lands. The application of engineering solutions, designed for the less physically demanding, resource rich conditions of Western Europe or North America, to more exacting conditions within the tropics can have drawbacks. Some of these are as follows:

- retaining structures, surface drains and other features which concentrate water such as cascades require rigorous maintenance; without this they in themselves can become a hazard;

- high quality structural designs may be beyond the scope of construction and maintenance budgets of less wealthy regions;
- engineering skills required for design, supervision and construction are often in short supply in remote areas;
- in poor mountain areas lack of information on materials and their behaviour have led to the over design of structures to meet an unknown factor of safety: in such areas risk minimization may be an adequate strategy;
- it appears that problems of erosion associated with construction are often more severe than is appreciated by foreign donor agencies, expatriate staff unfamiliar with local conditions and inexperienced nationals; rigid structures have not proved as successful at long term improvement of the problem as expected.

Lack of documentation and understanding of alternative measures of slope stabilization have led to the continued use of engineering structures and solutions to tackle the problems of slope stability and soil erosion associated with engineering projects. With the growing interest in the protection of the environment and a more holistic approach to environment and development emerging in more forward-thinking organizations, there is a revival in the use of vegetation for the protection and rehabilitation of damaged slopes.

THE ROLE OF BIOENGINEERING

Bioengineering is the designed use of grasses, shrubs and trees to improve and protect the land. The hydrological and mechanical effects of the plant community are used to fulfil an engineering function. In terms of slope stability and protection, the beneficial effects of vegetation on slope stabilization are recognized and maximized to create an increase in the factor of safety of the slope. Vegetation can be used alone or in conjunction with engineering structures, in which case it can be termed biotechnical engineering.

Many mountainous areas within the tropics have advantages in the application of bioengineering technology through resources such as:

- abundant labour;
- empathy of the majority of the population with agricultural work;
- great diversity of indigenous plants which are well adapted to the harsh site conditions and from which suitable bioengineering material can be selected.

Bioengineering has limitations in that it cannot affect the stability of the slope beyond the rooting depth. Frequently this is effectively limited to 1 m. Claims are often made for deep rooting depths of trees, bamboos and grasses. These should be treated with care as quoted figures tend to be exceptions rather than the rule. The effects of vegetation on a slope are also site specific and it is inappropriate to make generalizations which may generate false optimism on what can be achieved.

However, what bioengineering does offer is a highly cost effective way of ensuring the stability of the slope surface. Many major erosion features develop from the coalescence of a number of small failures. In this situation control of small failures prevents the development of much larger and more complex problems.

To date there are few publications which refer to bioengineering techniques specifically for, and based on experience in, mountain areas in less developed countries. The only two known in the English language are both from Nepal, namely, Meyer (1987) and Howell *et al.* (1991). Shrestha (1991) and Clark (in preparation), have studied the application of bioengineering to the eastern Himalayas. There have been some papers written on specific topics but these do not form a practicably accessible body of information. There is also a certain amount of "grey literature" (project reports, internal cyclostyled manuals, etc.) but this is rarely available for wider consumption. A number of manuals written and published for use in less developed countries have drawn heavily on European experiences and techniques. These include GTZ (1976), ITECO (1990) and FAO (1985). The World Bank publication on vetiver grass (The World Bank, 1990) made grandiose claims for the capability of vetiver to stabilize streams in the Himalayan Siwaliks which take no account of the severity of the erosion process or the mechanism of erosion in the lower Himalaya. Exaggerated claims such as these do nothing to further the cause of bioengineering and are in danger of creating a lack of confidence in vegetative methods through continual failures of prescribed techniques.

PRINCIPLES OF BIOENGINEERING

The nature of bioengineering and its empathy and response to local conditions requires that each area or project be assessed individually. A bioengineering solution cannot simply be transferred from one geo-ecosystem to the next. This means that rather than transferring techniques, what should be transferred from area to area are the principles which an engineer should follow in order to develop a bioengineering strategy applicable to the conditions where he/she is working.

Figure 2 shows a basic flow chart of the components under consideration in the design of a bioengineering programme. The flow diagram has divided the main tasks into three categories: site considerations; vegetation considerations; and organizational aspects. Each of these is considered below.

