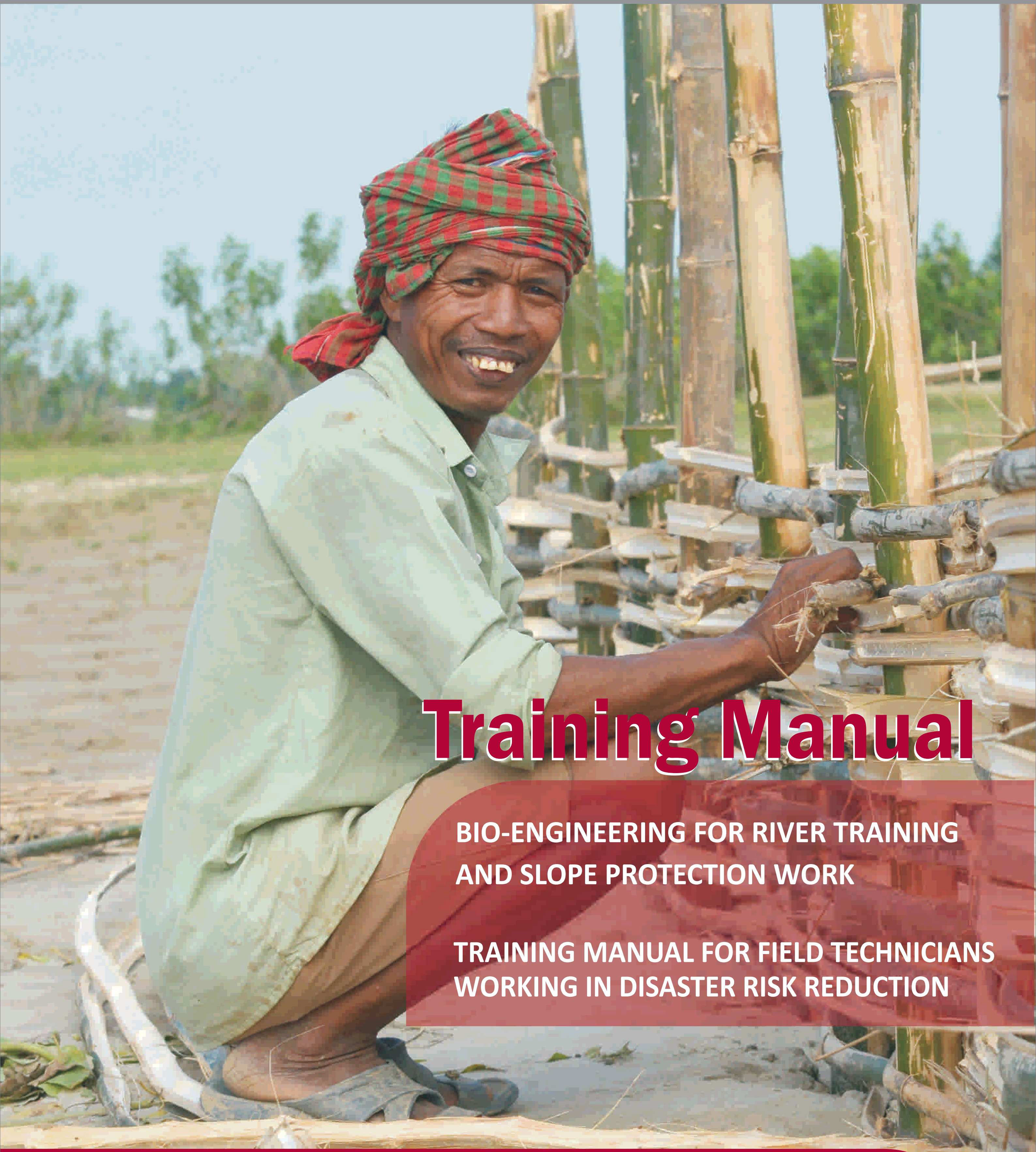

Training Manual

BIO-ENGINEERING FOR RIVER TRAINING AND SLOPE PROTECTION WORK

TRAINING MANUAL FOR FIELD TECHNICIANS WORKING IN DISASTER RISK REDUCTION

USAID
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Federation of Community Forestry Users, Nepal (FECOFUN)

TRUST FOR NATURE CONSERVATION NATIONAL NEPAL, 1982

MercyCorps

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FORWARD

With this training manual – “Bioengineering for River Training and Slope Protection Works: Training Course for Field Technicians Working in Disaster Reduction Project Areas” – Mercy Corps hopes to present a technically detailed overview of the practice of bioengineering in both theory and practice, focusing more on the needs of the skilled and semi-skilled practitioner, since you are the ones working to protect productive land, households, prevent destruction and save lives. This manual seeks to provide you with the background, thinking and the practical tools you will need to assess, analyze, design, implement and evaluate sound bioengineering infrastructure in areas of high risk of landslides, riverbank cutting and, to an extent, flooding.

The manual seeks to present a best-case scenario, while also realizing that every situation is different and complex in its own way, very often requiring difficult decision-making on the part of the practitioner as to whether one shouldinvest in longer-term, more comprehensive sub-basin or basin-oriented interventions or if one should instead implement more immediate short-term life or property saving interventions. This question is, unfortunately, often partially answered by limitations of budget, donor priorities, limitations of local or national government and capacity of the implementing organization, as well as 'moral' priorities of immediate need. However, the practitioner must be aware of that trade off between the short-term and the long-term and answer her/his own questions honestly, transparently and together with the community at risk.

This manual does not attempt to present, nor does Mercy Corps support, the idea of bioengineering as a panacea, of being able to address all situations of riverbank erosion or landslide risk. We instead consider bioengineering as one tool – a very effective and cost effective tool – in a wider collection of hardware and software approaches, techniques and solutions. We have found many situations in which bioengineering, when properly assessed, designed and implemented, has been the best and sole solution to serious risks to communities' safety, property, lives, livelihoods and productive agricultural land. We have also found many situations in which bioengineering is only part of the solution in considered combination with larger scale, more expensive check dams, gabion walls and other infrastructure, and cases in which bioengineering is inappropriate and insufficient. We are also keenly aware that badly assessed, designed or implemented bioengineering infrastructure (typically carried out with only a superficial knowledge or understanding of what bioengineering is) can lead to yet greater disaster risk, a false sense of community security and ultimate loss and disappointment on the part of affected communities. Bioengineering is not a simple matter of establishing bamboo baskets and establishing plants along a riverbank, but is rather a serious consideration of water flow, speed, impact points, variability of water levels, soil type, local plant varieties and root systems, community capacity and sociological context, contextual analysis, market or livelihood assessments, land ownership and much more.

Mercy Corps began the practice of landslide mitigation bioengineering in hilly areas of Nepal's Far Western Development Region with some good degree of success. When programs shifted to the more riverine areas, we were faced with the challenge of adapting that learning to the challenge of riverbank erosion. Working with communities, local government officials, technical experts and our own engineering teams, we were able to iterate and develop a model that we believe is workable, affordable, effective and innovative. We continue to iterate on our model with greater efforts toward local government and community capacity building, integration of disaster risk reduction activities like flood early warning systemestablishment and the direct causal in-building of economic development (as opposed to more limited income generation or livelihood enhancement) and fully intend to share our findings and best learning experiences as open source, hoping other organizations and DRR actors can build and improve upon our findings.

We see this manual as a technical introduction, which cannot hope to be comprehensive to include all conditions for all situations faced across Nepal. Feedback from readers, practitioners and others are very welcome.

We hope this manual will be useful, educational, illuminating and challenging, spurring more interest in our bioengineering approach, tempered with a caution against overenthusiasm for it as The Solution.

Jeffrey Shannon,
Director of Programs
Mercy Corps Nepal
November 2014

Content

MercyCorps, Nepal

.......................................Project

A ONE - WEEK TRAINING ON BIO-ENGINEERING
FOR
ENGINEERING TECHNICIANS

...................., ...2014

OPENING CEREMONY

8.30	Welcoming remarks	Mr/Mrs............................. Manager, ... Project.
8.35	Introduction	
9.05	Introduction to the Training Program	Mr/Mrs..........................., Manager, ... Project.
9.10	Comments on Participants' expectations	Mr/Mrs.................................... ...., ...Project
9.15	Opening remarks	Mr/Mrs.................................... ...., ...Project
9.25	Vote of thanks	Mr/Mrs.................................... ...., ...Project
9.30	Refreshments	

Introduction to the course

2.1 Rationale

A geographically diverse nation, Nepal consists of 3913 Village Development Committees and 58 Municipalities; most of which are rural in character. More than 80% of the population of Nepal depends on agriculture and development is impossible without infrastructure development.

Sustainability of development efforts is a burning issue in Nepal. The result of any project depends on its sustainability. The knowledge and skills acquired abroad may not always be applicable in the context of Nepal. Context-specific methodologies and procedures must be established to achieve the development goal. Keeping this in mind, the project will train its manpower according to the needs.

Bioengineering is not a new concept for Nepal. It has been applied to roadside slope stabilization and also practiced by farmers. In recent times, bioengineering has been extensively used to control erosion and reduce shallow seated instabilities on slopes. Most roads related bioengineering is carried out by Road Projects. Mercy Corps Nepal is also extensively using bioengineering for riverbank erosion control and hill slope stabilization. As a result, there is a need for engineers with a sound understanding and knowledge of bioengineering.

2.2 The aim of this course:

The Course aims to provide knowledge in the following areas:

- geological and geomorphological context of slope instability.
- causes and mechanisms of slope failure and its mapping.
- engineering functions of bioengineering systems.
- designing small civil engineering and vegetative engineering structures for the protection of slopes.
- plant selection for bioengineering purposes.
- the basic aspect of plant nurseries.
- the organization and planning of civil engineering and bioengineering works.
- the programming and cost estimation of bioengineering works.

Although these aims and objectives are described as a series of individual items, you will be able to integrate them in order to satisfy the general purposes of the course.

One-Week Training Course in Bioengineering
For
Site technicians of Disaster Risk Reduction program under Mercy Corps, Nepal
Time Schedule

Day	08:30-09:30	09:40-10:40	11:40-12:00	12:00-13:00	13:00-14:00	14:00-15:10	15:30-16:30
1	Opening ceremony 1	Introduction to course 2	Introduction to bio-engineering 3		Hill slope processes and Landforms 4	Rainfall and water movement 5	Slope and slope materials 6
2	Causes and mechanism of failure 7	Slope instabilities 8	Instability mapping techniques 9		Field work on instability mapping 10		
3	Small scale civil engineering structures 11		Drainage and gully protection work 12		Field work on small scale civil engineering structures 13		
4	Vegetative engineering structures 14		Compatibility of structures 15		Field work on vegetative engineering structures 16		
5	Selection of bioengineering plant species 17		Maintenance of vegetative system 18		Field work on maintenance task and plant type selection 19		
6	Estimating and costing 20	Programming work 21	Monitoring and quality control 22		Exercise on rate analysis, preparation of cost estimate and programming 23		
7	Introduction to nursery 24		Preparation for presentation 25		Presentation and evaluation 26		Closing ceremony 27

2.3 Bioengineering training for engineering technicians

2.3.1 Pre-training course questionnaire

1 Your current post

(a) Name of your organization:

(b) What is the title of your post ? Years

(c) How long have you been in this post ? Years

2. Your work experience of bioengineering

(a)	Have you seen bioengineering works?	Yes	No
(b)	Have you inspected bioengineering works?	Yes	No
(c)	Have you planned any bioengineering works?	Yes	No
(d)	Have you implemented any bioengineering works?	Yes	No
(e)	Are you currently doing any work related to bioengineering	Yes	No

3. Briefly say what you understand by bioengineering.

4. Your qualifications

What qualification do you hold?

subject

5. What do you hope to get out of this course?

2.4 Safety

It is a general principle that everyone is responsible for their own safety as well as that of others. We all want to complete this training entirely unharmed. This means we must all work to produce as safe a working environment as possible.

Most of the sites can be examined off-road. When you work on road, you must take particular care especially around bends and to watch out for traffic.

As we are looking at slope stabilization, most of the slopes that we examine are unstable even though they may appear stable.

You will also be undertaking practical work which, at times, will involve using sharp tools. Please take care when using them.

The following rules should help you and your colleagues work safely:

During site visits:

- Make sure you are suitably dressed;
- Ascend and descend slopes slowly and with care, even if they look stable;
- Never work directly above or below other people;
- Watch out for traffic when working on the road or walking to a site.

During practical exercises:

- Take care when using sharp tools or sharp edged material;
- Use precaution when you are in close contact with someone else.

The trainers will have a small first aid kit for use if anybody is injured.

If you have a medical problem, inform the trainers so that it can be attended to adequately. If necessary, transport will be arranged for you to receive medical attention.

Introduction to bioengineering

Nepal is prone to natural as well as human-induced hazards. Each year, several hundred lives and properties worth millions of dollars are lost and the soil ecosystem also gets disturbed. Earthquake, landslide, debris flow, glacier lake outburst flood (GLOF), avalanche, and cloud burst take a toll on lives and property in the mountains and sudden flooding in the Terai. When such hazards occur, bridges, roads and power lines located in the mountainous regions are destroyed. At the same time, landslides and debris flows destroy fertile fields and houses and also add to the sediment load in the river, which in turn washes away the paddy fields located along the bank of rivers in mountain areas. In the Terai, many paddy fields are either eroded or submerged by floodwater.

In this context, it is a big challenge for engineers to solve the problems of erosion and slope stability. It is too costly to construct heavy structures and use high technology to solve problems. The experiences of the past several years have shown that such types of problems can be solved by using low cost technology in combination with vegetative measures. For the purpose of reducing the shallow-seated instability and controlling erosion on slopes of any watershed, the use of living plants either alone or in conjunction with small-scale civil engineering structures, or non-living plant materials, is known as Bioengineering. It is not a new technique in Nepal. Similar indigenous methods have been in practice for centuries.

3.1 Scope of bioengineering

Bioengineering can be applied in different fields like slope stabilization on embankments and cut slopes, erosion control, water course and shoreline protection, wind erosion control, noise reduction, traffic control, mining and reclamation, construction sites, waste disposal and public health, reservoirs and dams, buildings, highways, railways etc.

3.2 Function of bioengineering system

Any structure is constructed to fulfil special functions whether engineering or otherwise. Generally, these structures are used for the fulfilment of the following six engineering functions.

3.2.1 Catch function

Loose materials have the tendency of rolling down the slope because of gravity as well as erosion. This tendency can be controlled by constructing any structure, which could catch the rolling-down materials.

3.2.2 Armour function

Some slopes are very water sensitive: they start moving or are liquefied easily when they encounter water. Or, there may be the case of a high rate of infiltration, which later, causes shear failure. Therefore, such types of slope should be covered so that water can be diverted easily.

3.2.3 Reinforce function

The soil may not be compacted due to the presence of voids, and it may need bonding of the grains for reinforcement.

3.2.4 Support function

On slopes longer than 15m, the lateral earth pressure causes the lateral and outside movement of the slope material. This tendency can be controlled by constructing any retaining types of support structure.

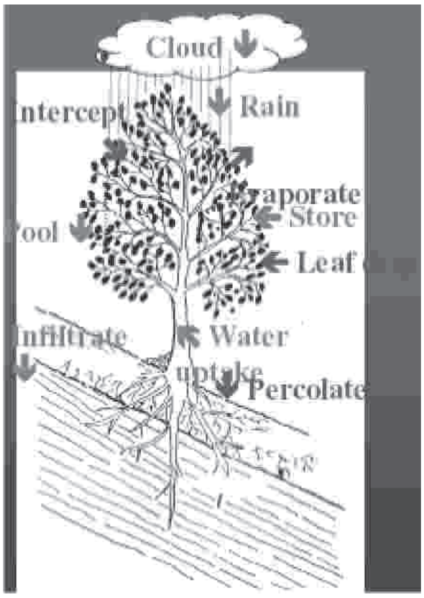
3.2.5 Anchor function

If there is the case of failure of overlying layers with respect to stable underlying strata, the upper strata can be pinned up with the underlying ones.

3.2.6 Drain function

Water is the main problem leading to instabilities on slopes. It could be either surface water or ground water. Therefore, water should be diverted safely from slopes.

3.3 Hydrological function



Besides the mechanical functions, plants perform hydrological functions as well. Leaves intercept raindrops before they hit the ground. Water evaporates from the leaf surface. It is stored in the canopy and stems. And the large or localized water droplets fall from the leaves. Similarly surface runoff is checked by stems and grass leaves. Stems and roots increase the roughness of the ground surface and the permeability of the soil and roots extract moisture from the soil, which is then released to the atmosphere through transpiration. From the study, it has been found that soil erosion is reduced significantly with the percentage of canopy cover. Basically, it depends upon the height of the plant, sizes of the leaves and the percentage of the canopy cover. When the leaves of the plants are big, it adversely affects the soil loss from the slope. Hence the plants with the small leaves are preferred in the bio-engineering works.

3.4 Criteria for the use of bioengineering

Criteria	Application
• Reducing instability and erosion	• By observation in the field.
• Increasing the slope's factor of safety	• By measurement in the field.
• Physical flexibility	• By observation in the field.
• Versatility in application	• By observation of a range of applications in the field.
•Only solving some problems	• This may be difficult to evaluate.
• Cost-effectiveness	• By cost comparison.
• Environmentally advantageous	• By observation and comparison of sites in the field.
• Socially advantageous	• By discussion with road corridor inhabitants and extension groups.

There is a major problem in which we cannot easily quantify the benefits of bioengineering.

Geomorphology and landforms

4.1 Geomorphology

Geomorphology studies the outer surface of the earth (*Geo* means the earth and *Morphos* means the shape). It studies the shapes of mountains, plateaux, rivers, glaciers, and also smaller features like landslides, fans, terraces, gullies, and streams.

4.2 Landform Classification of the Himalayas

The major landforms of the Himalayas are described below:

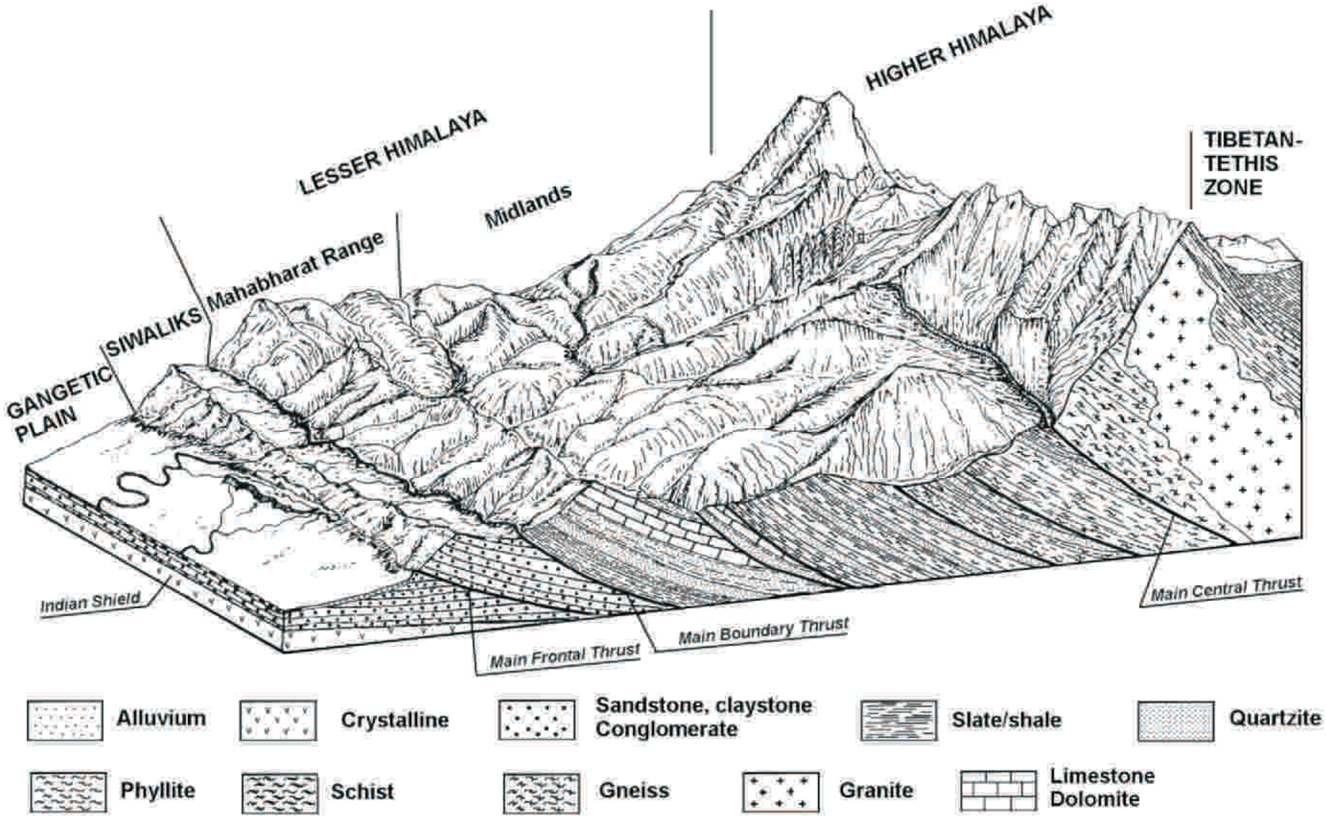


Fig 4.1: Block diagram of Himalaya showing main landforms and rock units

4.2.1 Gangetic plain (terai)

The terai plain lies to the south of the Himalayan Mountain Range. It is made up of sand, silt, and clay. The northern border of the *Terai Plain* consists of boulders and pebbles, and it is called the Bhabar Zone.

The *Terai Plain* is very gentle (slope is less than 2 degrees). The altitude of the *Terai Plain* is less than 150 m. Rivers meander on the *Terai Plain* and deposit sediments.

4.2.2 Siwaliks (chure or churia hills) The Siwaliks are the first foothills lying immediately north of the Terai Plain. The Siwalik rocks are very soft. They are represented by mudstone, soft sandstone, and conglomerate. Shallow slides and alluvial fans are found in the Siwaliks. There are many dun valleys within the Siwaliks. The Siwalik Hills range in altitude from 500m to 1,000m.

4.2.3 Lesser himalaya (Lower himalaya)
The Lesser Himalayan rocks lie to the north of the Siwaliks. This zone is further subdivided into the Mahabharat Range and the Midlands.