Definition of the area of interest

This amounts to the determination of boundaries within which erosion control is to be attempted. This may include watersheds or single slopes, or it may be confined to slope segments or even local failures. In mountain areas the

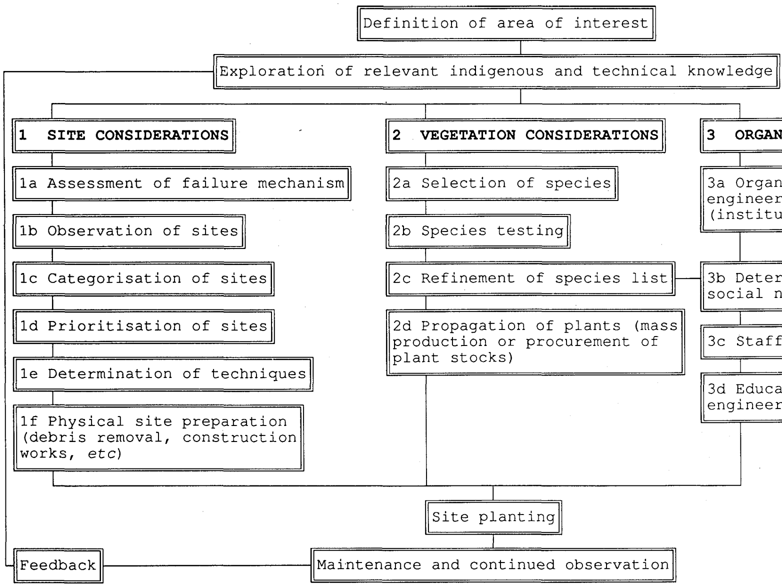

Fig. 2 Basic flow chart showing the main components under consideration in the design of a bioengineering programme.

complex linkages between activities on a slope profile may demand that control of erosion from a road line or an irrigation canal requires an integral slope approach.

Exploration of relevant indigenous and technical knowledge

In beginning any new work it is logical to review the existing information, as it has been accumulated by previous workers. This should take the form of a normal search of the literature, but in this context must also make maximum use of informal local knowledge. With regard to site conditions and available plant species, major sources of information lie with local farmers in anecdotal form.

Site considerations

Assessment of failure mechanism Assessment of the modes of failure in surface or deep seated erosion is the fundamental starting point for all design of erosion control measures. Unfortunately, this is often overlooked. Frequently, assumptions are made as to the mode of failure which lead to inappropriate techniques being applied.

For example, on many of the disturbed sites adjacent to roads in Nepal the infiltration rates are very high; they can be higher than even the most intense rainfall (Clark, in preparation). Under such conditions surface erosion will not be the main erosion process as rainfall will infiltrate the slope rather than create surface runoff. Failure by saturation at the surface, resulting in loss of strength, may be the most frequent failure process. The application of techniques designed to increase infiltration e.g. grass contour strips, will therefore be misplaced. Further, a site may demonstrate several different erosion processes: this would indicate the need for more than one treatment method.

Observation of sites This requires a long term approach during which the engineer will gain an appreciation of erosion processes on any site. Observation during rainfall is essential to develop an understanding of the processes. This may have to be supplemented with basic experimentation and collection of data on soil strength and permeability. Time lapse photography can help in maintaining records of specific sites and recording the scale of movement and damage over time.

Categorization of sites The cataloguing of all places where erosion and instability is of concern is essential if a systematic approach to erosion control is to be used. This should incorporate a basic classification which highlights the modes of failure and provides a basis for operational planning.

Prioritization of sites Some form of prioritization of sites is required, in order to work out which sites require treatment first. On areas of instability this has to take into account the cycle of erosion which occurs naturally as a landslide or gully goes through phases of active erosion and approaches natural stability or quiescence. Treatment of a site too early in this cycle can be wasteful as vegetation treatments require a certain amount of stability in order to become established. Prioritization also has to take risk into account. Where continued erosion in a specific site threatens to damage some form of infrastructure, a higher priority would be considered.

Determination of techniques A considerable amount of literature is now available which documents techniques which have been applied in Europe and North America (Scheichtl, 1980; Gray & Lieser, 1982; Coppin & Richards, 1990). Straight application of techniques designed for temperate conditions to tropical environments without due consideration for their function can have adverse effects on slope stability. Prior to the selection of any technique, consideration has to be given to the engineering function which the technique is expected to perform. Figure 3 illustrates a method of technique selection used on the Dharan Dhankuta road (Nepal).

Physical site preparation work Before bioengineering works can be commenced on any site, it is necessary to complete physical preparations. These may amount to the removal of dangerously unstable material or loose debris. For example, the heads of landslides frequently require trimming to