4.2.4 Mahabharat range
The Mahabharat Range lies north of the Siwaliks. It is made up of stronger rocks such as limestone, quartzite, dolomite, and schist. The Mahabharat Range is very active with many landslides. As the Mahabharat Range is actively rising, the rivers make gorges and have steep to vertical banks. The altitude of the Mahabharat Range varies from 1,000m to 2,000m.

4.2.5 Midlands
Midlands are situated between the Mahabharat Range in the south and the Higher Himalayas in the North. The topography of the Midlands is strongly dissected by many streams and rivers. There are old river terraces and thick residual soils. The altitude of the Midlands ranges from 700m to 1,500m.

4.2.6 Higher Himalaya
The Higher Himalaya includes the snow peaks and the mountains surrounding them. There are many glaciers, large rockslides, and talus deposits. The Higher Himalaya is made up of such rocks as schist, quartzite, a gneisses, and granites. They have rugged topography with altitudes ranging from 1,500m to 8,000m and more.

4.2.7 Tibetan-Tethys zone (Trans Himalaya)
The area north of the Higher Himalaya is called the Trans Himalaya. Many soil slides, debris flows, and talus deposits characterize the area. It is made up of soft sedimentary rocks and its altitude ranges from 2,500m to 5,000m.

4.3 Landform classification
The following small-scale landforms are observed in a watershed.

4.3.1 Geological plane
Term utilized for any more or less plane discontinuity or set of discontinuities cutting a body of rocks: bedding, foliation, fractures, joints, cracks and faults.

4.3.2 Dip slopes and counter dip slopes
The gentle slope of the mountain parallel to the dip of the geological plane is called the dip slope whereas the slope on the opposite direction to the dip is called the counter dip slope. The counter dip slope is always steeper than the dip slope and is formed by joints (see figure below).

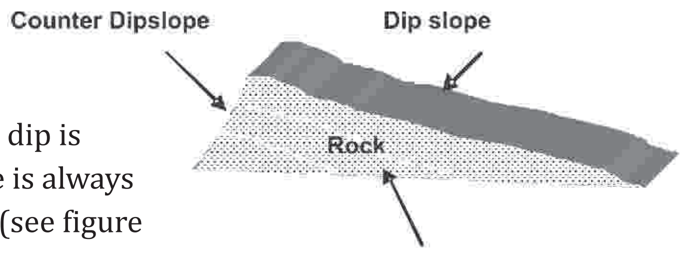


Fig 4.2: Dip slope and counter dip slopes

4.3.3 Landslide
It is the term used for the downward and outward movement of rock or soil mass.

4.3.4 Talus deposits or talus cones
Talus deposits are loose rock fragments deposited at the bottom of a steep slope. The main agent is gravity.

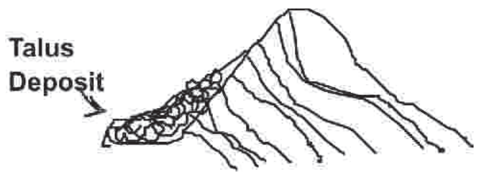


Fig 4.3: Talus deposits

4.3.5 Colluvial soils

Colluvial soils are angular in shape and area the disintegration product of the rock due to gravity (landslides) and running water.

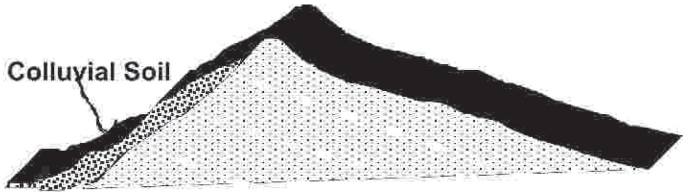


Fig 4.4: Colluvial soil

4.3.6 Alluvial soils and river terraces

The river deposits are called the alluvial soils. Generally the soil contains rounded pebbles and cobbles together with sand and silt. The terraces are relatively flat and horizontal or gently inclined, and sometimes long and narrow. Steeper ascending and descending slopes on each side bound them. In the Himalayas, the deposits form various levels called the river terraces. In this case, the older terraces are at a higher altitude and the younger terraces are in a lower portion.

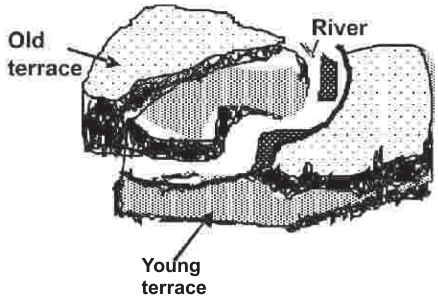


Fig 4.5: River terraces

4.3.7 Alluvial fans

When a river, stream or gully emerges from steep areas and flows through gentler slopes or plains, the sediment load carried by it is no longer possible to move. Consequently, the coarse sediments are deposited in the form of an alluvial fan.

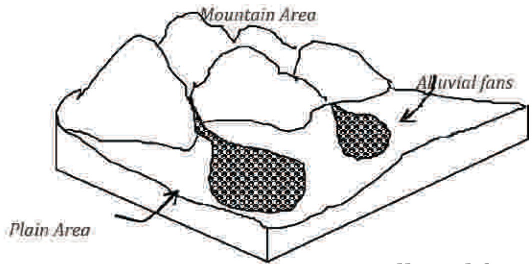


Fig 4.6: Alluvial fans

4.4 Mountain slope classification

While considering the alignment, design, construction, rehabilitation, and maintenance of irrigation canals and roads in the Hills of Nepal, it is important to recognize where land sliding or soil erosion is occurring and to distinguish between different types of slope failure and erosion processes.

The terrain, through which the canal passes, can be classified into mountain zones and these, in turn, can be separated into several land units based on criteria of slope stability/instability. All slopes within a land unit display similar characteristics and require similar geotechnical inputs. Figure below illustrates a mountain zone classification and it is also described in the table below.

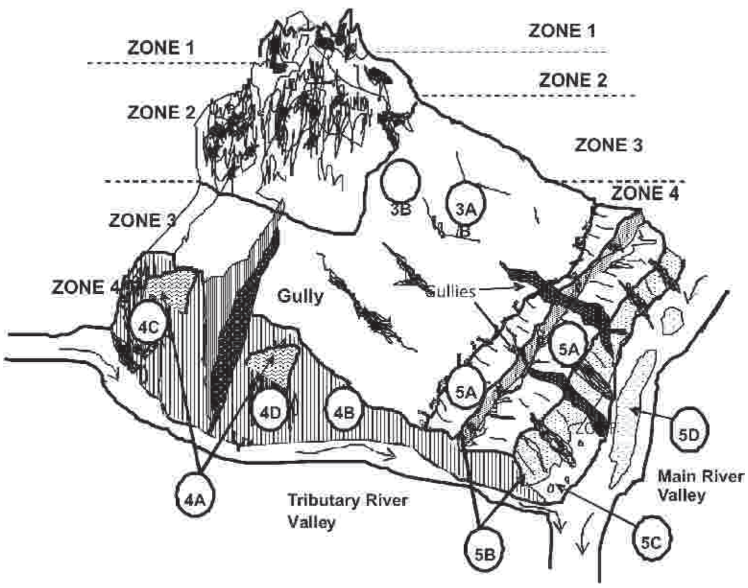


Fig 4.7: Mountain slop classification

4.5 Potentiality of slope angle to slope failure

- Inclination of slope is most important factor.
- 80% of debris slides and rock slide take place on hill slopes ranging from 30^{o} to 65^{o}.
- The peak value is 35^{o} to 45^{o} .
- In less than 30^{o} slope, soil play role in failure.
- Above 65^{o}, rock fall occurs.

Table 4.1: Mountain slope classification

Zone	Land Unit	Description
1 Snow peaks		Snow peaks
2 Zone glacier		Slopes with glaciers and moraines.
3 Degraded middle slopes (less than 35^{0})	**3**A	Ancient erosional terrace, covered with in-situ weathered profile of soil up to 3 m, slope angle generally less than 35^{0}, relatively stable, often farmer terraced, surface water erosion high.
	3B (4D)	Degraded colluvium, transported slope debris or landslide debris comprising gravel, cobbles, and boulders bound in silt/clay matrix, slope angle less than 35 ^{0}, relatively stable, often farmer terraced, variable permeability.
4 Active lower slopes (more than 35^{0})	4A	Bare rock slopes. Steep slopes angle often more than 60^{0}, stability dependent on orientation of discontinuities
	4B	Rock slopes with shallow (less than 2 m) loose debris cover, slope angle 45^{0}- 60^{0}, shallow instability and debris slides. as 4A.
	4C	Active colluvium, thick landslide debris often with toe being eroded seasonally by river, slope angle more than 35^{0}, actively degrading, highly unstable.
	4D(3B)	Degraded colluvium, see 3B but less stable.
5 Recent side terraces and valley floor (less than 20^{0})	5A	Higher terraces, oldest terraces often heavily dissected by drainage gullies, thick weathering profile up to 3 m, slope angle generally 0 to 20^{0}, generally stable but can be highly erosive if surface residual soil cover is penetrated.
	5B	Terrace scarp faces, steep, often sub-vertical, actively degrading usually as sudden slumps, highly erosive forming cones of loose debris.
	5C	Low terraces, usually above normal flood levels, but susceptible o periodic high floods, soil cover is generally less than 30 cm, highly permeable and erosive, slope angle 0 degrees - 10^{0}.
	5D	Flood plain, gravel/cobble banks, highly mobile and covered by annual flood levels, no established soil cover, highly permeable and erosive.

Rainfall and water movement

Water is the main agent to trigger hazards in Nepal. To understand these water related hazards, the knowledge on occurrence of precipitation, its spatial and temporal distribution, distribution of water over the ground and below the surface as rainwater come in contact to ground, is necessary.

5.1 Distribution of rainfall in Nepal

The temporal and spatial variation of rainfall in Nepal is very high. 80-90% of rainfall occurs during June to September. Nevertheless, rainfall in Nepal occurs with different mechanisms.

5.1.1 Orographic rainfall: This type of rainfall is due to the condensation of moisture-laden vapor as it meets orographic barrier (mountains). Rainfall in Nepal during the monsoon months (Jun-Sept) is mainly by this mechanism. During these months, the moisture-laden vapor from the Arabian Sea and the Bay of Bengal gets intercepted by high mountains of Nepal causing condensation to rise up. This results in high rainfall across the southern flanks of the Annapurna Range (windward face) and low rainfall along Trans Himalayan region (leeward face).

5.1.2 Frontal Rainfall: When dry cold wind and light moisture laden hot wind meet at front, heavy cold wind rises, resulting in condensation. This mechanism prevails in Nepal during winter as hot moisture laden wind from Mediterranean Sea meets cold wind from central Asia. As a consequence, winter rainfall is much significant in the western part of Nepal.

5.1.3 Convective Rainfall: This type of rainfall mechanism is very local in nature. During April, the temperature in Terai is high, causing significant evaporation from water bodies and soil and evapotranspiration from vegetation. However the environment at high altitude is still cold enough to condense the evaporated moisture convectively, locally resulting in rainfall.

5.1.4 Cyclonic Rainfall: Cyclones are the large concentric low-pressure zones. Such zones appear in the vicinity of the Bay of Bengal during autumn resulting in rapid condensation causing rainfall in Nepal.

5.2 Movement of water

Water can move over the surface of ground, into the surface to a depth of a few centimeters, further down into the soil profile, and deep into rocks. All these pathways can lead to instability in various forms.

5.2.1 Surface water movement

Conditions that lead to overland flow are:

- when the soil has a capping (compacted surface). A soil cap will prevent infiltration even if the soil itself is highly permeable.
- when the rate of precipitation exceeds that of infiltration (when the soil is not saturated).
- when the soil is saturated.
- when impermeable rock or impermeable soil is at the surface.
- slope, to a limited extent can determine whether or not overland flow takes place. If the slope is very steep, water flows over it no matter how permeable the surface is. However, for most practical situation, slope does not cause overland flow, although it certainly influences the rate of overland flow.

The result of water flowing over the surface is a flow without any damage to surface or sheet erosion, or rill erosion. Sheet erosion is the removal of soil, mineral or rock particles evenly over the whole surface. Sheet erosion persists in firm ground that resists rilling, e.g. very weak rocks. Mudstone and soft sandstone, the Siwalik rocks, are typical examples of this material. A thin weathered skin develops on these rocks that are then removed by rain-wash, to expose firmer rock beneath. Thus, softening and removal of the rock continues only on the surface. Rill erosion is the removal of soil, mineral or rock particles along water channels. This is by far the common form of erosion. As rills become larger and deeper, they develop into gullies. Fine soil of low cohesion, e.g. silt or silty soil, is most susceptible to rill erosion. This is because fine and cohesion-less particles are very easily detached by water and carried in suspension.

5.2.2 Subsurface water movement

When water percolates into the soil, it enters the voids and starts to fill them up. As a result, pore water pressure starts to rise. Pore water pressure is the pressure acting on soil grains by water held in the pores. Pore water pressure is negative when the voids are only partially filled with water (a state known as soil suction). It is neutral just before the point at which the voids become completely filled with water. And it is positive at the point when all the air has been expelled from the voids and the water phase in the soil-water mix becomes continuous. At that point, the water phase becomes a column; and the hydrostatic pressure, equivalent to the height of the column, is exerted within the pores and transferred to the soil grains.

If the hydrostatic pressure is sufficiently high, it forces the grains apart and the mixture will start to behave as a liquid. Hydrostatic pressure, developed near the soil surface as when the upper layer becomes saturated during heavy rain, causes the soil to flow.

When pore water pressure becomes positive along the walls of a fissure underground, a 'pipe' develops. A pipe is an enlarged fissure that forms underground in fine-grained, non-cohesive soil, especially silty or fine sandy soils. Enlargement of the fissure takes place when water flowing along the fissure or into the fissure from the side walls detaches particles of soil and carries them away in suspension. Pipes that have not broken through the surface can still sometimes be detected by the presence of an elongated hollow subsided ground pointing down the slope. The trench may be above the head of a gully and in the same alignment as the gully, indicating that water is moving into the gully head as ground water through a pipe.

If water travels downwards to the bottom of the soil profile, it commonly becomes halted in its path by the impermeable surface of the rock beneath. It then migrates downhill along the interface until it emerges as a spring at a point where the soil becomes shallower or the rock outcrops at the surface.

Pore water pressure may become positive at the base of the soil profile, resulting in a deep translational landslide (the commonest deep type) or circular failure.

5.2.3 Water in rocks

If water goes deeper than the soil profile, it goes into the bedrock. In horizontal rocks, it moves sideways, slowly, along the surface of an impermeable layer. In tilted beds, it moves more rapidly down the slope. If the rock is fractured, the water continues to go deeper. Hydrostatic pressure is exerted within the open joint systems of rocks in exactly the same way as in soils. If the water cannot escape as spring water, high pressure can develop and force the joints apart. This is the cause of many rockslides. The permeability of rocks is controlled by the permeability of the rock; the angle of bedding; and the number, orientation, openness and continuity of fractures.

5.3 Stream morphology

A study of the plan and profile of a stream are very useful in understanding stream morphology. Plan view appearances of streams are varied and result from many interacting variables.

5.3.1 Drainage pattern

By drainage pattern, we mean the shape of the streams as seen on a topographical map. The main types of drainage pattern are shown below.

5.3.1.1 Dendritic drainage pattern

By drainage pattern, we mean the shape of the streams as seen on a topographical map. The main types of drainage pattern are shown below.

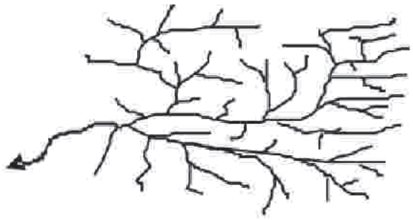


Fig. 5.1 : Dendritic Drainage pattern

It resembles the roots of a tree and it is found in areas with soft and homogeneous rock/soil.

5.3.1.2 Parallel drainage pattern

Parallel drainage pattern is controlled by the faults and fractures present in the rock.

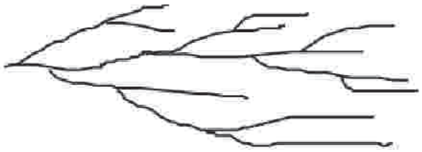


Fig. 5.2 : Parallel drainage pattern

5.3.1.3 Trellis drainage pattern

It is like a zigzag shaped drainage pattern as shown below.

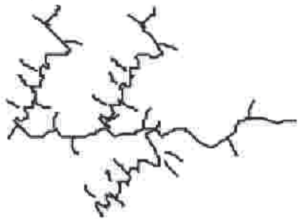


Fig. 5.3 : Trellis Drainage Pattern

5.3.1.4 Rectangular drainage pattern

In this drainage pattern, the streams are distributed in almost a rectangular pattern. Joints in the rock control most of them.

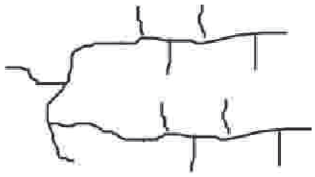


Fig. 5.4 : Rectangular drainage pattern

5.3.1.5 Centripetal drainage pattern

In this pattern, the rivers flow towards the center. An example of it is the Kathmandu Valley.

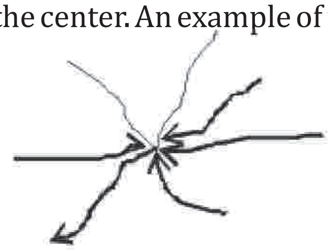


Fig. 5.5 : Centripetal Drainage pattern

5.3.1.6 Radial drainage pattern

In this drainage pattern, the streams are distributed in almost a rectangular pattern. Joints in the rock control most of them.

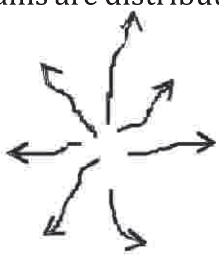


Fig. 5.6 : Radial Drainage pattern

5.3.1.6 Stream order

Streams can be grouped into various orders as shown in the figure given below.

The streams could be of:
First order,
Second order,
Third order,
Fourth order streams, etc

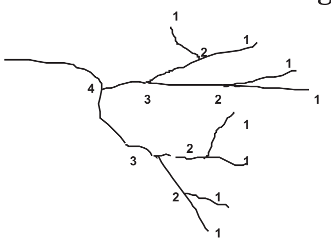


Fig. 5.6 : Stream orders

5.4 Mapping of a river for geomorphological study

For morphological mapping of a river generally following features are taken in consideration.

- Map the main river terrace levels.
- Map the flood plain and point bars.
- Sow the cut banks by the symbol.
- Indicate the rocky areas.
- Show the landslides by using different symbols to describe different features like soil slide less than 10 m in length, rockslide less than 10 m in length, soil slide from 10 to 50 m in length, rockslide from 10 to 50 m in length, soil slide more than 50 m, rockslide more than 50 m and so on.
- Show the alluvial fans:
- Show seepage zones:

5.5 Conclusion:

- Bioengineering can be applied to: rill erosion; shallow liquefaction failures; shallow mass movements (slides); and some kinds of shallow rock failure.
- Sheet erosion, although shallow, is difficult to arrest because plants will not grow in the rock beneath the weathering skin, and the skin itself is not thick enough to support plants. Even if plants are growing, they are in constant danger of being washed bodily off the slope along the interface with the firmer rock beneath.
- Nepalese soils and rocks are generally very permeable, containing voids and many fractures. These allow water into various depths, all of which can cause instability of various kinds

■ ■ ■

Soils and materials

There are relatively few soil types in the Sub Himalaya and Lesser Himalaya because slope movement prevents soil profile development from continuing for long in any one place. As you have seen in your life, the rocks break down under sub-tropical weathering into their constituent minerals and immediately begin to move downhill. The constant movement prevents a mature soil profile from developing. Instead, the mineral particles become thoroughly mixed and produce a soil that typically consists of fragments of rock in a silt matrix of low plasticity. The resulting mixed soil without horizons (layers) is called 'Colluvium'. Plasticity is low because weathering might have been rapid enough to break the rock down. It has not continued for long enough to reduce the weathering products to plastic clay minerals. Colluvium is very permeable because the fragments are angular and the matrix lacks clay. This makes it very susceptible to infiltration and liquefaction during heavy rain.

In the process of downhill movement, the rock fragments from the parent rocks also become mixed together. The fragments, found in soil, may come from one parent rock or rocks of quite different type, depending on outcropping on the slope above. Rocks rich in quartz tend to produce sandy soils. Rocks occurring widely in Nepal, metamorphosed sandstone, produces a sandy, silt soil containing coarse, hard, irregular pieces of metamorphosed sandstone. Platy, splitting rocks such as phyllites weather to a finer material, but the derived soil usually also contains fragments down to a few millimeters in size of unweathered or partially weathered phyllite. Most rocks contain some light mica, which remains unweathered in the soil profile, though it breaks up into tiny particles.

The action of movement downhill causes stones to rub against each other, rounding off the corners, but the fragments in colluvium retain a noticeably angular shape. Debris flows (wet, flowing landslides) hasten the process of rounding and produce soil particles of wide size ranges, varying from boulders down to fines, all are mixed together.

When colluvium reaches the valley bottom, it is moved along by the river. The material becomes separated, the fines moving in suspension and the larger fragments rolling and bouncing along the river bed. This material is called 'alluvium'. The movement by water is much more dynamic than steady movement downhill, causing:

- separation of the particles into discrete size ranges.
- breaking up of the weaker rock fragments such as phyllite and highly weathered gneiss.
- Rounding of the boulder, cobble and coarse gravel sized fragments to a spherical shape.

The most noticeable and easily-recognisable characteristics of alluvium are:

- the fragments are clearly rounded and many are almost spherical.
- they are of sandy texture.
- it usually shows signs of horizontal layering due to steady deposition as the river flow rate declines after a surge.

Alluvium often contains fragments of weak rock and weathered rock. As mentioned above, these become broken up relatively quickly during transport. Their presence in an alluvial deposit therefore indicates that the material has only relatively recently been introduced into the river bed and has not travelled very far or been travelling for very long. Alluvium, containing a high proportion of such fragments, cannot be used in engineering construction. When an alluvial deposit is selected as a source of material for crushing as aggregate, the hard cobbles are often picked by hand out of the river bed.

The rounded nature of the coarse fraction of river deposits generally makes them suitable for aggregate only after crushing, to increase their angularity and mechanical interlock. The presence of mica in the sand fraction can weaken concrete. Sand selected for high strength concrete, for example in bridge works, is often washed to remove the mica prior to use.