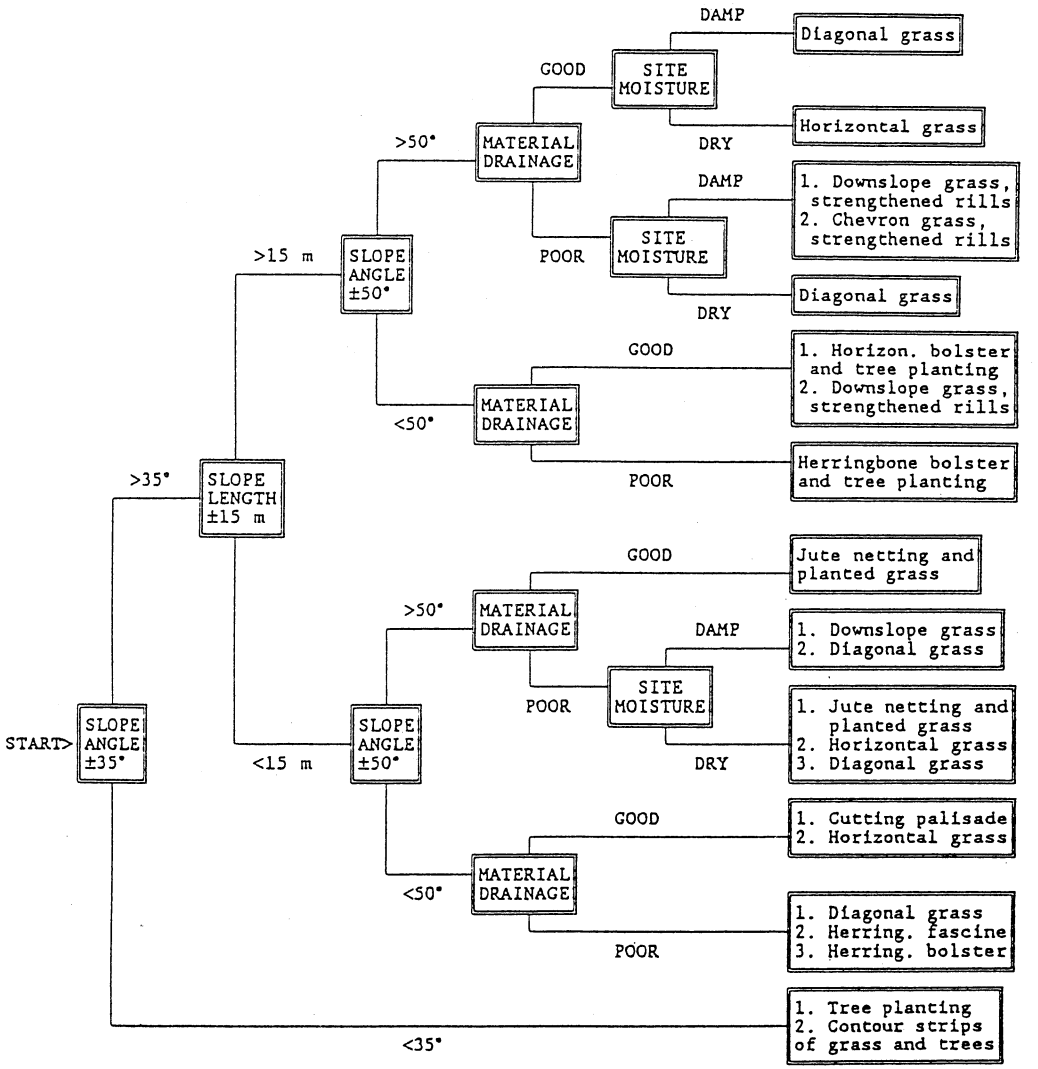

Fig. 3 Determination of techniques used according to site properties (from Howell *et al.*, 1991). "Material drainage" is an estimation of internal porosity; "site moisture" refers to the climatic site variables and the amount of rainfall likely to be received. "Bolsters" are tubes of small mesh gabion wire filled with stones and placed immediately below the surface, designed as a stronger alternative to wattle fences.

remove overhangs and to obtain a stable, rounded profile. In many cases the construction of complementary engineering works such as gabion or dry stone toe walls is also an essential prerequisite to planting. Modification of site conditions using techniques such as topsoil importation is not recommended on slopes steeper than 30 degrees: it is better to select a species which is adapted naturally to the site (Howell *et al.*, 1991).

Vegetation considerations

Selection of species The actual species selected for use in any bioengineering programme is of paramount importance. Slopes left unmanaged would recolonize with pioneer vegetation. In order to justify the cost of production and planting, managed systems have to enhance slope stability to a greater extent than the natural vegetation development on any site. The site conditions themselves offer the first limitations to the species of vegetation which will grow. A survey of vegetation growing in the surrounding area will provide a preliminary list. This should aim to include trees, shrubs, herbs and grasses. Considerable emphasis should be placed on the use of indigenous vegetation. Attempts to introduce universally applicable species have not been as successful as may have been supposed. For example vetiver grass, despite having a wide site tolerance, rarely performs well on degraded sites.

Species testing and refinement of species list A refinement of the initial plant list is essential. This will comprise critical evaluation of the vegetation on site. Detailed site records can help in this evaluation which would include survival rates and the rates and characteristics of growth of plant roots and canopies. Further applied research should be undertaken into the characteristics of both the rooting system and the canopy, aiming to quantify the effects which different species can have on slope stability parameters. Work carried out on the Dharan Dhankuta road (Clark, in preparation) has demonstrated considerable differences in the soil root reinforcement effect of different species of grasses and the way in which they interact with different soil types. Root soil adhesion qualities are shown to be important characteristics. The effect of plant canopies can be assessed by measuring interception under natural or simulated rainfall. This can yield much valuable information on the hydrological effects of vegetation on slope conditions.