6.1 Hill slope stability

The hill slope stability basically depends upon rock and slope parameters. The physics behind the stability is based on the interplay between two types of forces: Driving Forces and Resisting Forces. The driving forces promote down slope movement of material, whereas resisting forces deter movement. When driving forces overcome resisting forces, the slope is unstable and results in mass wasting. The main driving force in most land movements is gravity. The main resisting force is the material's shear strength of the materials (friction and cohesive property of materials against slope angle).

Slope stability can be defined as following very simple relationship of safety factor:

Safety Factor (SF) = The ratio of resisting force to driving force

$$\text{Safety Factor (SF)} = \frac{\text{Resisting Forces}}{\text{Driving Forces}}$$

If SF > 1 then SAFE

If SF < 1 then UNSAFE

A safety factor of ~1.25 or somewhat higher is acceptable for slope stability.

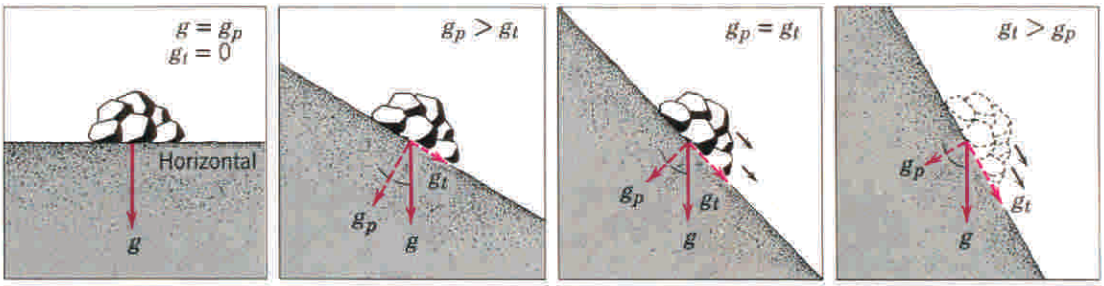


Fig. 6.1 : Act of gravity on rock lying on hill slope.

Gravity can be resolved into two components like perpendicular (g_p) and one parallel (g_t) to the surface. The perpendicular component creates resistance to sliding. When g_t is exceed g_p the object will move.

In terms of stress, the factor of safety can be defined by the following relationship.

$$\text{Factor of safety (F)} = \frac{\text{Shear strength (or resistance)}}{\text{Shear Stress}}$$

Where F > 1 Slope is stable

Where F < 1 Slope will fail

Homogenous materials on slope create rotational failure on.

6.2 Analysis of slope stability based on minerals and rocks

Introduction

Minerals are naturally occurring crystalline chemical compounds. Rocks are aggregations of minerals. The mineral constituents of a rock may have very different chemical compositions and properties.

A fresh rock sample may contain the following mineral groups:

- dark minerals
- light minerals (milky)
- white mica (platy, translucent)
- quartz (sugary, translucent but can be milky)

Rocks are affected by weathering, which is defined as "the physical and chemical alteration of rock by the action of heat, water, and air". Note that high temperature and high water content increase the rate of weathering

The relative order of susceptibility to chemical alteration in the common mineral groups is as follows:

Dark minerals	↓	Least resistant to alteration
Light minerals		
White mica		
Quartz		Most resistant to alteration

6.3 Rock resistance to weathering

The weakness of rock has direct relation with the minerals types. The rock resistance weathering as per the minerals types is shown in following diagram.

Weak ↓ Strong

Rock containing dark colored minerals

- Dark colored igneous rock (Basalt)
- Dark colored metamorphic rocks containing mainly
- Dark colored mica (gneiss, schist, phyllite, and slate)
- Dark colored sedimentary rocks (mudstone, shale, siltstone)

Rock containing light colored minerals
(granite, gneiss, phyllite, marble)

Rock containing mica
(gniess, schist, phyllite, sandstone)

Rock containing quartz (mainly quartzite and sandstone)

6.4 Slope stability as per rock and mineral types

The slope stability of rock can be interpreted as per the rock and mineral types found on slope. The slope stability and soil formation sequence can be defined in the following manner.

Weak gentle slope ↓ Very stable peak and cliff

High Soil ↓ Less Soil

- Slope of dark colored less compacted rocks
- Slope of light Colored Rocks
- Slope of rock containing more mica (gneiss, schist, phyllite, sandstone)
- Slope of quartz rich rock (mainly quartzite and sandstone)

6.5 Analysis of slope stability based on weathering grade

The mineral constituents of a rock may have very different chemical compositions and properties. A fresh rock sample may contain the following mineral groups:

- dark minerals
- light minerals (milky)
- white mica (platy, translucent)
- quartz (sugary, translucent but can be milky)

The rock, with such different minerals, generally leads to weathering process and creates thick soil formation above the bed rocks. Weathering is defined as 'the physical and chemical alteration of rock by the action of heat, water, and air'. Weathering is an umbrella term for the processes which wear rock and other materials down and break them apart. It happens because rocks and minerals, which formed at one set of conditions, are not necessarily stable at other conditions. To be more precise, the rocks and minerals are not in equilibrium with the environment around them. Weathering is the process by which rocks and minerals become equilibrated with their surroundings. High temperature and high water content increase the rate of weathering.

A weathered rock sample will show some or all of the following features:

- softness (i.e. minerals can be rubbed off by hand)
- discoloration
- loosening of grains
- intact white mica
- intact quartz

6.6 Types of weathering

There are three major kinds of weathering:

a. *Chemical*
   Minerals making up a rock are chemically altered. They either transform to other minerals or dissolve.

b. *Physical/Mechanical*
   Rocks are fragmented through inorganic mechanisms, while the chemical composition of the rocks' minerals does not change.

c. *Biological*
   Living organisms can accelerate either of the previous two mechanisms.

6.7 Weathering phenomenon

All denudation starts with weathering. Any loose material is immediately affected by gravity, so we can say that,

6.7.1 Weathering + Gravity => Mass wasting

If a moving substance capable for transporting rock particles -- a stream or consistent wind -- is also present, erosion takes place

6.7.2 Weathering + Gravity + Moving fluid => Erosion

Because of weathering, all rock surfaces (except for the very steep and very young, geologically speaking) are covered by a layer of weathered material. Furthermore, presence of plants leads to formation of soil. As a result, natural surfaces are typically formed of several layers of materials.

6.8 Rock weathering grades

The weathering grade can be described in numbers and used as per following parameters.

Table 6.1 : Weather grade

Weathering grade	Description
1a	Fresh rock. No visible sign of weathering.
1b	Faintly weathered. Discoloration on major joint surfaces.
2	Slightly weathered. Discoloration of all discontinuity surfaces or throughout rock.
3	Moderately weathered. Up to 50% of rock material decomposed and/or disintegrated to soil. Rock can be a continuous mass, or core stones.
4	Highly weathered. More than 50% of rock material decomposed or disintegrated to soil. Rock mass is discontinuous.
5	Completely weathered. All rock material decomposed and/or disintegrated to soil. Original mass structure still largely intact.
6	Residual soil. All rock material converted to soil. Mass structure and material fabric destroyed.

Conclusion

From this discussion, we can say that:

More chemical weathering → More soil formation → More chance of slope failure related to soil

More physical weathering → More rock fragment formation → More chance of slope failure related to rock

6.9 Analysis of slope stability based on fracture

6.9.1 Rock and rock fracture

Rocks of the earth crust are subject to the numbers of internal and external forces. These forces activate during and after the formation of rocks. The interaction of rocks and the activate forces is responsible for a variety of features and structures developed in the rocks. The size, shape and arrangement of layers in rocks are resulted from a range of forces that might have acted on those rocks during or after their formation. The layered, simple or complex bending, warping, fracturing and displacements along definite planes, surfaces or zones formed by the action of internal and external forces within the rock are usually termed as geological structures.

The rocks exhibit normally specific characters, features, and deformation or disposition patterns due to which rock masses show some features or design called structures. The study of the arrangement and significance of these features is termed as structural geology. It is a part of geo-tectonics and in other terms it deals with the structure, movements and the development of the upper envelopes of the earth.

Fractures are one of the major features of rocks. Most of the fractures are approximately parallel to each other and constitute what is called a 'set'. Most rocks contain several fracture sets. Rock strength is related to the number and weakness of fractures. The presence of fractures is the main cause of failure of rock slopes. Friction along the interfaces between the fractures blocks governs the shear strength of the rock. Shear strength is reduced when contact along the interfaces is lost. Strong rocks have fewer fractures or closed and cemented fractures. A highly weathered rock may fail through the rock body rather than along the joints.

Notice the following features of the rock

- Bedding
- Orientation of structures
- Fracturing and jointing

The orientation of these planes controls the resistance of the rock block failure to gravitational forces.

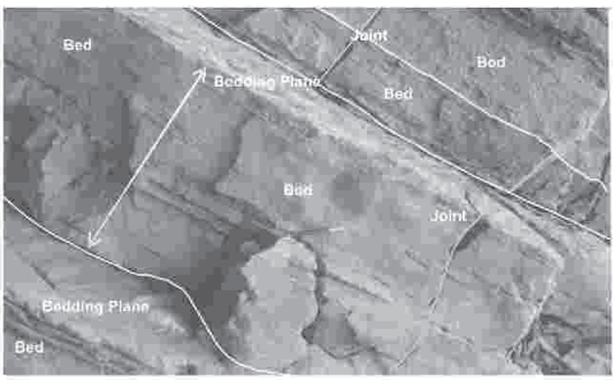


Fig. 6.2 : Rock fractures and bedding

6.9.2 Rock type and slope failure

A slope can be considered as rocky when even sparse outcrops of rock appear either directly at ground surface, within rivulets, or pointing out through a rather thin soil, which has originated from the underlying rock. For rocky slopes, stability greatly depends on the structure of the rock and on the geometrical relations between this structure and the slope. This is true at least for slopes with an incline greater than 38° - 45° degree, and is qualified by a variety of factors in equatorial and sub-tropical regions, where the weathering of rock is frequently deep and characterized by open fractures and laminations. In these regions, the transition from rock to proper soil is gradual and the entire cover is tied in with rock and its structure. For these reasons, equatorial and subtropical slope failures are chiefly ruled by rock mechanics in the mountainous areas.

Except for simple cases, however (e.g. a layer of hard rock sliding on clayey rock), slope stability calculations are highly complex and often too theoretical for practical use. A new method for evaluating the risks of slope failure adapted to work in remote areas was therefore tested during field work in Nepal. The method is laid out below.

On slopes with inclines less than 38° - 45° degree, water runoff is rather slow and percolation through the rock increases and travel is deeper. Consequently, weathering becomes an important factor and thick layers of soil can be built up. Rock structure ceases to determine slope stability, and failures are then ruled by laws of soil mechanics. The same is true for slopes covered with thick allogenic material (debris, old landslides or rock-slides), morainic material and alluvium although underlying rock structure sometimes continues to influence slope stability. When these soils are thin, however, stability may, nevertheless be directly determined by rock structure

Under similar conditions, the surface areas of rock-slides and debris slides increase as the number of types of geological planes (laminations and fractures) and structural wedges increase. It can, therefore, be assumed that the risks of slope failure indirectly rise with the number of geological planes and structural wedges. Other characteristics are also important, however, and should be described in detail. In all, the main factors responsible for the failure of rocky slopes are:

a) Structural
b) Lithological and mineralogical
c) Hydrological
d) Morphological

6.9.3 The structural factor

Several rules can be stated concerning rock structure. The risk of slope failure rises as the number at types of geologic planes increases. The intersecting geological planes from a structural wedge which is capable of leading to slope failure provided the inclination of the intersection which is less than or equal to that of the slope. For slope failure, the axis of intersection must be parallel the direction of the slope, when only one critical wedge exists.

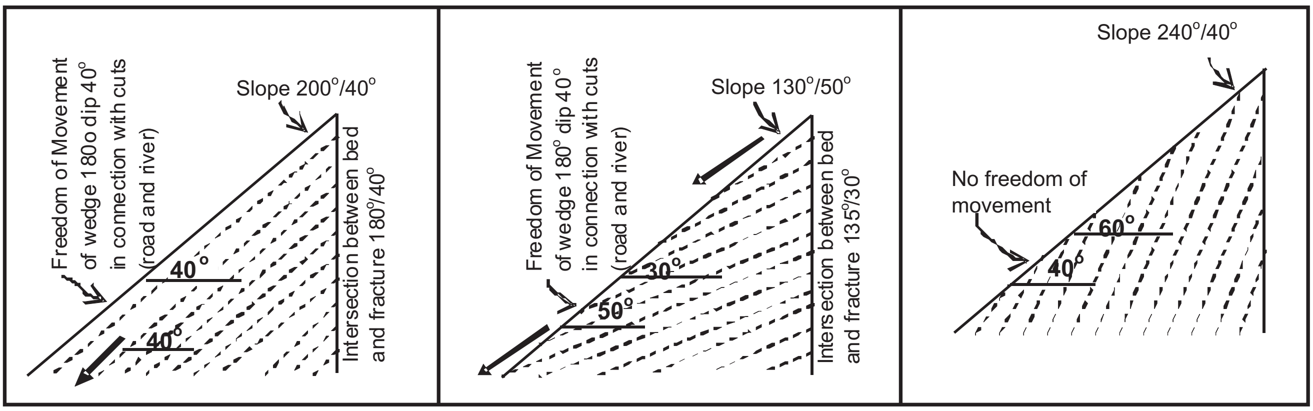


Fig. 6.3 : Joint orientation and slope failure

No slide is theoretically possible when the incline of intersection is greater than the incline of slope. A lateral or very lateral wedge is usually unable to create a slope failure.

6.9.4 The lithological factor

Weathering, which is finally the root cause of landslides, depends chiefly on the lithological nature of the mother-rock. Logically, the types of rocks least subject to weathering are those constituted by hard minerals and by minerals non-reactive to acids. Quartzite is frequently the least weathered of rocks, precisely for this reason. On the other hand, mans, calcschist and alternating layers of clay-origin rocks mixed with carbonate rocks are logically among those most prone to weathering, due to the dissolution of m calcite and clay minerals. Rocks of clay origin not only weather easily because of their lithological nature, but also because they are often fissile i.e. they have a high number of cleavages. When bearing carbonaceous matter, these rocks weather even more readily. Gneiss and granite are subject to weathering under sub-tropical conditions because of the feldspars and ferromagnesium silicates they contain. When gneisses are interbedded with schist the potential of sliding is considerably increased.

A statistical analysis, conducted along roads in the Mahabharat area, appears representative of rocks throughout the foothills of Nepal, and similar conditions may be found in other mountainous areas under tropical and sub-tropical conditions, from the results of the study a Lithological Coefficient for the Potential to Slide (LCPS) is obtained (Table 1).

Table 6.2 : Slide potential of Rock of Nepalese Mountains

Group	Rock type of Nepal	Lithological slide potential
I	Slate, phyllite and schist, closely interbedded respected with calc-slate, calc schist, lime stone, dolomite and dolomitic quartzite.	Very High (LCPS 16)
II	Slates, phyllites and schists	High (LCPS 10)
III	Slates, phyllites and schists closely interbedded respect with quartzite and gneiss	Medium (LCPS 5-10)
IV	Gneiss	Medium (LCPS 5-10)
V	Quartzite	Low (LCPS 1)
VI	Massive Lime stone and dolomite	Very Low (LCPS 0 – 1)

(Source: Krahenbunl, J. and Wagner, A., 1983)

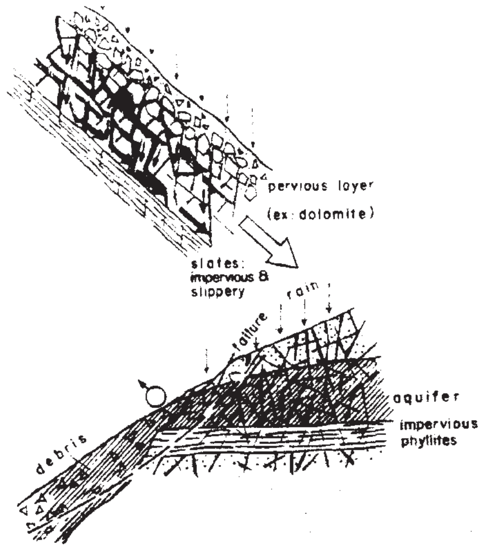
The lithological slide potential can be increased or decreased by the presence of minerals subject to weathering. By giving off sulphuric acid, pyrite (FeS_2) is able to increase greatly the weathering even of quartzite, which can be considerably weakened in the process. Chlorite acts in much the same way, though less obviously, by oxidation. The presence of calcite in quartzite can be the determining factor for instability when inter-bedded with rocks of clay origin. In this case, the dissolution of calcite allows later to become more easily trapped by quartzite. Due to the presence of clayey layers, water pockets are then constituted, and these can create disastrous mass movements of rock. The presence of sericite, a kind of hydrous mica, can increase the potential to slide, as other micas seldom do. Graphite (carbon) can also increase the potential to slide, while carbonaceous matter (frequently containing pyrite) can, as stated above, increase the weathering of rock.

6.9.5 The hydrological factor

The presence of water, whether as rivulets adjacent to, or as springs and seepages within weathered rock, obviously increases the potential of the occurrence of a slide. The quantifiable role played by the water factor is nevertheless difficult to analyze because rivulets, springs and seepages are often far from perennial, and thus may not be visible at the time surveys are carried out in tropical and sub-tropical climates. Nevertheless, water plays a determining role at the time of occurrence of a slope failure.

The shape of the slope is very important in assessing the effect of water. Because they act as natural collectors, combs and concave slopes are in this sense more subject to slope failures than are crests and convex slopes.

Rocks with open cracks and fractures, as well as those showing signs of karstic dissolution, easily collect water. Where these rocks are inter-bedded with layers of impermeable rock, especially in structural patterns prone to trapping water, major perennial or intermittent seepages or springs may appear. Large pockets of water may also accumulate within karsts. These conditions can rapidly deteriorate and lead to slope failure.



Hydrological Factor for failure

6.9.6 The Morphological Factor

The incline of a slope is an important factor where the stability of rocky slopes is concerned. Experiences show that about 80% of debris-slides and rockslides take place on hill slopes ranging from 30° to 65°, with a peak between 35° and 45°. Slides on originally rocky slopes with inclines less than 30°, at least subtropical areas are generally controlled by soil mechanics. Above 65°, rock-falls occur.

As stated above in relation to water, the shape of a slope is also an important morphological factor for instability evaluation.

6.10 The forecasting of potential landslides according to rock fractures

The factors with highest probability of leading to large debris or rock- slides (slumps excepted) can be summarized by the presence of

- a structural slope
- an incline of slope between 45° and 55° (other inclines should nevertheless not be excluded)
- more than 3 - 4 geologic planes. The planes are open.
- several structural wedges, arranged in a fan. At least one central or centro - lateral wedge is needed for a slide to occur. If the total of central and centro-lateral wedges is greater than the total of lateral and very lateral wedges, the slide will tend to be narrow and long. If the inverse is true, the slide will be broader.
- rocks of clay origin closely inter-bedded with carbonate rocks and with or without detrital rocks (sandstones, quartzite end conglomerates)
- rocks of clay origin or of clay and detrital origin closely inter-bedded
- subsidiary minerals such as pyrite or graphite as well as chlorite and sericite
- springs or seepages
- a concave topography, as a more or less pronounced coomb.

On the other hand, highly stable rocky slopes can be recognized by the combined presence of:

- a structural slope
- not more than 2-3 geologic planes. The planes are "closed', without fillings or coatings
- no structural wedges or exclusively lateral and very lateral wedges or one centro-lateral or lateral wedge
- unweathered or slightly weathered rock including quartzite, massive limestone, dolomite and marble, as well as gneiss, phyllite and schist
- an area free of water and unconnected with rivulets, springs or seepages
- convex topography, humps, crests or ridges.

There are, of course, a great variety of intermediate conditions existing between these two extremes. The above rules are immediately applicable for surveys of zones of limited extension such as bridge sites and any constructions of limited size.

■ ■ ■

Causes and mechanism of failure

7.1 Causes of failure

Landslides can be triggered by both natural and man-made changes to the environment and its conditions. The geologic history of an area, as well as activities associated with human occupation, directly determines or contributes to the conditions that lead to slope failure. The causes of landslide can be inherent, such as weaknesses in the composition or structure of the rock or soil; variable, such as heavy rain, melting snow, and changes in ground-water level; transient, such as seismic or volcanic activities; or due to new environmental conditions, such as those imposed by construction activities (Varnes and the IAEG, 1984). Among these factors, rainfall, earthquake and human activities are important trigger factors.

7.1.1 Monsoon rainstorm

The Himalaya Range is affected by the monsoon, as are other parts of South Asia. Due to Summer Monsoon near the Bay of Bengal towards northwest, there is a general decrease in rainfall from East to West. Thus while Eastern Himalayas (Assam) have about eight months of rainy season (March-October), the Central Himalayas (Bhutan, Sikkim, Nepal and Kumaon) have only four months (June-September) and the Western Himalayas (Kashmir) receive active summer monsoon for two months (July-August) (Chalise, 1994).

Monsoon rainstorms initiate many landslides each year in the Himalaya region. During heavy rainstorm, loose/unconsolidated deposits, and strongly weathered and fractured sedimentary and metamorphic rocks become saturated with an increase of precipitation and ground water level. As a result, these materials are especially prone to sliding when slopes are steep. Rainstorms, therefore, are recognized as important landslide triggers in the Hindu Kush-Himalayan region.

The relationship between rainfall and incidence of landslide has been studied by many scientists in China, India and Nepal (Li and Li, 1985, Dhital et al, 1993, Joshi, 1997). The studies carried out in China show that:

- If cumulative precipitation amounts to 50 to 100mm in one day, and daily precipitation is more than 50mm, somewhat small-scale and shallow debris-landslide will occur;
- When cumulative precipitation, within two days, amounts to 150 to 200mm, and daily precipitation is about 100mm, the number of landslides has a tendency to increase with precipitation;
- When cumulative precipitation exceeds 250mm in two days, and has an average intensity of more than 8mm per hour in one day, the number of large and vast landslides increases abruptly.

Study of the relationship between rainfall and landslides in China has also showed that under the same rainfall conditions, the landslides may differ in quantity, size and density depending on geological and topographical conditions. Therefore, the landslides have obvious regional characteristics. For a given region, the conditions of geology and topography are the decisive factors under which a landslide can be induced.

The principal geological factors impacting landslide process are the type of bedrock, crack and structure, soft band, the thickness of weathering zone, the thickness and the grain composition of the soil (the surface deposits). The impact of topographical conditions is represented in two respects. On the one hand, there are the regional cut depth, cut density and the erosion basis plane. On the other hand, there are impacts of the gradient and the form of slope and water convergent area on the upper part of the slope.

7.1.2 Earthquakes

The Himalaya mountain belt represents an orogen formed due to collision of two continents, the Asia and India. The mountain lies in a major global seismic belt where earthquakes of magnitude 4.5 to 5.5 occur every year. In the region of Himalaya bounded by latitude 22N to 38N and longitude 72E to 98E, over 600 earthquakes of magnitude 5 and above have occurred during the period of 1950 to 1990. Till date, four very major (great) earthquakes of magnitude more than 8 have been recorded in the Himalaya or adjacent regions. These are the Great Assam earthquake of 1897, Kangra earthquake of 1905, Bihar-Nepal earthquake of 1933 and the Assam earthquake of 1950 (Thakur et. al. 1999).

Earthquakes not only trigger landslides, but over time, tectonic activities create steep and potentially unstable slopes when causing significant numbers of landslides when earthquake magnitudes are greater than 6. In the mountain areas, large-scale landslides triggered by earthquakes can block rivers and form lakes.

Apart from the characteristics of earthquakes themselves (i.e., seismic accelerations, continuous time of shock, focal depths, and angle and direction of the approach of seismic waves etc.), environmental factors, such as geology, landform and drainage, play an important role in the formation of landslide induced by earthquakes.

The influence of geology is reflected in both geological structure and lithological character. The landslides triggered by the Songpan earthquake (Aug. 16, 1976, M = 7.2), in north-western Sichuan Province, can be taken as an example. The earthquake induced more than 170 slumps, slides, and falls, which occurred predominantly along the active tectonic faults in the strong seismic region. On slopes consisting of loosened limestone and igneous rocks, falls occurred readily, but on slopes consisting of clay stone, shale, and phyllite, the falls were fewer in number.

7.1.3 Surface water

Erosion, or soaking of surface, causes shallow sliding, the effects of water infiltrating from the surface, causes shallow failures. There are various surface treatments, according to material type:

- Grass planting with or without the combination of jute netting and mulch for soils.
- Revetments for steep toe slopes in soil and soft rock.
- Surface renderings for rock slopes without noticeable ground water presence.

7.1.4 Ground water

Ground water causes increased pore water pressure at depth. This is why the failure plane is deeper than in surface water failure. The best way to mitigate the problem is removal of ground water by drainage.

7.1.5 Weathering

Rock shear strength is reduced by water. Water breaks minerals into weathering products and clay minerals, which weakens or breaks physical bonds between rock constituents. The rock can fail along weakened fracture planes or through its body

7.1.6 Undercutting

Undercutting of slope occurs by a flowing stream or by the opening up of road cutting. Incision (down cutting) or lateral scour by streams is a major cause of slope failure. The initial failure extends rapidly up slope. Hence the best way of reducing undercutting is by protecting the stream bank and stream bed, but additional work has to be carried out to prevent progressive failure up slope.

7.1.7 Addition of weigh

Weight added usually by the dumping of spoil or landslide debris. Extra material should be removed and the slope re-vegetated to prevent failure.

7.2 Failure mechanism

7.2.1 Erosion

This is a phenomenon of removal of particles from the surface by flowing water. An arbitrary depth limit of 25mm has been adopted for erosion. This depth refers only to the initial removal of particles and is used to distinguish erosion from mass movements. If particles are continually washed away, the surface will be progressively lowered, giving rise to the forms of erosion described in 'a' to 'c' below. For example, a gully 2m deep can be developed by the steady removal of particles from its sides to a depth of no more than 25mm at a time. The process, which causes this, is still erosion.

7.2.2 Sheet erosion

Water flows over surface in an even film, not in channels. Vegetation stabilization should be adequate to prevent sheet erosion.

7.2.3 Rill erosion and gully erosion to less than 2 m depth

Surface water flow in channels. Gullies begin as very shallow, narrow incisions in the slope (rills). An arbitrary depth limit of 2m has been set for gullies as erosion features. If a gully is deeper than 2m, its sides fail in ways similar to a normal hill slope. Hill slope protection measures are then appropriate. Check dams are the best mitigation measure to stabilize the gully floor.

7.2.4 Piping

Removal of fines along an underground channel. Percolating water in permeable fine soils of low plasticity can remove fines along fissure to a point where an underground stream is formed. The roof of this stream cavern can enlarge upwards towards the surface and eventually collapse to create an open, elongated chasm or pit. It is difficult to stabilize pipes unless underground waterways are exposed and treated as gullies. Even this will not stop piping in lateral channels. A deep interceptor drain can be considered.

7.2.5 Slide within soil or along soil/rock interface

Any mass movement of soil or debris down a slope includes translational slides of soils or debris, rotational slumps, and flows. The plane of failure can be:

- within a soil or debris mass
- along the interface between soil and weathered rock
- the uppermost layer of weathered rock
- between soil and rock plane in unweathered rock

Translational slides are the most common form of slide in Nepal. In these a 'slab' of material of more or less uniform thickness slides off the surface. Translational slides are typically rectangular, with a straight head scar and straight sides running parallel down slope. They are frequently quite shallow, i.e. one meter deep or less. They can be caused by ground water pore pressure along a slide plane or by weathering or undercutting of the slope. They can be shallow or deep, according to the structure of the superficial layers.

A slump is a rotational movement of material, forming a spoon-shaped scar on the hillside, which is roughly circular. The debris forms a bulge near the toe. Slumps are commonly caused by high ground water pore pressures deep in the hillside, and the slip circle usually goes several meters deep.

Many slides are a compound of the two types, in which a rotational component at the head degenerates into a translational component below. This is because coarse, non-plastic debris masses cannot sustain a circular slip plane except at the crown. Deciding which mode is dominant, is useful because rotational failures indicate a deep failure plane and may therefore be more difficult to stabilize than a

Flows are caused by liquefaction of material, usually by the action of heavy rainfall upon a permeable soil surface. The soil literally flows down the slope. The failure plane is usually shallow, sometimes only a few centimeters deep. However, the fluid mass is very difficult to control or stop. Deep flows, which can travel a long way, are very destructive and potentially pose a high risk to life and property.

For slides less than 100mm deep, vegetation and/or bolsters should hold slope. Fences may become undercut by liquefaction.

For slides 100 -250mm deep, diagonal vegetation may be sufficient to preserve rill system, provided maturity is reached. Support slope at base with gabion wall.

7.2.6 Plane failure in rock

Any mass movement whose failure plane or planes is controlled principally by fracture planes in rock, and whose debris consists chiefly of rock fragments. The weathering grade of the rock is 1 -4 (the rock rings when struck with a hammer). Failure types commonly include plane failure, wedge failure, and toppling (rock fall).

7.2.7 Disintegration

Tensile failure occurs in very soft rock or consolidated soil. A special type of rock failure, found in massive or sparsely jointed permeable weathered rocks, e.g. porous sandstones, and in dense soils and unconsolidated materials that stand in a vertical or near vertical face. Upon landing, the material breaks up into a pile of loose debris, consisting mostly of loose rock mineral particles e.g. sand containing a few boulders of weathering grade 4 or 5. All traces of rock structure or stratification are destroyed in the fall. For this reason, the mechanism is distinguished from a fall of hard rock, which is considered a plane failure. Saturation and weathering cause the rock to fail by planar or arc-like shearing throughout the mass. Sometimes this is partially controlled by weakly developed joint planes. Strictly, the mechanism is a 'fall', but the form of failure is distinctive. The mechanism is typical of thick beds of soft Siwalik sandstone and terrace deposits. It is very difficult to stabilize and needs to be cut back to a stable angle, which is determined by shear strength of saturated, weathered material.

7.2.8 Fall

Weathering of rock layers whose susceptibility to weathering is strongly contrasting. This failure occurs typically in alternating thin beds of hard and soft rock e.g. sandstone and mudstone or siltstone. These formations are characteristic of the Middle Siwalik rocks of Nepal. The cause is a combination of weathering of the soft rock layers and plane failure of the hard rock layers. The soft rocks weather back from the face to leave the hard rocks sticking out. Eventually the hard rocks overhang so far that they break off along vertical fractures. The process then starts again and the whole face retreats. This mechanism is very common in Nepal.

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Slope instabilities

There are many classification schemes for mass movements proposed by different authors like Campbell (1951), Hutchison (1968, 1969, 1977), Crozier (1973) and Varnes (1958, 1978). Hutchinson's classification considers movement criteria including depth, direction and sequence of movement with respect to the initial failure (Varnes 1978). Classification is based on nature of source material and the type of movement involved.

8.1. Types of landslide according to varnes

The types of mass movements proposed by Varnes (1978) are most commonly used in the world. It was also adopted by Landslide Committee, Highway Research Board, Washington D.C. It divides landslides into falls, topples, slides, lateral spreads and flows. Wherever two or more types of movements are involved, the slides are termed as complex. Varnes (1978) has divided the material prone to failure into classes, e.g. rock and soil. The soil is again divided into debris and earth.

Table 8.1 : Types of mass movements (Varnes, 1978)

Type of movement			Type of material		
			Engineering soils		Bedrock
			Predominantly fine	Predominantly coarse	
Falls			Earth fall	Debris fall	Rock fall
Topples			Earth topple	Debris topple	Rock topple
Slides	Rotational	Few Units	Earth slump	Debris slump	Rock slump
	Translational	Few Units	Earth block slide	Debris block slide	Rock block slide
		Many Units	Earth slide	Debris slide	Rock slide
Lateral spreads			Earth spread	Debris spread	Rock spread
Flows			Earth flow	Debris flow	Rock flow
			(Soil creep)		(Deep creep)
Complex			Combination of two or more principal types of movement		

8.1.1 Falls

Falls are abrupt movements of the slope material that becomes detached from steep slopes or cliffs. Movement occurs by free-fall, bouncing, and rolling. Depending on the type of materials involved, the result is a rock fall, soil fall, debris fall, earth fall, boulder fall and so on. Typical slope angle of occurrence of falls is from 45-90 degrees and all types of falls are promoted by undercutting, differential weathering, excavation, or stream erosion.

8.1.2 Topples

A topple is a block or series of block that tilts or rotates forward on a pivot or hinge and then separates from the main mass, falling to the slope below, and subsequently bouncing or rolling down the slope.

8.1.3 Slides

Although many types of slope movement are included in the general term "landslide", the more restrictive use of the term refers to movements of soil or rock along a distinct surface of rupture, which separates the slide material from more stable underlying material. The two major types of landslides are rotational slides and translational slides.

8.1.4 Rotational slides

These slides refer to a failure, which involves sliding movement on a circular or near circular surface of failure. They generally occur on slopes of homogeneous clay, deep weathered and fractured rocks and soil. The movement is more or less rotational about an axis that is parallel to the contour of the slope. Such slides are characterized by a scarp at the head, which may be nearly vertical. These slides may be single rotational, multiple rotational or successive rotational types, accordingly they may have a single surface of rupture or multiple surface of rupture. A "slump" is an example of a small rotational slide.

8.1.5 Translational slides

These are non-rotational block slides involving mass movements on more or less planar surfaces. The translational slides are controlled by weak surface such as beddings, joints, foliations, faults and shear zones. The slides material involved may range from unconsolidated soils to extensive slabs of the rock and debris. Block slides are transitional slides in which the sliding mass consists of a single unit or a few closely related units of rock block that moves down slope. Translational slide may progress over great distance if conditions are right.

8.1.6 Lateral spreads

Lateral spreads are a result of the nearly horizontal movement of unconsolidated materials and are distinctive because they usually occur on very gentle slopes. The failure is caused by liquefaction, the process whereby saturated, loose, cohesion less sediments (usually sands and silts) are transformed from a solid into a liquefied state, or plastic flow of subjacent material. Failure is usually triggered by rapid ground motion such as that experienced during an earthquake, or by slow chemical changes in the pore water and mineral constituents.

8.1.7 Flows

There are several types of flows:

(i) Creep

Creep is the imperceptibly slow, steady downward movement of slope-forming soil or rock. Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small ripples or terracettes.

(ii) Debris flow

A debris flow is a form of rapid mass movement in which loose soils, rocks, and organic matter combine with entrained air and water to form slurry that then flow down slope. Debris flow areas are usually associated with steep ravines where there are some active landslides. Individual debris flow areas can usually be identified by the presence of debris fans at the termini of the drainage basins. In general, conditions like slopes of 20 to 45°, saturated loose rock and soil materials with high content of clay minerals and high intensity and duration of rainfall are important for formation of a debris flow.

(iv) Debris avalanche

A debris avalanche is a variety of very rapid to extremely rapid slide-debris flow process.

(v) Earth flow

Earth flow has a characteristic "hourglass" shape. A bowl or depression forms at the head where the unstable material collects and flows out. The central area is narrow and usually becomes wider as it reaches the valley floor. Earth flows generally occur in fine-grained materials or clay-bearing rock on moderate slopes and with saturated conditions. However, dry flows of granular material are also possible.

(vi) Mudflow

A mudflow is an earth flow that consists of material that is wet enough to flow rapidly and that contains at least 50% sand-, silt- and clay-sized particles.

(vii) Complex movements

A complex movement is a combination of two or more types of movements mentioned above. Generally huge-scale movements are complex such as rock fall, rock/debris avalanches etc.

8.2 Landslide zones

A landslide has distinct parts. Recognizing and assessing these individually helps us understand the character of the landslide; in particular, its severity.

A landslide has four zones:

- zone of cracking: above the slide and sometimes around its sides.
- zone of failure: the head scar (crown) and failure surface which may occupy only a relatively small area at the top of the slide.
- zone of transport: a damaged slope, scarred by the passage of debris on its way down slope, this part of the slope may be stable, and may recover on its own;
- debris pile: the detached, mobile material.

We describe the stability of a slope in terms of the factor of safety. A factor of safety of 1 means the slope is at the dividing line between being stable or unstable. If the factor of safety is more than 1, the slope is stable. If it falls below 1, it will be unstable.

8.3 Severity of instability and repair prioritisation for landslides

8.3.1 Types of slopes :

Bioengineering works should be prioritized on the basis of its scope and thus, landslides should be classified in the following manner:

i. vegetation plus some 'light' engineering to protect the young plants, or
ii. normal civil engineering methods, supplemented with vegetation, or
iii. civil engineering methods are possible but very expensive, the risk of failure may be high, or
iv. impossible to stabilise with resources available, or not worth it

From the above classification, it is understood that bioengineering is applicable only for the first and second classes of slides. Like wise, depth of the failure is also another criterion which should be considered for the prioritisation. For this purpose, it can be grouped as following:

8.3.2 Depth to failure plane

i. less than 25 mm
ii. 25- 100mm
iii. 100- 250mm
iv. 250- 1000mm
v. more than 1000 mm

8.3.3 History of a landslide

i. not moved within the last 5 years
ii. moved within the last 5 years but not this year
iii. moves every year -diminishing
iv. moves every year -constant or getting worse
v. moved this year for the first time

8.3.4 Life progression of a landslide

i. stable slope formed, or will stabilise naturally
ii. further movement expected, by less serious mechanism (post-slide adjustment)
iii. repeated movement expected, by initial mechanism or another equally serious

8.4 Procedure for setting priorities for landslide repair by bio-engineering

Step 1: Severity rating

Repair is considered feasible by vegetation or vegetation in conjunction with civil engineering methods. (Severity rating = 1 or 2).	**Go to step 2**
Repair is feasible only by medium-scale or large-scale standard civil engineering methods. (Severity rating = 3 or 4). No bioengineering requirement at this stage. Wait until works are complete and then re-assess.	**End**

Step 2: History and life progression of slide

History > Life progression	No movement in last 5 years	Moved this year for the first time	Moved within last 5 years but not this one	Moves every year by initial mechanism - diminishing	Moves every year by initial mechanism - constant or worsening
Stable slope formed, or will stabilise naturally	priority 4 no need to stabilise	priority 4 Want & See	priority 4 Help to stabilise	priority 2	—
Repeating by less serious mechanism	priority 2	priority 3	priority 2	priority 1	—
Repeating by same or worse mechanism	—	Go to Step 3	Go to Step 3	Go to Step 3	Civil engineering only

Step 3: Depth of failure

Less than 25 mm 25-100mm 100-250mm	Shallow flow Deep flow or shallow slide	PRIORITY1 PRIORITY 1 PRIORITY 2
250-1.000mm	Medium depth slide Civil engineering works alone.	Plus civil engineering works Not applicable Re-assess when complete.
More than 1.000mm.	Civil engineering works alone.	Not applicable Re-assess when complete.

Slope instability mapping

This procedure will help you map an unstable site and observe all its significant features. The procedure is given in logical order but you do not have to follow this order in every case. An advantage of observing the site in a methodical way is that there will be less risk of missing an important feature. The column on the right suggests the action you should take.

The basis of the site record is a drawing of the site. A simple sketch will do. It does not have to be to scale. Its purpose is to help you understand geometric relationships between features of the landslide. It also enables you to record concisely your measurements and where you took them from. Any notes you make can also go on the drawing. Use separate pages if the notes are lengthy or if you wish to describe the slide in detail with additional drawings and notes, which may be best recorded separately in your notebook. It is good practice to make all your drawings and notes in one notebook. In this way, pages do not get lost and records are kept in sequence.

Steps in a suggested procedure		**Draw, measure or describe**
Step 1	Geomorphic situation Look at the general locality and situation of the site: • make a note of the exact location so that you can direct others to the site if necessary; • see if it is in a part of the landscape where instability is possible; • see if the orientation of the rocks, outcropping on the hillside around the site, indicate that the cause of the failure may be due to rock structure, either as planes of weakness or movement of water along fractures; • look at other sites in the area; they may have a similar geomorphic situation and a similar life progression.	Draw
Step 2	Sketch the site from the road or other good observation point: • concentrate on getting the general proportions correct. • estimate the length from top to bottom. Record this on the drawing. • estimate the width across the base. Record this.	Draw
Step 3	Look for the landslide zones: • scar • transport • debris Note that you cannot yet see whether there is a zone of cracking above the scar. You do not have to record these zones on the drawing, but the completed drawing should be sufficiently well illustrated and labelled to let another person recognize which zones are present and where they are.	Draw

Step 4	Examine the material forming the original hill slope: • debris; soft rock; hard rock or alternating hard and soft rocks. All of these could be present on one landslide. The drawing should show where they are.	**Draw**
Step 5	Sketch a slope profile of the site from top to bottom. Angles do not have to be real, but should indicate relative steepness. This can be augmented with more detail (e.g. with slope measurements) as you walk up the slide. Note that slopes >35° tend to be unstable unless of solid rock.	**Draw**
Step 6	Sketch the surface water drainage: • streams • any springs that may be visible from where you are standing.	**Draw**
Step 7	Sketch areas of rock outcrop	**Draw**
Step 8	Landmarks: • note any obvious landmarks on the site, such as prominent trees. This will help you to keep your bearings as you walk over and around the site.	**Draw**
Step 9	Walkover survey: Walk up the centre of the slide to the crown (head of scar). Measure the angles of major slope units.If the slope is too steep or dangerous, walk around the edge, looking into the scar.	**Measure**
Step 10	Rock Visit each rock outcrop. Measure any relevant rock planes or observe how the planes relate to the slope and failure planes. Make sure that the rocks observed are true outcrops (attached to solid rock beneath) and not simply large boulders partly buried on the slope. Note: • uniformity or layering (bedding) of the rock units. • degree of weathering (hardness) of the rocks. • degree of fracturing, especially any open fractures. • signs of water movement along fractures.	**Measure** **Describe**
Step 11	Debris and slope Indicate the area of the slide that is occupied by debris: • location and extent of landslide debris; • composition of debris • wetness of debris • depth of debris / depth of failure plane • location, orientation and size of any cracks in the debris or on the slope. any back-tilted slopes, where water may collect. (The presence of these indicates a) • tilted trees. These can indicate tilted ground. • disrupted engineering structures, e.g. masonry surface drains; • points of ground water seepage.	**Describe, draw**
Step 12	Margins and top Look for: • Cracks in the ground. Cracks are most frequent above the head of a slide, but they often occur also around the sides. The presence of cracks shows that the ground is under tension and that it will probably fail, and soon. Note the location, dimensions and orientation of the cracks. This information tells you where, and in which direction, the ground is under tension. The area of cracking tells you the area over which failure	**Draw**

	• Streams, springs, irrigation canals or drainage structures, especially masonry drainage ditches. These features may be sending water into the slide. They may either have caused it in the first place, or they may be contributing to further failure. Irrigation canals and masonry drainage ditches should be inspected closely for any signs of cracking and leakage; • irregular topography, not due to rock outcrops. This may indicate the presence of an old landslide, in which case you will have to survey the whole of this, too. Continue up the slope above the landslide until there is no further evidence of instability. This may mean walking at least fifty metres higher than the landslide scar, and much further if necessary.	
Step 13	Base of the slide Describe the features and ground conditions at the base.	**Describe**
Step 14	Causes and mechanisms of instability	**Describe**
Step 15	History and life progression of slide	**Describe**
Step 16	Severity of instability Fill in the scores on the Score Sheet for assessing severity of slope instability.	**Describe**
	Find out the nick points of the gully and map it.	
	Analyze the severity of instability.	

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Instability mapping field exercise

Before we undertake any remedial work on an unstable slope, we need to try to understand what is happening on the site. This exercise provides an opportunity for you to apply your work on causes and mechanisms of slope failure, components of an unstable slope and the severity of instability. The site contains more than one kind of material and more than one type of instability. In order to get a general idea of what you are looking at, start by drawing a clear, simple map. Identify major features that are visible from your position. Then walk up the site, examining it as you go and adding further information to your map. You have got the Handout 10-1 with the steps how to map instabilities. Follow it step by step and prepare a short presentation at the end. You have an hour for this activity.

Discuss with your friends about the findings and sketch it on the chart paper. Information collected in words can be described verbally. Everyone from the group should present the findings. So divide the portions who will present the part wise.

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Small-scale civil engineering structures

11.1 Types of small scale engineering structure.

11.1.1 Toe walls

A low toe-wall placed at the foot of a slope permits local over steepening of the slope at its base and flattening of the slopeabove. The latter makes it easier to establish vegetation on the face of the slope and reduces the danger of surfacial erosion. Excavation at the toe also can cause stability problems in very unstable slopes. This situation may require dry weather excavation or excavation & construction in "slots" of increments. If neither alternative is feasible, then a toe-bench structure that does not entail excavation at the toe wall is used. It is also possible to use the scaled material within the structure itself (e.g., as crib fill), provided it meets gradation and other requirements for such usage. Ideally if it is desirable to balance the cut and fill requirements along a reach of slope to avoid undue soil disposal or burrow problems.