Local farmers should be consulted before any plant is used on a large scale as it may have adverse properties which would not be acceptable to the farming community. Although a plant may have many acceptable bioengineering properties it may have a tendency to become a weed in fields adjacent to erosion control sites. For example *Lantana camara* has become a weed which is difficult to eradicate in much of the Indian sub continent.

Propagation of planting material Vegetation selected should have the capability of being multiplied efficiently to produce the large numbers of plants required for a planting programme. Details should be collected on propagation methods, seed collection times, storage and germination. Plant propagation is most commonly carried out in nurseries. In mountainous areas, it is often best to arrange a series of small nurseries to produce plants specifically for planting in the neighbouring sites. This strategy has secondary advantages such as the reduction of disease risk and the spreading of awareness of the programme among local people.

Organizational aspects

The organizational capacity required to implement a bioengineering programme should not be underestimated. The timely production of inputs is crucial to success. Adequate amounts and quality of planting materials must be available at the right times.

Organization of bioengineering system Organizational aspects of a bioengineering programme have to be addressed early in the planning stage of the programme. This should take into account the provision of staff, support and equipment necessary for the management of the programme and provision for maintenance of sites in the future. Long term institutional arrangements should be considered early in the programme to ensure sustained management.

Determination of social needs In predominantly rural areas where erosion control and slope stabilization work is being carried out adjacent to agricultural land, it is important to consider the interactions between agricultural land and the site. An approach alien to the engineering sector but known in forestry and natural resource management, that of community participation, must be considered. In regions where financial resources for the repair and maintenance of road side slopes are limited, local populations can be employed or encouraged to participate in their management for the mutual benefit of both farmer and engineer. The use of bioengineering techniques is especially suited to community or individual participation. Steep slopes can be used to produce species of plants which are both useful to the engineer and which can provide the farmer with a resource such as fodder or thatch grass.

Staff training There is a wide difference between the skills required by bioengineers and those used in standard engineering. It is necessary to build a team of trained staff who have the correct technical and professional backgrounds and yet who have an appreciation of engineering. It is unlikely that specialist training courses will be available, so it is necessary to incorporate a certain amount of in-service training for personnel who are qualified in forestry or agriculture. In a multidisciplinary project, the status of bioengineering staff must be equivalent to that of engineering staff for comparable tasks, through the use of a single employment structure.

Education of civil engineers In many situations, long term institutionalization of bioengineering depends at least partly on the uptake of its technology by the mainstream engineering establishment. It is therefore necessary to educate professional engineers to the effect that the techniques offer more than just an aesthetic "greening" of slopes beside structures. Considered use of vegetation can offer a significant contribution to slope stabilization under certain circumstances. In many countries, the bioengineering component of a project is delegated to a civil engineer who is expected to oversee work in addition to other duties. As a result of the lack of understanding of the complexity of the task it is frequently not carried out with the due consideration necessary to ensure success. Increasing the awareness as to what is involved in the establishment of a bioengineering component may help to redress this error. The creation of a cadre of specially trained bioengineers available to offer advice would provide a source of information.

Site planting

This forms the climax of all the foregoing planning and careful preparation. The actual planting of a site has to be seen as an operation requiring at least as much site investigation and planning as an engineered construction. Care in the execution of all planting operations and attention to detail in the thorough and appropriate treatment of all sites is often the most critical part of the entire programme.

Maintenance and continued observation No bioengineering system can be fully predictable due to the uncertainties of plant establishment. In this respect there is a major contrast with civil engineering practice. A bioengineering structure may take more time and care to establish. However, once established it will become stronger over time. To ensure successful establishment and continued development of the site, regular monitoring and maintenance are essential: this is the same as for standard engineering structures. A critical evaluation of the success of techniques provides valuable feedback for future design improvements.

CONCLUSIONS

As development of tropical and subtropical steeplands continues, the need to protect these areas from the adverse consequences of development grows. The problems of soil erosion control and slope stability demands solutions which are designed with specific consideration for the failure mechanisms and for the local conditions. The adoption of heavy engineering structures may be both beyond the scope of maintenance budgets for rural areas and in many cases may not be the most cost effective solution. The revival of interest in more environmentally sympathetic techniques of bioengineering may have much to offer mountain environments. However, it is important that in order to be effective, techniques should be designed and built with particular regard for the environment in which they are being implemented. Therefore, rather than the direct transfer of techniques more important is the adoption of the principles of bioengineering which will help the engineer to design suitable techniques.

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