11.1.2 Toe-bench structures

A toe-bench structure is similar to a toe-wall. The primary difference is in the amount of excavation required at the toe and slope of the backfill. Firstly, a toe-bench structure is constructed farther away from the foot of the slope (hence requires little or no excavation at the toe). Secondly, it entails little or no flattening of the slope above. And finally, it incorporates a level or very gently sloping backfill. Toe-benches can be used to provide a fairly level bench at the foot of a slope on which vegetation can be readily established to eventually screen the slope above. They also buttress the base of the slope and catch debris coming off or rolling down the slope.

Toe-bench structures are suitable for vegetative screening of high, steep rocky slopes that cannot be vegetated because of lack of soil or excessive steepness. If an open face or porous face is employed, the structure itself can be vegetated and screened as well. Toe-bench structures, however, require mere clearance at the base of a slope than toe-walls (to avoid excavation at the toe). This may constrain their use somewhat along cut slopes adjacent to a road where the foot of the cut is next to the roadway. If excavation for a toe-wall is not possible and insufficient solution such as a slope grating should be considered.

11.1.3 Basic types of retaining structures

Many different types of retaining structures are available, each with particular advantages, requirements and limitations. In general retaining structures can be classified into two major categories: gravity and non-gravity structures. Gravity structures can be further classified into: buttress structures, coherent gravity walls, articulated block walls, breast walls, and revetments.

Gravity structures and retaining walls resist lateral earth forces by their weight or mass. A gravity retaining wall constructed from poured concrete steel, wire encased stone, or reinforced earth essentially behaves as a coherent, unitary mass. Articulated block walls and rock breast walls are also gravity structures; articulation, interlocking, and friction between structural units provide coherence and resists local shear of rupture. Gravity walls, like earth-retaining structures, must be capable of resisting external forces causing overturning and sliding along their bases.

11.1.4 Cantilever and counterfort walls

Cantilever and counterfort walls are constructed from reinforced concrete; they are usually classified as semi gravity walls because they do not rely solely on their own weight but also on the weight of the backfill that rests on their bases. Cantilever and counterfort walls can be masonry or concrete gravity walls. Cantilever walls can be used for heights up to 10m. A cantilever wall is reinforced in the vertical direction to withstand bending moments (a maximum at the base of the stem) and in the horizontal direction to prevent cracking. The buttresses behind a counterfort wall are also heavily reinforced to resist tension. Both types of walls are relatively expensive and require careful design.

11.1.5 Crib walls

A crib retaining wall consists of a hollow, box-like, interlocking arrangement of logs, timbers, reinforced concrete beams or steel beams filled with soil or rock etc. A variation on this theme, known as a bin wall, consists of steel boxes or bins that are bolted together in modular units and filled to form a wall. The cribwork can be vertical or tilted backward (battered) for greater external stability. The crib members can be designed to have opening sand are usually flexible enough to tolerate some differential settlements. Structurally, cribs and bins are gravity walls and are designed accordingly. In addition, the crib itself must be analyzed for external stability (i.e., the structural members must be capable of resisting stresses caused by the cribfill and backfill).

11.1.6 Gabion walls

Gabions are wire baskets made of coarse wire mesh. These baskets are filled with stone or rock and stacked atop one another to form a gravity-type wall. Gabions depend mainly on the shear strength of the rock fill for internal stability, and their mass or weight to resist external, lateral earth forces. Gabions are porous structures that can be vegetated. They are very flexible, easy to erect and inexpensive.

11.1.7 Reinforced earth walls

The original Reinforced Earth wall consisted of a granular matrix or fill reinforced with successive layers of metal strips. Shear stresses that develop in the reinforced backfill are transferred via interface friction to tensile resistance in the metal strips. The strips are connected with facing elements- typically thin, precast concrete panels stacked atop one another. Very little lateral earth stress acts of the facing elements at the front of the structure because most of this earth stress is taken up in tensile resistance along length of the reinforcing strips. The reinforced volume can be regarded and analyzed as a coherent gravity structure. Internal stability requires, in addition, the metal strips be designed to resist breaking in tension or failing by pullout.

11.1.8 Mechanically stabilized earth walls

Many different types of inclusions with various shapes and properties are used to reinforce retaining wall backfills today. These inclusions range from geogrids fabricated from polymeric nets or welded-wire mesh to continuous filaments fabricated from polyester fibers. Backfills that are stabilized or reinforced with such tensile inclusions are referred to as "mechanically stabilized earth." A welded-wire wall is a composite wire and granular soil structure. L-shaped, wire mesh sections are placed and connected between successive lifts of backfill. The wire mesh provides both reinforcement in the backfill and containment at the face of the wall. Welded-wire walls are basically gravity structures that share features of both gabions and reinforced earth walls. Synthetic geogrid walls utilizing tough, flexible, polymeric reinforcements can be constructed by wrapping the geogrid around successive lifts of backfill without need of a separate facing, in a similar manner to welded-wire walls. Both types of walls are relatively low cost, easy to erect, and well adapted to vegetative treatment.

11.1.9 Rock breast walls and articulated block walls

Both rock breast walls and articulated block walls can be considered as gravity structures that resist lateral earth forces mainly by their weight. There must be sufficient friction or articulation between the units (rocks or blocks) to resist local shear rupture. These walls must be erected on a firm base and are usually placed against a slope with only a small amount of fill behind them. Neither type of wall is intended nor designed to resist large lateral earth stresses; hence they are limited in height. Their main function is to protect the toe of the slope against damage and provide some lateral restraint. They are usually constructed with a substantial batter to improve stability and minimize lateral earth forces. Rock breast walls and most articulated block walls are quite porous which provides opportunities to incorporate plants in the voids and interstices.

11.1.10 Pile and tie-back walls

Pile and tieback walls are occasionally used as retaining walls in situations where space constraints or foundation conditions limit use of gravity structures. Pile may consist of a row of bored, cast-in place concrete cylinder piles or, more typically, driven steel H-piles. Driven pile walls have been used to support low-volume roads, where they traverse steep terrain characterized by weak but shallow residual soils underlain by a zone of weathered rock that increases in competency with depth. The use of driven piles in this situation avoids excessive bench excavations that would be required for gravity or bearing type wall. Tieback walls essentially consist of a relatively thin, flexible facing connected to a network of anchored tie rods. The tie rods may be connected to imbedded plates or concrete blocks in the backfill or conversely may be grouted in place.

11.1.11 Check dam

Check dams are usually placed at critical points along the length of the gully. These include knick points, where there is some sudden change in gradient of the gully long profile, or at headcuts, where the gully is actively extending up, often into uneroded areas. These critical locations are easily identified by the recent exposure of soil and removal of any vegetative cover. They can often be protected by planting of trees and shrubs around the wings of the check dam. In addition to placing check dams in these critical positions, dams must be constructed to a design spacing that is related to the height of the dam and the gully gradient. In turn selection of the dam height is dependent of the objective. If the aim is to maximize the amount of sediment deposited, high widely-spaced dams would be most appropriate. If, whoever, the objective is to reduce overall gully gradient, small closely-spaced dams are more effective. The most efficient and economical, spacing, as defined by Heede, is to place each check dam at the upstream edge of the final sediments trapped by the next dam downstream. This can only be estimated at the time of construction, with the spacing modified when the real deposition pattern confirms or disputes these estimates. Over design results in unjustifiable expenditure, whilst under design can cause damage to all other installations upstream and downstream.

Check dam spacing can be calculated by the equation $x = \frac{H_E}{K \tan S \cos S}$ where, x-spacing, H_E -effective dam height as measured from the gully bottom to the spillway crest; S- Slope of the gully floor; and K is the constant (K=0.3 when tan S$\leq$0.2; and K=0.5when tanS>0.2)

11.1.12 Surface drainage

A rise in the groundwater level, caused by infiltrated rainwater that also reduces effective soil strength, is a major cause of landslides. Therefore, draining runoff water and preventing it from entering stable areas through landslide areas is often carried out to control landslides, and this is the least expensive technique. The methods of surface drainage include reshaping of slopes. Construction of ditches and sealing all tension cracks so that rainwater cannot get inside and build up pore water pressure.

11.1.13 Subsurface drainage

Draining ground water to reduce water pressure is the main purpose of the subsurface drainage systems. The methods used to drain ground water include tunnels, subsurface trenches, deep-seated counterfort drains, vertical and horizontal boreholes, and water catchment well works.

The deep-seated counterfort drain is the main measure used to treat small and medium scale landslides. It is also an important subsidiary measure in treating large-scale landslides, because it not only drains ground water but also has a strong supporting force against sliding.

11.1.14 Excavation and fill

Excavation is the removal of rock and soil from the head of a landslide to reduce the driving force and thereby improve the stability of the landslide. This method is only suitable for rotational landslides. It is ineffective of planar failures on 'infinite' slopes or flow type landslides.

Excavation techniques that can be used to increase slope stability are as follow:

- removing the entire slide mall;
- reducing the height of the slope;
- backfilling with lightweight material;
- constructing benches;
- flattening the slope angle.

In some situation, removing the entire slide mass is an effective and economic solution. In general, it is only practical on small slumps or small rotational slides. Large-scale excavation of large landslides areas is usually not recommended.

In some cases, correct excavation of landslide materials can improve landslide stability and may even increase the stability.

The following guidelines are mostly applicable to the control of rotational landslides where the head, toe and side boundaries are apparent.

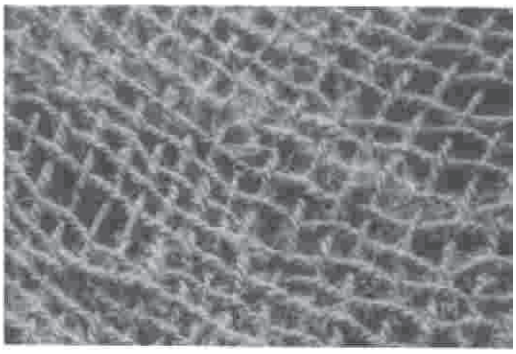
- In general, the head of an actual or potential landslide should be unloaded and its toe should be loaded.
- The head of the large landslides should be full-benched and the material end-hauled. No side casting should take place in the landslide area.
- As far as possible, the toe of the landslide should be built up with end-hauled fill materials and cuts made as small as possible.

Corrective fills at the toe of the landslide are generally preferable to corrective cuts at its head for several reasons.

- The increase in the factor of safety is greater with fills.
- Fill stability improves with time, where as cut slope stability decreases with time.
- In large complex landslides with more than one potential sliding surface, toe leading will protect against all failures, but a cut may destabilize the sliding surfaces.
- In general, a combination of soil removal from the head with fills at the toe of the landslide is most suitable for controlling medium-sized rotational slides.

11.1.15 Jute netting

Jute is a plant fibre obtained from the plant corchorusobtorius or C.Capsularis. It is generally woven in a wire net to make an inert structure. The following materials and tools are required for jute netting.



- Woven jute netting
- Hardwood cutting from shrub or tree, 2 to 5cm in diameter and 30 to 40cm long
- Tools for cutting wood and jute
- Iron bar for making hole
- Wooden mallet

Method:

(i) Trim to an even slope: Make sure that there are no small protrusions or depressions, which will interfere with the netting, remove protruding rocks if possible.

(ii) Peg the netting: starting at one end of site, peg the end of one roll of netting 30cm above the slope to be covered.

(iii) Slowly unroll the netting down the slope.

(iv) Peg the netting: Allowing some slack in the netting, begin to peg it from the bottom of the slope. Hammer hardwoods cutting or pegs through it at intervals of 50 to 100cm leaving the cuttings protruding about 8cm. While working on the slope, never hang on the netting. Always stand on the pegs.

(v) Cover the whole slope with netting: Repeat the process making sure that the vertical edges of the net meet, until the whole slope is covered in netting.(vi) Butts joint the strips: Place a series of pegs down each side of the butt joint so that the jute is held together at a continuous net.

(vii) Carefully adjust the netting: If necessary adjust the netting in order to reduce the tension and let it hug the surface closely. If it remains tight, it will not lie right against the slope surface.

(viii) Place additional pegs: Add further pegs as necessary to ensure completes surface contact.

(ix) Trim lower edges: Cut the netting strips to the length required.

Jute netting has the following advantages:

- It provides rapid cover for the slope surface.
- Even on the harshest sites the young seedlings are protected from run-off and drought until they become established.
- Jute netting is easily produced locally.

The disadvantages of jute netting are:

- It can only be used in limited places because it has a high moisture holding capacity.
- Netting has a short life span unless it is bituminised and then it will last only for than 3 years.

11.1.16 Gabion wire bolsters

Gabion bolster panels are normally of 5m x 1m. If larger bolsters are required, 5m x 2m panels can be woven. They are made on a conventional gabion-weaving frame but with a much smaller mesh than usual. Heavy coated 10 swg wire is used for the border and 12 swg for the mesh.

The following materials and tools are required to prepare Gabion Wire Bolsters (GWB)

- Woven gabion panels
- 12mm mild steel rod cut into 2m lengths
- Boulders
- Tools for digging trenches and for working with Gabion Wire.

Method:

a) Trim the slope: First trim the slope to be treated to an even slope with no small protrusions or depressions, which will interfere with the bolsters. Remove protruding rocks if possible.
b) Mark out the contour: Starting about 2m from the bottom of the slope, mark out a contour line across the slope with the aid of a spirit level.
c) Dig a trench along the line: The trench should be about 30cm wide and 30cm deep.
d) Lay a gabion bolster panel lengthways along the trench: make sure the edge of the panel on the lower side is flush with the edge of the trench.
e) Fill the bolster with stones larger than mesh size.
f) Fold the upper edge of the panel over the stones and join it to the lower panel edge. Leave a 10cm flap from the upper edge extending over the lower edge.
g) Join abutting bolsters across the lope: from the bolsters into a continuous line across the slope and close the extreme ends with wire.
h) Backfill: Backfill the material around the bolsters, compact it and clean away surplus debris.
i) Peg with steel bars: Drive mild steel bars into the ground at right angles to the slope every 2meters along the bolsters. Position them immediately below and touching the bolsters, and drive them in far enough so that they cannot be pulled out by hand.
j) Cover remaining site: Repeat steps 'b' to 'i' 2m higher up the slope and repeat again until the area is covered.
k) Starting from the top of the slope, clean away surplus debris and make sure that backfill is complete and firm.

Gabion wire Bolster has the following advantages.

- Provide very strong and durable surface scour checks.
- Stronger and longer lasting than wattle fences.
- Freely drained and so little moisture is accumulated on the slope.

The disadvantages of GW Bolster are:

- Relatively expensive to install.
- Contour bolsters give rise to an increase of infiltration, which can cause slumping on some slopes.

■ ■ ■

Table 11.1 : Applications of small-scale civil engineering structures

Function Catch	Application	Position	Life span	Site requirements	Limitation
(i) Wattle fence	Cheap easy to install	Mid slope	1 season	Stakes can be driven	Weak. Undermining. Very small amount of material.
(ii) Jute net unbituminised	Cheap Sandy soil >30° slope	Top & mid slope	1-2 seasons	Smooth plane slope Homogeneous materials	Shrinks. Not on fine plastic soils. Not on cobble size soil. Cannot be used in rilling soil. Weak, light in weight and requires many pegs.
(iii) Bituminised jute netting	Sandy soil >30° slope	Top & mid slope	5 years +	Smooth plane slope Homogeneous materials	Small amount & size of material. Not on fine plastic soils. Not on cobble size soil. Cannot be used in rilling soil.
(iv) Wire netting	Hard rock slope	Up & mid slope	20 years +		
(v) Wire fence	>30° slope	Mid slope	10 - 20 years	Stakes can be driven	Expensive. Difficult to install. Not on soft rock.
(vi) Checkdam	Small gullies	Gullies	25 years +	Good foundation Need to be well keyed	Expensive.

Function Armour	Application	Position	Life span	Site requirements	Limitation
(i) Slope cover	Permeable slope Any slope	Top & mid slope.	1-3 seasons		Temporary measure. Wind damage. Installation difficult for large area. Damaged by debris & swift water.
(ii) Stone pitching	Erodible soil slope.	River banks Gully base & floor	25 years +		
(iii) Rendering	Non-weatherable fractured rock Coarse consolidated material Up to 90° slope		25 years +	Smooth face	No resistance to any stress.
(iv) Revetment wall	Debris slope >50° slope	Usually at toe	25 years +	foundation needed Space needed for () shape	
(vi) Dentition	Alternate rock slope 30°- >50° slope Homogeneous slope	Usually mid slope	25 years +		

Function Support	Application	Position	Life span	Site requirements	Limitation
(i) Toe wall	Debris slope	Base	25 years +	Required [] shape	Mass movement < 250 mm.
(ii) Bolster	Debris slope Up to 50° slope	Mid slope	25 years +	Not too coarse & rocky soil	Can be undermined.
(iii) Prop wall	Alternate rock layers Irregular shape	Mid slope	25 years +	Specialised skills & materials Foundation bed Hard bed not too	Mass movement < 250 mm.
Drain (i) Unlined earth ditch	Consolidated debris. Slope >15°	Top slope		Impermeable soil	Easily evoked.
(ii) Unbound masonry drain	Consolidate debris Slope <50°	Any	25 years + in theory	Must be neatly built	Easily damaged.
(iii) Bound masonry drain	Consolidate debris Slope <50°	Any	25 years +	Good foundation	Non flexible. Cracks & leaks.
(iv) French drain (subsurface gravel drain)	Consolidated debris Wet sites (ground water & surface water) slope <50°	Any	25 years +		Maximum depth 2m. Difficult to install when depth >1m. Expensive.

Soils and water management and gully protection works

Water is the main cause of slope instability and therefore its management is a major consideration in slope stabilization, whether it is by civil or vegetative methods. The process we have worked through in this session should help plan more effective schemes for managing sub-surface drainage.

12.1 Surface drainage system

Surface drains are installed in the surface of a slope to remove surface water quickly and efficiently. Surface-water drains often use a combination of bioengineering and civil engineering structures. Cascades are surface drains designed to bring water down steep sections of slope. Certain drain types can be used on slopes up to 45° (e.g. drains constructed using gabion wire or concrete-bound masonry). Cascades are normally used on slopes steeper than 45°.

12.1.1 Practical features

- Always design drainage systems to run along natural drainage lines. Choose locations for the drains so that the maximum effect can be achieved using the minimum possible volume of construction.
- Always ensure that drain outfalls are protected against erosion.
- Only use a rigid geometrical pattern of drains on newly formed fill slopes where there are no clear natural drainage lines.
- Excavate a foundation until a sound layer to build on is located. Drains must be well founded like all other civil structures.
- Run main drains straight down the slope. Feed side drains in on a herringbone pattern.
- Never use contour drains: These block are very easily and highly susceptible to subsidence. A blocked or cracked drain can create terrible damage.
- Design and construct the drains in such a way that water can enter them easily on the higher side but not seep out on the lower side. Use weep holes and thick (20 gauge), black polythene membranes carefully to achieve this.
- A flexible design is usually an advantage. Concrete masonry can be easily cracked by the slightest movement in the slope, and then leakage problems result.
- If there is a risk of people or animals damaging the drain, make sure that the construction is strong enough (e.g. use gabion rather than dry stone construction).
- Once the drain is completed, backfill around it and compact the fill thoroughly.
- Apply appropriate bioengineering measures to enhance the effectiveness of the drain.

Table 12.1 : Surface drains and cascades, and sub-surface drains: design and integration with bioengineering (all drainage systems are assumed to be dendritic)

Drain type				
Structure Surface drains	Bio-engineering	Main sites	Advantages	Limitations
(i) Unlined natural d rainage system (rills and gullies already developed on bare surfaces).	Grasses in the rills and gullies, and grasses and other plants on the sides.	Existing landslide scars and debris masses.	By far the cheapest form of surface drain. Rapid drainage is assured.	There is a risk of renewed erosion in exceptionally heavy rain in weak materials.
(ii) Unlined earth ditch system.	Grasses and other plants on sides and between feeder arms.	Slumping debris masses on slopes up to 50º, where the continued loss of material is not a problem	By far the cheapest form of surface drain.	There is a serious erosion hazard, especially on steep main drains, Leakage into the ground may also occur.

(iii) Unbound dry stone system of ditches.	Grasses between stones, and grasses and other plants on sides and between feeder arms.	Almost any site, however unstable, where the ground is firm enough to hold stone pitching and the flow of water is not too excessive.	A low-cost drain type. Strong and very flexible. These two features make it good on unstable slopes.	A membrane of thick, black polythene may be required to stop leakage back into the ground.
(iv) Bound cement masonry ditch system.	Grasses and other plants on sides and between feeder arms.	Only on stable slopes with suitable material for good foundations.	A strong structure for heavy discharges.	Relatively high cost. Very inflexible, high risk of cracking and failure due to subsidence and undermining.
(v) Wire bolster cylinders (herringbone pattern).	Grasses and other plants on sides and between feeder arms.	Almost any site without excessive amounts of stone and with the firm ground and less discharge.	A medium-cost shallow type of drain. Very strong and flexible, which makes it good for unstable slopes.	A membrane of thick, black polythene may be required to stop leakage back into the ground.
(vi) Open gabion ditch system	Grasses and other plants on sides and between feeder arms.	Almost any site, however unstable, where the ground is firm enough to hold a relatively big structure with large volume of discharge	A large and high-cost type of drain. Very strong and flexible, which makes it good for unstable slopes.	A membrane of thick, black polythene may be required to stop leakage back into the ground.
(vii) Dry stone cascade.	Grasses and other plants along the sides.	Any slope section steeper than 50º, where foundations are adequate and discharge is relatively low.	A low-cost form of cascade with a degree of flexibility.	A membrane of thick, black polythene may be required to stop leakage back into the ground.
(viii) Mortared masonry cascade.	Grasses and other plants along the sides.	Very stable slope sections steeper than 50º, where foundations are very good.	A strong structure for heavy discharges.	Relatively high-cost and inflexible cascade type, so there is a high risk of cracking and failure due to subsidence and undermining.
(ix) Gabion cascade.	Grasses and other plants along the sides.	Any slope section steeper than 50º, where foundations are adequate and discharge is likely to be high.	Very strong and flexible, which makes it good for unstable slopes.	A relatively large and high cost cascade type. A membrane of thick, black polythene is required to stop leakage back into the ground.
(x) Concrete cascade.	Grasses and other plants along the sides.	Very stable slope sections steeper than 50º, where foundations are very good	A very strong structure for the heaviest discharges.	Very high cost and inflexible cascade type. The risk of cracking and failure due to subsidence and undermining is partly offset by the innate strength of the construction.

12.1.2 Why you should avoid using cut-off ditches or catch drains above cut slopes

Cut-off ditches, otherwise known as cut-off drains or catch drains are:

- almost certain to become blocked;
- very likely to suffer from settlement of the foundations and crack as a result;
- often difficult to maintain because they are above slope and out of sight.

A cut-off ditch becoming blocked or cracked is a common cause of a landslide or the severe erosion of a cut slope in Nepal. Damage to a cut slope can be considered the usual outcome of the installation of a cut-off ditch.

This warning applies to all surface ditches that are out of sight of the road, and therefore they are best avoided unless there is no alternative. Water should be brought down the slope along its natural course, protected with vegetation and civil structures as required and if necessary carried into the nearest roadside ditch by a cascade. Localized damage then can be seen and repaired as soon as it occurs.

12.1.3 Comparative advantages and disadvantages of two approaches to drainage

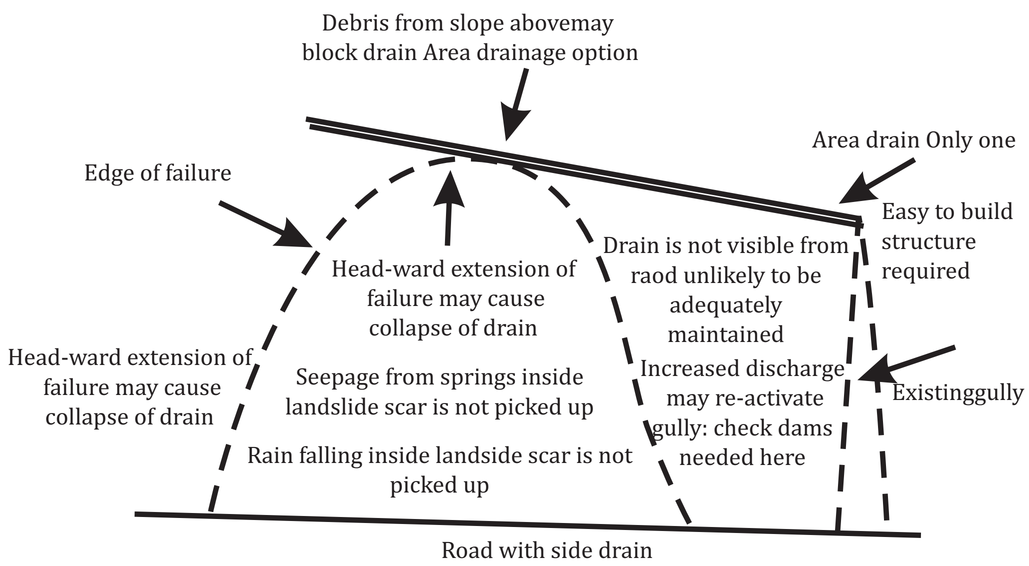


Fig. 12.1 : An example of cut off ditches.

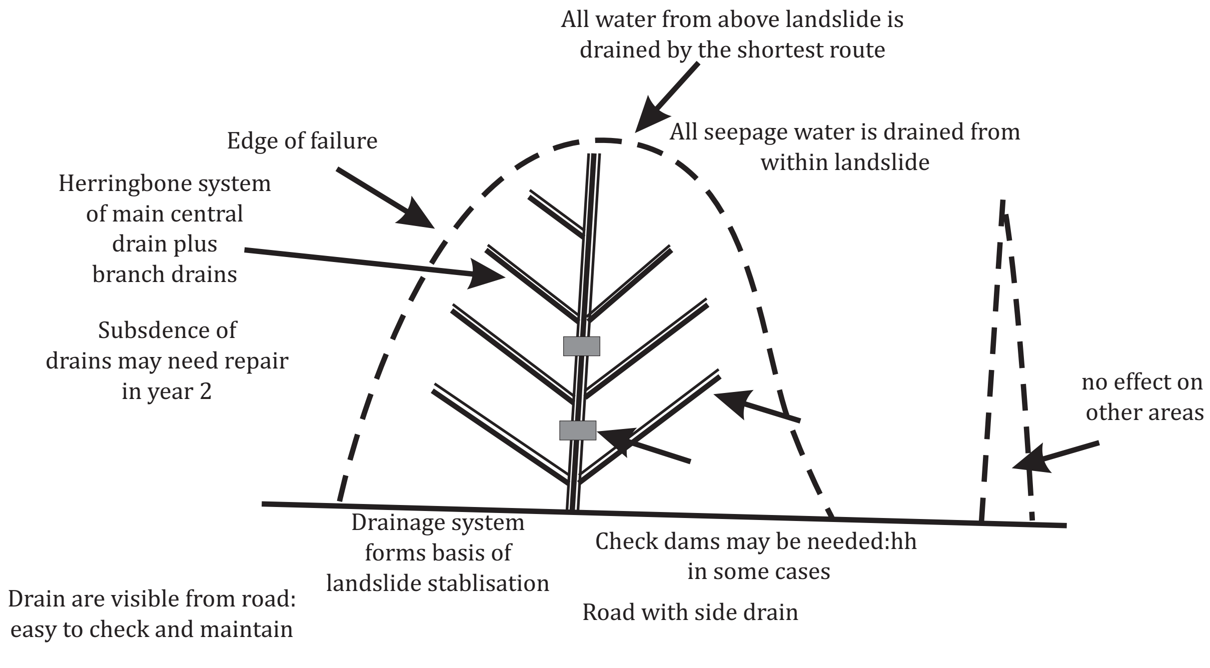


Fig. 12.2 : Example of catch drains.

12.2 Sub-surface drainage system

Table 12.2 : Sub-surface drains : design-2 integration with bio-engineering.

Surface drains				
Structure	**Bioengineering**	**Main sites**	**Advantages**	**Limitations**
Sub-surface drains				
(i) French drain system (perforated pipe (of durable, high grade black polythene, 150 mm diameter with approximately 40 holes of 5 mm per metre) in a drainage medium of aggregates).	Grasses and other plants along the sides and between feeder	Almost any site, however unstable, where the ground is firm enough to hold the structure and the flow of water is not too excessive for this construction technique.	A relatively low-cost and common sub-surface type of drain. It is very flexible, which makes it good for unstable slopes.	A membrane of permeable geotextile should be used. If the flow is too great, piping may occur underground. The outfall must be monitored to check that the drain is functioning, but the hidden nature
(ii) Site-specific design of drain to pick up seepage water. An open ditch or a drain with a flexible gabion lining is preferred.	Plant grasses and other species along the sides.	Any slope with obvious seepage lines.	Specific drains leading to the optimum collection of water.	Great care is needed to ensure all seepage water is trapped by the drain. Movement in the slope may affect this.
(iii) Deep surface drain types (deeper versions of the surface drains described above, designed to catch shallow ground water seepage).	As for each surface drain type described above.	As for each surface drain type described above.	Open drains allow easy cleaning and repair, as well as monitoring of effectiveness	The usual practical maximum depth is about 1.5 metres. Special care must be used to allow water to seep into the drains.

12.2.1 Construction Steps for Sub-Surface Drains

(i) The site should first be trimmed to an even slope. There should be no protrusions or depressions that will interfere with the bolsters. Loose rocks should be removed if possible.

(ii) Starting from the bottom of the slope, mark out the lines for the drains. The main drains should run straight down the slope. The branch drains should be at 45º to the line of the slope and each slanting piece should normally be 5 meters

(iii) Dig trenches along the lines, normally about 500 mm wide and 1000 mm deep.

(iv) Lay a sheet of black polythene along the bottom and lower side, but not the higher side, of the branch trenches (but not the main drain trenches).

(v) Lay 1.3 m wide Gabion bolster panels lengthways along the trenches.

(vi) Inside the wire mesh, lay sheets of geotextile terram paper and cut to the same dimensions.

(vii) Fill the main drain bolster with angular 40-70 mm chippings (aggregate). Stones must be poured in from above and packed firmly but at random within the mesh.

(viii) Fold the terram paper carefully over the stones so that there are no gaps. Then fold the upper edge of the wire bolster panel over the top and join it together.

(ix) Repeat steps vii and viii for each of the branch drains.

(x) Tie the wire of the branches (or herringbones or ribs) to the wire of main drain.

(xi) Backfill by soling (placing on end) around and above the bolsters with boulders of 100-200 mm size.

(xii) Compact the material around the drains and clean away surplus debris as necessary.

(xiii) Implement bio-engineering works throughout the site.

12.3 Gully protection work

In the process of water flow there will be the tendencies of widening, deepening and further scouring of the flow channel. The channel thus formed is called a gully. Any activity to prevent the gully from deepening, widening and further extension is called gully protection work. Check dams are simple physical constructions to prevent the down cutting of runoff water in gullies. They ease the gradient of the gully bed by providing periodic steps of fully strengthened material. Check dams are designed to accept an active pressure if it applied in the future, while permitting a safe discharge of water (and perhaps debris) via a spillway.

12.3.1 Practical features

- Choose locations for the check dams so that the maximum effect can be achieved using the minimum possible volume of construction.
- Excavate a foundation in the gully bed on a sound layer. The base of the dam should be at least 660 mm thick if it is one meter high. For every additional meter of height, add a further 330 mm to the width.
- Construct the check dam using the best-drained and most cost-effective materials. If possible, use dry stone masonry or gabions to improve drainage.
- If using concrete-bound masonry, include weep holes to drain water from behind the check dam and reduce hydrostatic pressure.
- The ends of the dam should be keyed right into the gully sides and should be raised at least 250 mm to form a central spillway or notch. This ensures that water coming over the dam will then run down the middle and not scour the ends.
- An apron must be provided below the dam to ensure that energy is dissipated and that flow continues in the center of the gully below the check dam.
- If there is a risk of people or animals damaging the top of the dam or if it is in a gully likely to take a large flow of water, point the top layer with cement mortar.
- Once the construction of the check dam is completed, backfill behind the wings and sides and compact the fill thoroughly.

12.3.2 Longitudinal profile of gully

Over the 100 m section of gully there are three favorablel locations for check dams. These are shown in the sketch below.

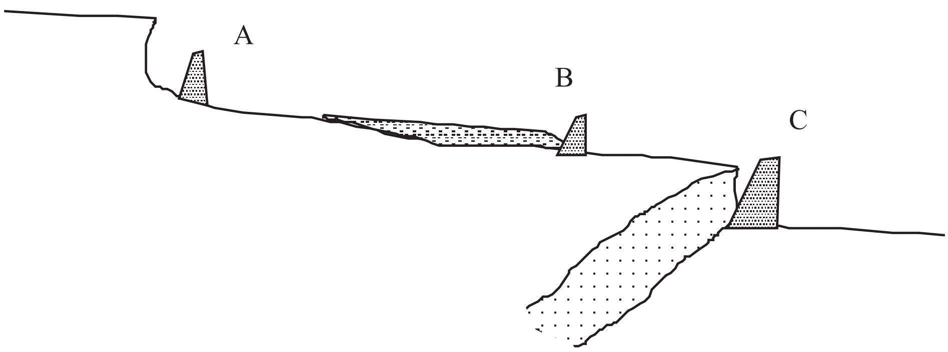


Fig. 12.3 : Longitudinal profile of gully

12.3.3 Cross section of gully

A checkdam should have a top profile that encourages the water to flow through the center, not near the ends, where it will scour the gully sides and possibly expose the extremities of the checkdam. The ends should be keyed at least 0.5 m into the bank at each side and a similar depth into the floor. Masonry checkdams should have weep holes all the way up. Water flowing over a checkdam to the left or right of center can strike the side walls of the gully on the downstream side. This will cause undercutting and scour. Planting and stone pitching should be laid to prevent this.

Debris halted in its path by a checkdam often comes to rest in a convex heap causing the stream to flow along the edges of the debris, against the bank. The stream can scour the bank widening the gully and bringing very large quantities of debris into the bed. This situation is even more difficult to deal with than a V-notch cross section. However, it is a consequence of installing checkdams and it must be considered in the design of schemes. Bioengineering measures must be added along the lower gully sides. Resilient shrub such as 'simali' (Vitexnegundo) is probably the best for this, as it resists partial burial and battering by rocks. 'Simali' has good root systems to resist scour by armoring the surface, and to support the bank, and it traps or catches debris. The plants should be planted when the checkdams are being installed to allow them to grow as large as possible before they are called resist moving debris. If the stream starts to undercut the banks very actively, guide walls can be considered in addition to a program of planting. The top of the gully sides can be smoothed off into the surrounding hill side and the whole planted with grasses. The gully side slopes can be protected with shrubs and small trees, especially at the base, where support will be needed. Grass can be used on the middle part.

12.3.4 Stabilisation of a gully head

Stone or masonry apron should be installed with plants below on the downstream edge.

12.3.4.1 Sketch design of civil engineering works to stabilise gully head

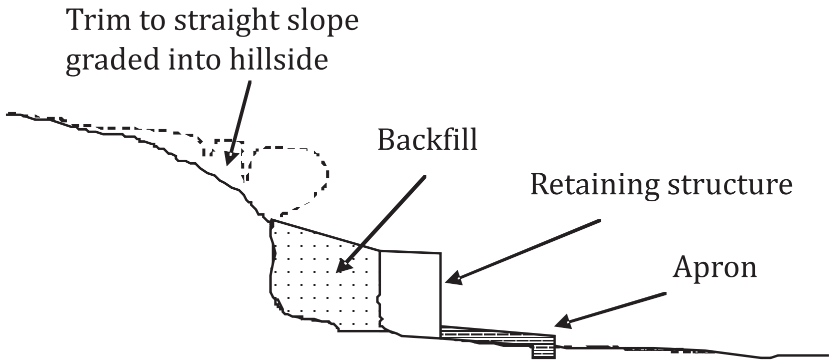


Fig. 12.3 : Civil engineering works to sketches gully head.

12.3.4.2 Bioengineering scheme to stabilise gully sides

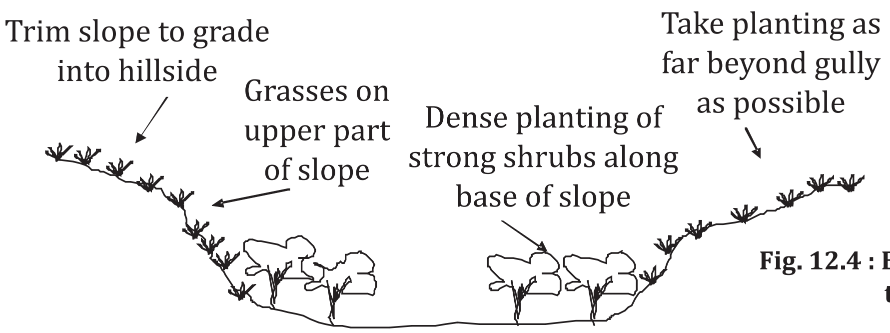


Fig. 12.4 : Bio-engineering scheme to stabilise gully sides.

12.3.4.3 Sketch design for bioengineering scheme to stabilise gully head

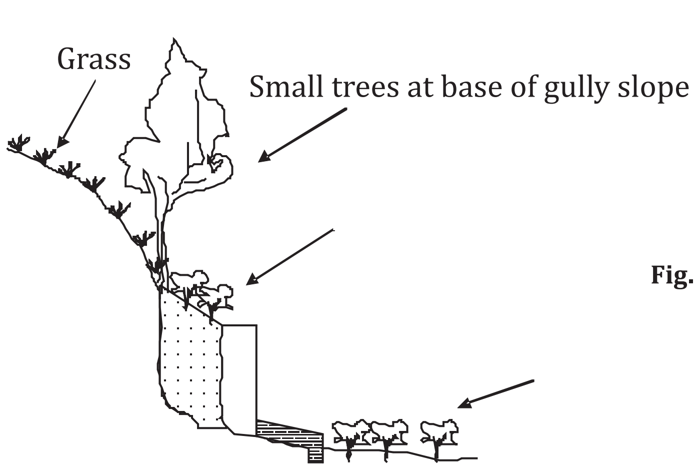


Fig. 12.5 :Sketch design for bioengineering scheme to stabilise gully head

Small-scale civil engineering systems field exercise

In this exercise, you will examine three sites with different instability problems. In each case, combinations of small-scale civil engineering and bioengineering have been used to stabilize the area. Today you should concentrate on the site characteristics and the small-scale civil engineering systems. You will be examining the vegetative structures on these sites in a future field exercise.

You have 20 minutes for examining each site and the civil engineering structures on it. The points listed below will guide you as you carry out this examination. Draw a sketch map of the main features of the site to help in your evaluation.

When the time for site examination is up, you should be ready to discuss your conclusions with the other group working on the site.

Your investigation should be based on :

- the nature of the parent material and soil.
- the causes and mechanisms of failure on the slope.
- what small-scale civil engineering systems are present.
- what engineering functions they perform.
- how they perform these functions.
- how well the systems are fit to the site.
- what alternative systems could be used on this site.
- how well the systems are working and if they are not working why they are not.
- any weaknesses in the way, in which they have been implemented.
- any unavoidable weaknesses in the systems.

Keep a note of the information that is collected and the points that come up during the discussion. These will form the record for the session.

■ ■ ■

Vegetative engineering systems

14.1 Introduction

The structures constructed for the purpose of slope stabilization and protection work with the use of living plants or plant materials are named as vegetative engineering systems. There are mainly three systems:

- Bioengineering systems developed from the use of seed.
- Bioengineering systems developed from the use of seedlings.
- Bioengineering systems developed from the use of live cuttings.

14.2 Types of grass planning

14.2.1 Seeding

- Broadcasting.
- Direct sowing in holes.
- Suitable for sandy site.
- for armouring and reinforcing.

Seedling

- Tree and shrub planting
- Slope up to 30 degree.
- Spacing 1m x 1m
- Engineering function
- Support, anchor and reinforce

14.2.2 Grass planting

Horizontal line of grass planting

Spacing:

Line to line

= 100 cm –if the slope angle of the slope is<300

= 50 cm –if the slope angle of the slope is300 –450

= 100 cm –if the slope angle of the slope is>450

Plant to plant 10 cm

Main function: catch, armoring and reduce run off surface

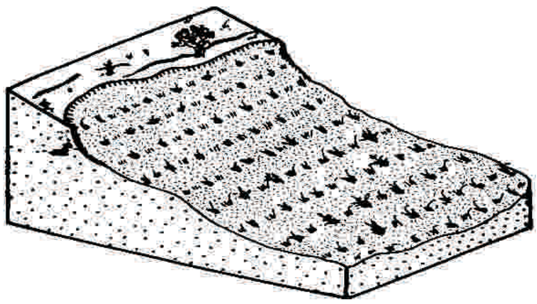


Fig. 14.1 : Horizontal line of grass plantation.

14.2.3 Vertical line of grass planting

Spacing:

- Line to line 50 cm.
- Plant to plant 10 cm.
- function : surface drainage, reduce infiltration and armour.
- On slopes up to 65 degree, clay type soil.
- Limitation: likely to develop rills.
- Diagonal line of grass planting.

Spacing:

- Line to line 50 cm.
- Plant to plant 10 cm.
- Function : Surface drainage, reduce infiltration and armour.
- On slopes up to 65 degree, damp sites.

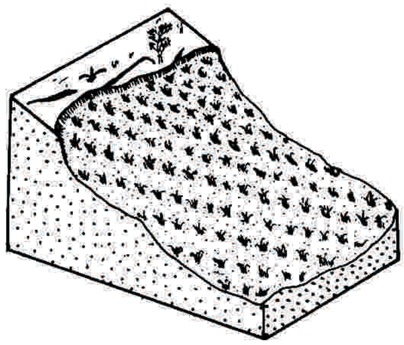


Fig. 14.2 : Diagonal line of grass plantation.

14.2.4 Chevron and herringbone pattern of grass planting

- Widely used in new gully and ridge

Spacing:

- Line to line 50 cm.
- Plant to plant 10 cm.
- Function: Drain and armour.

14.2.5 Random grass planting

Spacing : 10 cm x 10 cm

- On slopes between 45 to 60 degree and 15 m slope length.
- Function: Armour and reinforce.

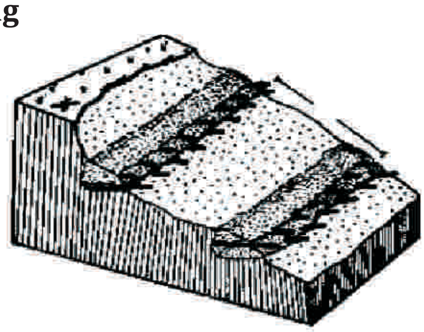


Fig. 14.3 : Brush layering

Table 14.1 : Design aspects of vegetative engineering structures

System	Functions	Method of operation	Applications & site requirements	Time to maturity	Limitation
Horizontal line grass planting	Catches, reinforces, supports	Dense line retards surface water flow	Dry, slope <45^o, erodible, cut slope	2 seasons	Thin line easily broken
Diagonal line grass planting	Catches, reinforces, some support	Dense line guides water along the line	Wet, permeable, fine, cut slopes	2 seasons	Rills break through
Grass seeding	Catches, reinforces, supports	Dense grass, mat, rooting system	Consolidated debris slopes <45^o	3 seasons	Can cause liquefaction, young plants get washed away or dried
Palisades	Catches, reinforces, supports	Dense line above and below the ground retards surface and shallow water flow	Slope <30^o, dry, erodible and consolidated debris	2 seasons	Causes small slumps, requires many cuttings, high mortality
Brush layering	Catches, reinforces, supports	Dense line, strong buried branches retard surface and shallow ground water flow	Slope <45^o, dry, erodible and consolidated debris	One season if planted early and watered	Destructive to slopes during the excavation, requires many cuttings
Fascines	Catches, supports, drains	Woody bundle, dense stems, porous, can drain soil if laid down	Consolidated debris slopes, <45^o	3 seasons	Destructive to slopes, requires many cuttings, slow to develop, high mortality
Shrub planting	Transpires, catches, armours, reinforces, anchors, supports	Bunchy leaves, multiple stems, lateral roots, root cylinder, tap roots slope	Any slopes < 45^o	At least 4 seasons	
Tree planting	Transpires, armours, reinforces, anchors, supports	Lateral and near vertical rooting systems, root cylinder	Any debris slopes <45^o, gully side slopes	At least 5 seasons	Top heavy on steep slopes, leaf drip, canopy shades smaller plants
Bamboo planting	Transpires, catches, armours, reinforces, supports	Dense poles, massive rooting systems, dense leaves, grows all year	Slope <30^o, base of slope, erodible slopes, preferably wet places	At least 5 seasons	Source plant damage, delicate, requires nursery space, heavy to transport

14.3 Implementation of vegetative systems

14.3.1 Direct seeding (grass and shrubs)

14.3.1.1 Grass Seeding

- prepare the site well in advance of the date of sowing. Remove all irregularities likely to allow slumps or gullies and clean loose debris away.
- immediately before sowing, scarify the surface of the slope. This means scratching the surface or carrying out basic cultivation to give a loose surface into which the germinating grass seeds can send their roots.
- spread the seeds or grass seed heads liberally over the slope. Ideally, the whole surface should be very lightly covered in seed material. An application rate of 25 gms per square meter is normal.
- cover the seeds completely with a layer of mulch, made from cut herbs such as eupatorium adenophorum (banmara), or with hessian sheeting. Vegetation mulch is preferable.

14.3.1.2 Shrub and tree seeding

- Clear all loose debris from the site.
- Make a small hole, a little bigger than the seed, using a planting bar.
- Push the seed right into the hole and cover it with soil; or, if it is in a rocky crevice, check that it is right out of direct sunlight. Make sure that the seed coat is not damaged in this process,
- Seeds are normally shown at a rate of one every 25cm, centre to centre.

14.3.2 Planting grass lines

- Prepare the site well in advance. Remove all debris and either remove or fill in surface irregularities so that there is nowhere for erosion to start. If the site is on backfill material, it should be thoroughly compacted, preferably when wet.
- Always start grass planting at the top of the slope and work downwards.
- Mark out the lines with string using a tape measure. Make sure they run exactly as required by the specification, whether it is contour, diagonal or down slope.
- Split the grass plants out to give the maximum planting material. Trim off long roots and cut the shoots off about 10cm above ground level. Wrap the plants in damp hessian to keep them moist until they are planted.
- With a planting bar, make a hole just big enough for the roots. Place the grass into the hole, taking care not to tangle the roots or have them curved back to the surface. Fill the soil around them, firming it gently with your fingers.
- If compost or manure is available, scatter a few handfuls around the grasses. If the site is very stony, this is important for improving early growth. You may have to incorporate it into the surface material to prevent it from being washed off.
- If it looks rather dry and there is no prospect of rain for a day or two, consider watering the plants.

14.3.3 Planting shrub and tree seedlings raised in polypots

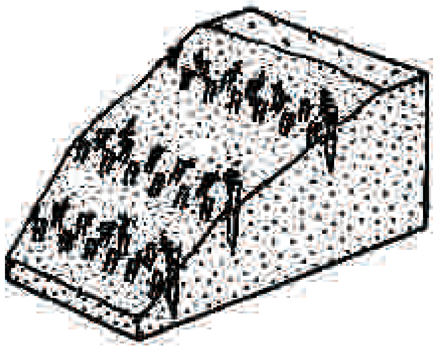
Prepare the site well in advance of planting. Remove all debris and remove or fill surface irregularities. If the site is on backfill material, thoroughly compact it, preferably when it is wet. Cut all weeds.

- If possible, dig pits for the shrubs or trees well in advance of the planting program, but refill them the same day.
- When the ground is wet enough to support reasonable growth, plant out these seedlings. The bigger the hole made, the better it is for the plant; but there must be a compromise between helping the plant and avoiding excessive disturbance to the slope.
- Carefully remove the polypot by slicing it down the side with a razor blade to tear it carefully along the joint. Take care not to cut the roots.

- Plant the seedling in the pit, filling the soil carefully around the cylinder of roots and soil from the polypot. Ensure there are no cavities. Firm the soil all around the seedling with gentle foot pressure.
- If available, mix a few handfuls of well- rotted compost with the soil around the roots when you are back filling the hole.
- Remove any weeds around the plant; add mulch so that it does not touch the stem.

14.3.4 Planting lines of hardwood cuttings (Palisades or "live staking")

- Before planting, trim and clean the site removing irregularities and loose debris.
- Mark out the lines to be planted with string.
- Always start at the top of the slope and work downwards.
- Using a pointed bar, make a hole in the slope that is bigger than the cutting and deep enough to take at least two thirds of its length.
- Carefully place the cutting in the hole; preferably so that at least two thirds is buried firm the soil around it, taking care not to damage the bark. Ideally, only one node of the cutting or about the top 3cm should protrude from the soil. On steep, unstable sites, however, a greater protrusion helps to raise the delicate new shoots above the zone of moving debris and to trap more debris.



14.3.5 Brush layering

Using string mark the lines to be planted, starting 50cm from the base of the slope.

- Always brush layer from the bottom of the slope and works upward.
- Form a small terrace with a 20% fall back into the slope. The terrace should be 40cm wide. If you are brush layering a gravel-filled road embankment slope you should by a 5cm thick layer of soil along this terrace to improve rooting conditions.
- Lay the first layer of cuttings along the terrace, with 5cm interval between the cuttings. Leave at least one bud and up to 1/3 of the cuttings sticking beyond the terrace edge and the rest inside. The branch growing tips should point towards the outside of the terrace.

Brush Layering

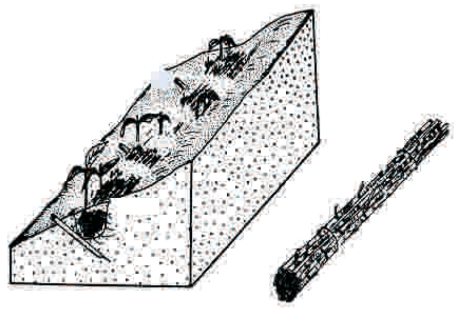
- Lay a 2cm thick layer of soil in between the cuttings to provide loose cushion.
- Lay a second layer of cuttings on the top of this, staggered with the first layer. On a gravel-filled embankment slope, lay an 8cm layer of soil over the cuttings before you do any backfilling.
- Partly backfill the terrace with the excavated materials. This should not more than 5cm thick.
- Mark a line 1m above the first brush layer and set the string for the next layer.
- Follow steps 3 to 7. As the next terrace is cut, always fill the lower bench with the material excavated from above and compact it reasonably well by gentle foot pressure

14.3.6 Fascines

Prepare the site well in advance. Clear all loose material and protrusions and firmly in fill depression.

- Mark on the slope the lines were fascines are to be installed. Supervise workers carefully to ensure that the lines follow the contour or desired angle precisely.
- Always construct fascines from the bottom of the slope and work upwards.

- Dig about 5 meters of trench at a time, carrying out step 5 at the same time. This ensures that the soil in the trench is exposed only for a short period, retaining residual soil moisture. The trench should be about 20cm deep and 20cm wide.
- Lay the cuttings together, filling the trench and with their ends overlapping so that they form a single cable right across the slope. Four cuttings per bundle are normal, but sow eight per bundle if there is a lot of material available or if the site is very critical.
- The fascines can be bound as first laying strings across the trench and then tying it when the cuttings are in place install them. This helps to keep the cuttings together during backfilling but is not essential.



- Backfill the trench as soon as possible, lightly covering the cuttings, and tamp the soil down firmly around it.
- If the slope angle is more than 25°, you should peg the fascine. Hammering a large cutting into the slope immediately below the fascine can do this. Use one peg per 50cm run fascines.

14.3.7 Planting bamboo culms cuttings

- Keep the root ball wrapped in wet hessian until you are ready to plant it,
- Remove loose debris from the site and carry out other site preparation in advance.
- Dig a sufficiently large hole and plant the cutting in it.
- Carefully backfill the hole, making sure that buds are not damaged to the base of the cutting. Firm the soil.
- Place a layer of mulch over the disturbed soil and the surrounding area.
- Water thoroughly.
- Do not place bamboo cuttings closer than 2m apart across the slope or 5m up and down it.

14.3.8 Live check dams

- Choose the location for the live check dam so that the maximum effect can be achieved.
- Make a hole deep and big enough to insert vertical hardwood cuttings of the largest size available (cuttings of up to 2 meters in length are best). Use a crowbar if necessary.
- Insert the vertical cuttings by carefully pushing them into the hole and firming the soil around them. They should protrude about 30cm above the ground surface.
- Place fascines or long hardwood cuttings on the uphill side of the vertical stakes.
- Key these horizontal members into the wall of the gully.
- Backfill around the check dam and compact the soil with foot pressure.

Interaction between plants and inert structures

In slope stabilization we may have a choice whether to use civil engineering on its own, or vegetative engineering alone, or combination of the both.

As slope stabilization technicians, we need to understand the principles underlying the relationship between vegetative engineering systems and civil engineering systems.

15.1 Relative strength of structures over time.

The strength of a structure at different stages of its life can be related to its maximum strength. This can be described as a percentage of the maximum strength.

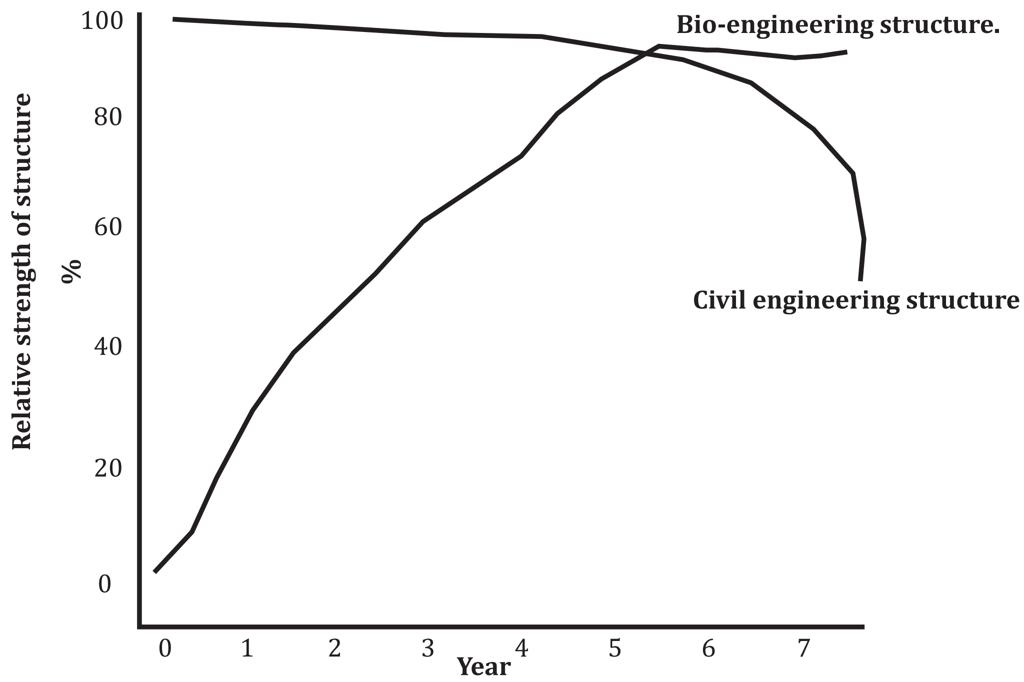


Fig. 15.1 : Yearwise strength comparisons of civil engineering structure.

As the relative strength of engineering structures decrease, the relative strength of plant structures increase. They do not compare the actual strength of the civil engineering structures compared with the strength of the vegetative engineering structures.

Jute net and grass can both be used to perform a catching function. In the beginning the fine soil retaining capacity of the jute net is very high and each small square behaves as mini check dam. With time the jute decays which weakens the net and consequently its soil retaining capacity decreases. Ultimately the net will fail to carry out any retaining function. The grass slips grow with time and start to retain soil on the slope due to the development of root and shoot systems. When grass is fully grown, it stays at 100% relative strength. As the relative strength of the jute net declines the relative strength of the grass increases. The soil retaining function of the jute net is handed over to the grass.

15.2 Physical relationships between civil and vegetative engineering structures

Various relationships may exist between the functions of civil and vegetative structures:

a. toe wall below bamboo - structure protects plant
b. plants around end of toe wall - plant protects structure
c. trees above toe wall -plant improves performance of structure
d. fence with young plants below -plant replaces structure.

15.3 Selection of optimal techniques

Choosing optimal stabilization techniques is a complicated process, which is not fully understood. There are many variables, most of which cannot be measured in the field. These notes give a practical analysis to reach an optimum course of action. Do not consider this information definitive. Always remember the most important part of the analysis is attention to detail.

A slope segment can be defined as a length of slope with a uniform angle and homogeneous material that is likely to erode in a uniform manner. The most straightforward way to approach the choice of stabilization technique is to split sites into segments of slopes. The assumption is that each segment can be treated using the same technique or techniques. But first, there are two important questions to answer.

Table 15.1 : Selection of optical technique

Question	Action if answer is yes
Is the slope segment longer than 15 metres?	There may be a risk of serious surface erosion. Therefore some kind of physical scour check should be used, such as wire bolsters.
Is the slope made up of poorly drained material, with relatively high clay content?	There is a danger of shallow slumping. Techniques used on this sort of material must be designed to drain rather than accumulate moisture.

15.4 Guidelines for applying bioengineering techniques

The diagram entitled 'Guidelines for applying bioengineering techniques to all slopes', is an attempt to define the techniques to be used on different sites. Many factors determine the optimum technique or combination of techniques, but only the most important have been included here for the sake of simplicity. The following notes explain the five columns.

15.4.1 Slope angle

This is the primary distinction, as it is used to identify the sites which need only mild soil conservation treatment, i.e., those less than 30°. A slope steeper than 45° will present greater erosion problems.

15.4.2 Slope length

The length of 15 meters is partly arbitrary but represents a good dividing figure between 'big' and 'small' sites. Slope segments longer than 15 meters are open to greater risks in terms of both gullying and deep-seated failures.

15.4.3 Aspect

Aspect is the orientation of a site relative to the sun. It also covers the environmental dryness of each individual site. The entire site moisture regime must be considered.

15.4.4 Material drainage

This column relates to the internal porosity of soils and the likelihood of their reaching saturation and losing cohesion, thereby starting to flow. Those materials, which have poor internal drainage, tend to have high content of clay relative to sand and silt in the fine fraction. They tend to be prone to shallow slumping if too much moisture accumulates. Stabilization requires some kind of drainage in addition to protection

15.5 Optimal techniques

One or more techniques are given which are known to be successful on general sites of each type. However, the general picture may not cover every case and so this flow chart cannot be considered fully comprehensive. Some local variations may be needed; the engineer needs to determine this on site.

Table 15.2 : Guidelines for selection of optimal techniques

Slope angle	Slope length	Aspect	Material drainage	Optimal technique
START ⬇	➡	➡	➡	➡
$>45^{0}$	>15 metres	N, NE (NW,E)	Good	Diagonal grass lines
		S, SW (SE,W)	Good	Contour grass lines
		N, NE (NW,E)	Poor	1 Downslope grass lines and strengthened rills or 2 Chevron grass lines and strengthened rills
	>15 metres	S, SW (SE,W)	Poor	Diagonal grass lines
		Any	Good	Jute netting and planted grass
		N, NE (NW,E)	Poor	1 Downslope grass lines or 2 Diagonal grass lines
		S, SW (SE,W)	Poor	1 Jute netting and planted grass or 2 Contour grass lines or 3 Diagonal grass lines
30^{0}-45^{0}	>15 metres	Any	Good	1 Horizontal bolster cylinders and tree planting or 2 Downslope grass lines and strengthened rills or 3 Grass seeding, mulch and wide mesh jute netting
			Poor	Herringbone bolster cylinders and tree planting
	>15 metres	Any	Good	1 Brush layering with woody cutting or 2 Contour grass lines or 3 Grass seeding, mulch and wide mesh jute netting
			Poor	1 Diagonal grass lines or 2 Herringbone fascines and tree planting or 3 Herringbone bolster cylinders and tree planting
$<30^{0}$	Any	Any	Good	1 Contour strips of grass and trees or 2 Tree planting
			Poor	1 Diagonal lines of grass and trees or 2 Tree planting
Any	Any	Any rocky material		Direct seeding of shrubs or small trees

Notes: 'Any rocky material' is defined as material into which rooted plants cannot be planted but seeds can be inserted in holes made with a steel bar.

A chevron pattern lokks like this: <<<<<

A herringbone (fish bone) pattern looks like this: ↼↼↼↼↼

Bioengineering systems field exercise

This exercise will be carried out on the three sites you used for the examination of civil engineering systems. This means that you should be concentrating on the vegetative structures and the interaction between the civil and vegetative engineering systems.

At each site, you will spend 20 minutes examining the existing systems and evaluating them. You will find that drawing a sketch map of the main features of the site helps your evaluation. Then you will discuss your conclusions with the other group working on the site.

Your discussion should be based on :

- what systems are present
- what engineering functions they perform
- how they perform these functions
- how the civil and vegetative systems are integrated
- how well the systems are fit to the site
- what alternative systems could be used on this site
- how well the systems are working or not working. If they are not yet ready to function, when are they going to take over the job
- any weaknesses in the way in which they have been implemented
- any unavoidable weaknesses in the systems

Keep a note of the information that you collect and the points that come up during the discussion. These will form your record of this session.

■ ■ ■

Selection of bioengineering species

17.1 Factors governing distribution of vegetation in Nepal

Plant type selection is a skilled job in bioengineering. There are more than 10,000 plants in Nepal. About 6,000 are easily available in all parts of the country but only a few selected plants are recommended for bioengineering. In Nepal, the vegetation bands are broadly related to altitude. The main factors, which govern the distribution of vegetation, are:

- Altitude
- Aspect
- Rainfall and its distribution
- Geology and soils (relatively minor scale Plant distribution depending on the physiographic zones of Nepal

Nepal can been divided into six ecological zones, with one of them divided into two sub-zones. They are:

- Terai
- Chure
- Inner Terai
- Lesser Himalaya
  - MahabharatRange
  - Midlands
- Higher Himalaya
- Trans-Himalaya

17.2 Vegetation zones

Although the classification of vegetation types is based primarily on altitude, we must not think that the altitudinal zones descriptions are rigid. Many tree species occur over a wide range of altitudes, and though they may predominate in a particular zone, they may also occur in zones above and below it. For example, 'gobre salla' (Pinus wallichiana) has its main range from 1,800 meters to 4,000 meters, but it may occur 80 or 100 meters below this level.

The following lists provide some examples of the vegetation types found in different zones.

(i) Tropical zone: upper boundary at about 1000 m

- sal forest
- khayer + sisau forest
- other riverain forest
- grassland
- asnaforest

(ii) Sub-tropical zone: range 1000 - 2000m in the west and 1000 - 1700m in the east

- khote salla
- chilaune + katus
- utis
- riverain forest (tooni + siris).

(iii) Lower temperate zone: range 2000 - 2700m in the west and 1700 - 2400m in the east

- khasru
- gobre salla
- banjh
- lower temperate mixed broadleaf forest.

(iv) **Upper temperate zone:** range 2700 -3000 m in the west and 2400 - 2800 m in the east
- banjh
- gurans
- coniferous forest (gobre salla)
- broadleaf forest

(v) **Sub-alpine zone:** Range 3000 - 4200 m in the west and above 3000 m in the east:
Basically, forest species are found growing in the cool desert areas having a rainfall of less than 300 mm/year. Small spiny shrubs are found in the Mustang and Dolpa areas. Species include gurans, gobre salla and dhupi.

(vi) **Alpine zone:** Above the snow line: Species include gurans, dhupi, thorny plants and shrubby species.

17.3 Local species

We can only produce a list of the locally available species in an area by carefully examining it. These are some of the local species that are found within the Kurintar area:

Trees:	Sal, bhalyo, banjh, kavro, simali
Shrubs:	Paineti, asuro, dhanyero, areri, dhusun
Grasses:	Sito, muse kharuki, kans

17.4 Selection of plant species based on plant community

Plant community is defined as an established group of plants living more-or-less in balance with each other and their environment. The group can be natural or managed.

17.5 Ideal plant communities for bio-engineering

An ideal plant community for bioengineering will contain a variety of different plants, which meets the engineering needs of the site.

17.6 Management of plant communities in bioengineering

a. Do not use single species at first, have a mixture of plants in the initial planting. If you rely on one species and this fails, there may be a complete loss of the planted material.
b. Start with pioneer species. For example, with a damp and north facing slope you might introduce utis and some under story grasses.
c. Plan a balance of plant species in the community including grasses, shrubs and trees.
d. Remember that dominant plants such as utis must be replaced or thinned out within three years. Otherwise, the under story plants will be overshadowed and eradicated completely.
e. Thin the plants out properly to maintain a balance.
f. Clear weeds to reduce competition.
g. Replant gaps.
h. Always think whether the selected plant is the associated plant of the dominant species.

It is always recommended that the improvement plants should be introduced for rapid establishment of plants. Likewise, the pioneer plants are the choice for the sites in the initial stages and colonizers should be avoided to keep the system functional.
The other factors to be considered for the selection of plant species are:

17.7 Availability

Availability means the planting material has to be obtainable where it is wanted, at an affordable price, when it is required and in the required quantities. Local species are generally better suited than species from another area to conditions in a particular place. This means that our first choices are generally plants that are found in the area where bioengineering is being implemented. Nurseries are established in order to provide the planting material that is required, at the right time and in the right place. If the availability requirement is to be met they must be well managed.

Health may also affect the choice if we are selecting between a species which suffers from disease and one which is resistant to diseases.

17.8 Selection of plant species according to morphological characteristics

There is vast diversity of plants with regards to the shape and size of their parts. You will look at the major types of roots, stems, and leaves, and will be able to find out their role in slope stabilization. There are various types of roots: some are very deep and others are shallow, some have many lateral roots and others do not. Obviously, each type will perform different types of engineering functions. Similarly, strong and rigid, weak and flexible or creeping stems and the shape and size of leaves affect soil erosion control and slope stabilization depending on the environmental conditions of the site.

17.9 Growth characteristics of bio-engineering species

In bioengineering, we require plants which will become well-established in the season of planting so that they are able to survive the dry months until the next monsoon. Many bioengineering sites have very poor soils which drain easily. This makes good establishment even more important.

17.10 Persistence

Many plants are annuals. This means they complete their life cycle in less than a year and then die. If we were going to use them for bioengineering, we would have to replace them every year and they would never become established as strong plants.

Clearly we will not want to use annual plants. Neither will we want to use plants that only have a short life cycle of more than one year unless they fill a special role until a plant which lives longer can become established. Many of the plants we use are trees and shrubs and others are perennial plants such as many of the grasses which will live for several years.

17.11 Ease of propagation

In bioengineering, a large amount of planting material is required. Kans, a grass commonly used in bioengineering is propagated by slips. A slip is a piece that is separated from a clumping grass so that it has shoots with buds and as much roots as possible. Thousands of such slips may be grown in a nursery. Therefore, only the species, which can be easily propagated by slips, can be regenerated with this method.

17.12 Selection of species based on drought factor

Depending upon the drought factor, an appropriate species can be selected from the list provided in the Bioengineering Site Handbook, page 130-143. For this purpose, some characteristics of the site are assessed. The factors to be assessed are: slope angle, stoniness altitude, rainfall intensity and aspect of the site. A scoring system has been developed based on the experience of roadside bioengineering.
The system is as follows:

		Slope	Score
a.	**Slope angle:**	< 30°	1
		30 - 34°	2
		35 - 39°	3
		40 - 44°	4
		45 - 49°	5
		> 49°	6

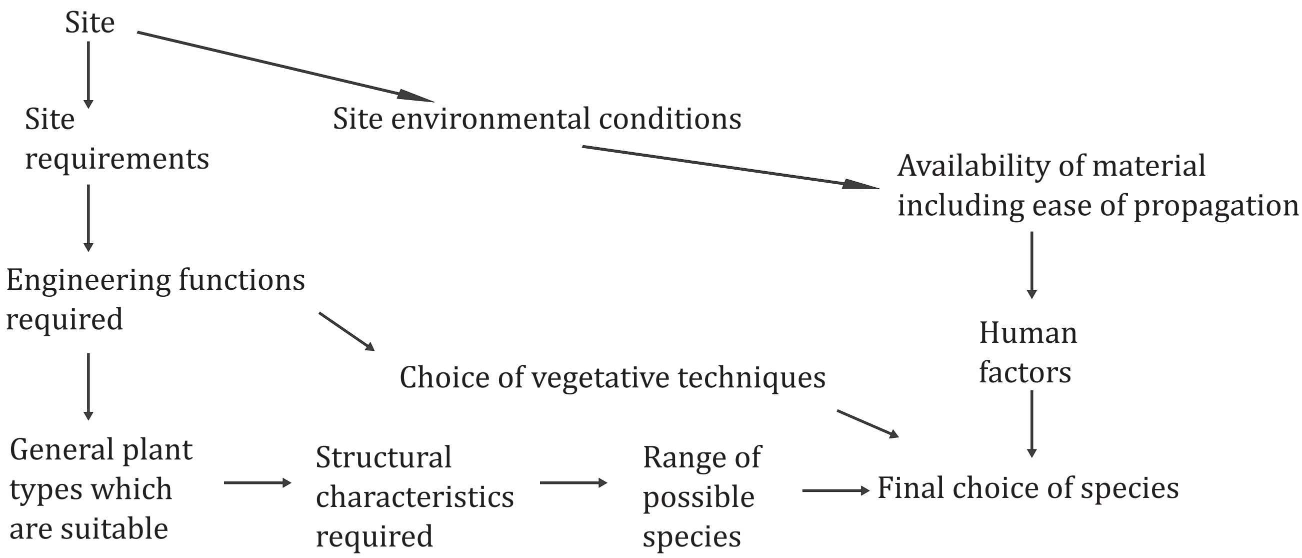
		Fines	Score
b.	**Stoniness:**	> 25%	1
		20 - 25%	2
		15 - 19%	3
		10 - 14%	4

		5 - 9%	5
		< 5%	6
c.	**Altitude:**	**Altitude**	**Score**
		> 2500 m	1
		2000 - 2500 m	2
		1500 - 1950m	3
		1000 - 1450 m	4
		500 - 950 m	5
		< 500 m	6
d.	**Aspect:**	**Aspect**	**Score**
		North	0
		Northeast	2
		Northwest	4
		East	6
		West	8
		Southeast	10
		Southwest	10
		South	12
e.	**Annual rainfall:**	**Rainfall**	**Score**
		> 2500 mm	1
		2000 - 2490 mm	2
		1500 - 1990 mm	3
		1000 - 1490 mm	4
		500 - 990 mm	6
		< 500 mm	8

Highway slope site drought factor classes:

Score	Class	Definition
< 6	I	Cool, moist sites
6 - 11	II	Damp sites
12 - 17	III	Moderately dry sites
18 - 23	IV	Warm, dry sites
24 - 30	V	Very hot and dry sites
> 30	VI	Very severely hot and dry sites

17.13 Selection of plant species for bioengineering



Bioengineering maintenance and care of young plants

Roads like any other structures are subject to deterioration with time even if materials standards and construction methods are monitored. Similarly bioengineering works also deteriorate with time. Deterioration commences as soon as each component of works is completed and is progressive.

Deterioration of bioengineering works may cause slope failure, followed by obstruction of traffic or even complete blockage of the road. This leads to costs for road users, social costs resulting from closure and road repair costs. To reduce such indirect and direct costs, maintenance of the bioengineering works is essential.

18.1 Categories of maintenance tasks

The tasks involved in maintenance can be divided into five groups:

a. Protection works:
   e.g. protection of plants and planting sites from grazing, theft of firewood and timber, and fire protection works.
b. Plant treatment:
   e.g. weeding, mulching, trimming, pruning, grass cutting, thinning and training of plants;
c. Repair to vegetation structures:
   e.g. repairs to palisades, fascines and brush layering, and turfing and vegetation enrichment.
d. Repairs to inert structures:
   e.g. repairs to revetment and prop walls, gabion walls, bolsters, jute netting and wire netting, and sealing cracks.
e. Geophysics:
   e.g. small slope trimming, small slip clearance, cleaning subsoil drain outlets.

18.2 Frequency of carrying out maintenance activities

Maintenance of bioengineering works can be divided into four categories in terms of the frequency with which it is carried out:

a. routine maintenance:
carried out continuously, though not necessarily at the same location repeatedly.

b. recurrent maintenance:
required at varying intervals during the year with a frequency that depends mostly on the seasons.

c. periodic maintenance:
carried out at longer intervals and is particularly related to the replacement of worn out civil engineering structures.

d. emergency maintenance:
needed to deal with emergencies and problems calling for immediate action e.g. when the soil slope is threatened.

18.3 Care of young plants

Environment Management

18.3.1 Shading

Plants in all nurseries in Nepal require shading. It is needed for a variety of reasons at different stages of growth but needs to be used carefully. Unfortunately, it is often poorly managed or misused. The shades may be left on for too long or used at the wrong time. Although the comparatively cool, humid conditions in the nursery are good for young plants, they will suffer severe shock if they are suddenly exposed to normal conditions, especially if these are hot and dry. As a result, their chances of survival are much lower. It is usually needed during germination, for protecting recently pricked out seedlings, and for protection against adverse climate such as excessively hot sun, heavy rain, hail, or frost.

Shade reduces the day-time temperature and the rate of evaporation from the bed, particularly under hot sun. It generally makes conditions more uniform throughout the first 24 hours. Shade also reduces the amount of light reaching the plants. If it is left on too long the plants will grow tall, thin and weak or 'etiolated'. The plants may even lose their natural green color and become yellowish or 'chlorotic'.

In winter, if there is a danger of frost, raise shades each evening, remove them early the following morning. Do not leave them on all day at this season. Frost protection shades are most effective when they are just a few centimeters above the plants. Similarly, shades for protection against hail should only be raised when required and not left on indefinitely. Hail usually occurs in the months immediately before the monsoon and during this period raise shades at night or when staffs are absent from the nursery during the day. When the nursery staffs are present, they should only raise shades when a storm is seen to be coming. Similarly, during the monsoon, shade for protection against the rain should only be used when it is actually raining or at night or during the day when staff are absent.

Shade helps germinating plants because it slows the drying out of the growing medium and the seed. It also prevents damage from rain. Shade over germinating seed should be waterproof. Plants also require shade for a few days after they have been pricked out, to protect them from the sun and to keep the soil moist. However, shade over pricked-out seedlings is often kept too long. Remove it gradually, starting as soon as new leaf development is seen. At first, take the shades off for a short time in the morning and afternoon, keeping them in place at the hottest times. Gradually increase the time they are removed each day until after about a week the shade can be completely removed, without causing any damage to the plants.

The amount of shade needed during germination and after pricking out varies with the weather. If it is used when it is not necessary, for example during spells of cool cloudy weather, the beds may become too moist and this often leads to the development of damping-off disease.

Make shades of locally available materials. They should be easy for one person to handle and movable but capable of being fixed so that they cannot be blown away in strong winds. The height of the shade depends on its use. It should be about 30 cm above seedbeds and recently pricked out seedlings, and 75 cm above ground level for protecting larger seedlings against hail, hot sun and heavy rain. Construct beds along an east-west line if possible and the shade should slope downwards from north to south. The slope carries water off and the alignment gives maximum protection against the mid-day sun.

You can make shades from woven bamboo matting, hessian cloth or the stalks of maize or wheat. They should be wide enough to overhang the bed slightly and can be up to two meters long. Shades made from crop residues, grasses or leaves will only last one season. Longer lasting shades can be made from wooden or bamboo slats tied together with spaces between them to allow some light and air to penetrate. They can be rolled up for easy storage and unrolled very quickly when needed. They are heavy enough not to need fixing. They can have polythene sheets spread over them to make them waterproof when necessary.

18.3.2 Watering

Watering in most small nurseries is done most efficiently with an 8 liter watering cans or a hose pipe. Use a hose with more care than a watering can to ensure a uniform application. One may try to speed the process up by removing the rose and using their fingers on the end of the hose to direct a jet of water at the beds. This damages both plants and soil and should not be done. In a standard nursery producing 25,000 plants, a watering can is best. Use two sizes of rose, a fine rose for use on seedbeds and recently pricked out seedlings and one with a heavier spray for watering well-established plants and grass slips.

There are no rules for watering and it is a mistake to try to teach naikes to water on a fixed schedule. The amount and frequency of watering required varies with weather conditions, species, and stages of development of the plants, soil type, and nursery management such as the use of shade. An inexperienced naike cannot be expected to know how often and how heavily to water. It is far better to teach the naike the basic principles of plant water requirements and develop their experience. A good naike will quickly learn from experience.

Keep seedbeds, seed trays and recently pricked out seedlings moist but never allow them to become saturated. This often means frequent, small applications of water, sometimes two or more per day. However, shading and mulching reduce the need for frequent watering. In cool cloudy weather water may not be required at all on some days. Check the beds periodically so that decisions can be made on the needs of the seeds or plants. Remember that the object is to keep the seeds or the seedling roots moist but not soaking wet.

The rate of growth of plants in polypots or beds depends on the water supply. Plants which have begun to grow again after pricking out usually need watering once a day in the evening, but under very dry conditions they may need watering twice a day. When the plants are 10 - 15 cm in height only water them once a day. If they are growing too quickly you can water less frequently. Always do this towards the end of the nursery growing period as part of a process known as 'hardening off' of the seedlings. Unfortunately, in Nepal the period just before planting is characterized by pre-monsoon rains, so one loses some control over watering, and cannot harden off the plants as well as one likes. Because of these rains it may only be necessary to water occasionally from April to June (Baisakh to Jestha).

Apply enough water to wet the soil to a depth of 20 - 25 cm in beds and the whole of the soil in pots. You may have to water in two or three stages depending on the soil texture. If water is forming in pools on the surface of the bed or pot, the soil either has enough water already or it needs time to sink in. Stop watering, wait 5 - 10 minutes and then check to see if the water has penetrated deeply enough or if more is required. After watering, the soil should not be so moist that water can be squeezed out of it by hand pressure. Weed, lichen and moss growth on the soil surface slows down and even prevents water infiltration into the soil. With heavier soils the surface may become 'crusted' or compacted, and this also hinders infiltration. Keep the surface free of weeds and break up crusted or compacted soils by cultivating the beds with hand tools, and the soil surface of pots with small sticks.

Always check the soil to the required depth before and after watering, to see if watering is required and when enough has been applied. Too much water is likely to cause just as many problems as too little. A frequent cause of fungal diseases is excessive moisture.

You can water very small seed by placing a seed tray, with holes in its base, inside another slightly larger tray containing water for a few hours. The germination medium in the seed tray will absorb water from the outer tray. You can add water to the outer tray when the surface of the germination medium shows signs of drying out. This is one way of avoiding the problems of watering small seeds with watering cans.

18.3.3 Nursery irrigation systems

In nurseries on fairly level ground with an abundant supply of water, you can use flood or capillary irrigation for plants in beds. This is particularly useful in large grass nurseries. In both these methods, water is taken to the beds through a series of canals. A main canal distributes water from the source to a series of secondary canals built at progressively lower levels. Water is directed into any particular part of the nursery by opening and closing the entrances to the canals. You can do this with short lengths of bamboo, which can be stopped up, passing through the walls of the main canals, or wooden or metal plates can block the canal opening, or water can be allowed to pass by simply breaking down and later rebuilding the canal walls.

In capillary irrigation, canals are built below the level of the beds, about one meter apart. Water is directed to the canals around a section of beds and the canals are left full so that the water moves into the beds from beneath and is immediately available in the rooting zone.

Flood irrigation canals are built above the level of the beds and may be as much as 10 m apart. Water from them is flooded onto the beds, which must be very level. This system can damage the plants if silt collects on them and it may block up the pores in the soil surface and form a hard crust, impeding water infiltration. It also tends to cause fungal diseases.

Both systems require well-planned nursery beds and canal systems and large quantities of water. They are not likely to become important in small nurseries in Nepal.

18.3.4 Spacing out plants

Grasses can be multiplied rapidly in the nursery, particularly if they are planted as slips into beds by the best method for each species. When they have grown up and completely filled the beds and the clumps have almost joined, lift them, split them and plant them again. By re-spacing the grasses, you can maximize the rate of shoot and root production. One bed of large plants ready for splitting usually fills at least three beds once transplanted. This can be done three times a year in a fertile nursery below 500 meters altitude but correspondingly less frequently with increasing altitude. Do not re-space within six weeks of the grass plants being required for transfer to site.

The lifting, splitting and replanting procedures are exactly the same as for the initial planting. The slips should have a shade of a sheet of hessian and watered for a few days after re-spacing.

18.3.5 Pricking out

This is the process of transferring seedlings from the seed beds to polypots. It is a very delicate operation which should be done with great care, preferably by workers with previous experience. For most species the best time is shortly after germination, when the seedlings have only three or four primary leaves in addition to the cotyledons. If pricking out is delayed, the roots will be too long, and many lateral roots will have developed. The seedlings are then much more difficult to prick out without damaging, or distorting the roots. Pine seedlings can be pricked out three or four days after germination, when the seedcoat is still attached to the cotyledons giving the appearance of a match-stick. Do the pricking out on a cloudy day or in the late afternoon or evening.

18.3.6 Polypot management

Spacing out polypot seedlings

Plants growing close together in the nursery compete for moisture, nutrients and light. Their growth and form is affected and they become tall and thin, with weak, soft stems and poorly developed root systems.

When the plants are in polypots, the density is determined by the number of seedlings growing in each pot, the size of the pot and the space between one pot and another. After direct sowing many pots may contain two or more seedlings. Reduce the number in each pot to one. Use the extra seedlings for pricking out into pots with no seedling, or simply destroy them. Sometimes nurserymen will leave two seedlings in a pot thinking that if one dies there will still be a plantable seedling left. Two seedlings may be produced but both are likely to be of unacceptably poor quality for planting out.

Plants grown in 4" × 7" pots to a height of over 30 cm do not have enough growing space. Provide additional space by separating the rows of pots across the bed, leaving a space of up to 10 cm between them. You can make the spaces with wooden sticks, bamboo laths, bricks, stones, or old filled polypots without seedlings. Spacing between plants within the rows is not necessary. Spacing requires more bed area in the nursery and you must consider this in planning bed sizes. Where insufficient area is available, spacing only between pairs of rows is a reasonable compromise.

As well as encouraging more uniform growth, spacing assists the process of hardening off, by encouraging the development of a more lignified and better proportioned stem. Height growth is reduced but root-collar diameter and overall shoot biomass remain about the same. This improves the overall quality of the seedlings. When to space the plants depends on the growth habits of the different species. Usually it should be done when competition sets in, or when the need to control height growth becomes evident, whichever is earlier. Do not do it when pots are first placed in the beds, because this will reduce the availability of moisture during the plants early growth. Where possible, time spacing to coincide with root-pruning. While the plants are being handled they can also be graded by height, with those of similar height set out together. This minimizes plant disturbance and maximizes the utilization of nursery labor time.

The relationship between plant quality and spacing in the bed means that appropriate spacing is equally important for the production of stumps and bare-root plants. It is most easily achieved by growing plants in lines across or along the bed. Sow sufficient seed so that optimum spacing along the lines can be achieved by thinning out extra plants. For good quality stumps, a minimum spacing of 10 × 10 cm between seedlings is required.

Root-pruning polypot seedlings

One reason for root-pruning is to prevent the growth of excessively long roots in the nursery. If long roots are allowed to form, they must be cut when the plants are transferred to the field. This can result in death or severe shock.

Overall, the effect is to produce a stronger and better balanced plant, with a greater root to shoot ratio. This ratio is an indicator of plant quality. Generally, root-pruning increases the ratio because the reduction in growth of the shoot is greater than that of the root. Root growth is also restricted to a manageable size for planting.

Plant roots usually grow quickly to the base of the pot and will then grow round in coils unless they can get out. When the seedling is planted, this coil remains and the roots forming it get larger as the plant grows. Such roots eventually strangle each other, causing a reduction in growth and sometimes death. The knot of roots which develops may act as a weak point or pivot so that the tree may be blown over by strong winds. One answer to root coiling is to cut off the bottom one or two centimeters of the root ball immediately before planting the seedlings. This removes the root coil and can account for as much as half of the root mass, but it does not permit any management of the plant and obviously leaves a very poor root system.

Efficiently carried out root-pruning helps to reduce or prevent root coiling. The polypots should have a number of well-formed holes of adequate size in the lower third, to facilitate the growth of the roots out of the pot into the soil in the bed beneath. Allowing the roots to grow out of the pots reduces coiling and permits effective root-pruning. Efficient root-pruning cannot be done if the roots do not have ample opportunity to grow out of the pot. Prune roots by lifting up the pots and breaking protruding roots cleanly with the finger nails, a pair of scissors or a sharp blade.

When to start, and how often to prune roots, varies with the altitude of the nursery and the species. You can check the need for it easily by lifting up a few pots to see if roots have grown out of them. Do not allow the roots to develop too well in the soil beneath the pots, because the shock when they are eventually broken off may cause the shoot to die back, and in some cases the plant may die. If root-pruning causes the plant to wilt slightly, it has been done at the right time.

As with watering, root-pruning cannot be carried out according to a fixed timetable but must be done according to the needs of the plant, as ascertained by frequent checks.

18.3.7 Weeding

Weeds compete with plants for moisture, nutrients and light and must be carefully controlled in the whole of the nursery area. Keep the fence line, unused areas and paths all weed free. Weed throughout the whole year.

Less time will be needed for weeding if it is done frequently, so that the weeds are small. Their removal complete, with roots, is easy, and damage to the plants is minimized. Water the beds or pots before you start to weed, and pull the weeds out with their roots. If the roots cannot be pulled out, weeding has been started too late.

In some nurseries a growth of algae, moss and lichens may develop on the surface of the beds or pots. This is often associated with compaction of the soil surface. It slows down the infiltration of water and air into the soil and must be prevented by periodic cultivation of the soil surface with a small stick. If the growth is allowed to develop into a thick layer it can only be removed by taking away a layer of soil with it, which may lead to the exposure of roots. If this happens fill the pots up with more soil.

When plants are grown in beds, it is easier to weed in between them with a narrow blade if they are grown in straight lines along or across the beds. Use a blade to dig out weeds between the lines and remove it by hand.

18.3.8 Insect and mammal pest control

Serious losses from insect damage are less common than losses from disease, but they are occasionally severe. Once again prevention is better than cure. Good nursery practice, in particular keeping the whole area free of weeds, and cultivating any unoccupied areas during the winter are required.

Damage by insect larvae can lead to serious losses, especially just after germination. Some types live in the soil and come out to feed at night. They usually cut the stem of the young plant close to the soil surface, and they may also eat the leaves. Where possible it is best to control larvae by carefully examining the beds each day, and killing them. Insecticides containing methyl parathion, such as Metacid and Paramar are effective. Make a 0.05% solution (i.e. mix 1ml with 2 liters of water) and apply this with a sprayer if possible, or if not, a watering can with a fine rose. Chemicals must be accurately measured with a 4 ml hypodermic syringe. Adding 1ml of a 'sticker', such as Triton AE, to each liter of the mixture, will help the insecticide be effective for longer.

The 'white grub' is an insect larva which is a major pest. It lives in the soil and eats plant roots. It is a large, thick, white larva, usually C-shaped, and may be more than 3 cm long. It passes the winter deep in the soil, and comes up to feed nearer the surface in the spring. Affected plants first become chlorotic. Growth is stunted until they either die, or recover by regenerating new roots - which may also be attacked. White grubs are most commonly found in open beds. Sieving the potting mixture components will usually eliminate them from polypots. Chemical control measures recommended are to mix a 10 % BHC or Aldrin dust into the top 30 cm of the soil at 5 - 10 gm/m^2. Crickets and grasshoppers can also be a problem. You can control them by regularly cultivating all areas not being used for plant production, including paths, to a depth of 10 cm, in the winter. Cultivation brings the eggs to the surface where they die. Applying Metacid as described above will also control these insects. Ants occasionally eat seed after sowing. If this is a problem, sprinkle the area lightly with Aldrin dust.

Use of the seeds and leaves of the 'neem' tree (Azadirachta indica) to control insects, although not practiced in Nepal, is worth trying. They contain a chemical, azadirachtin, which has insecticidal properties. Digging them into the beds, or mixing them with other tree seed for storage, may reduce insect damage. Farmers in India store grain mixed with 'neem' leaves and also obtain an extract by crushing the fruit in water which they use for spraying their crops in the fields. It is said that 'bakeno' has similar properties.

Very serious losses of seed are often caused by rodents. It is usually the larger seeds, including those of the pines, which are eaten. The only reliable prevention is to cover the seedbeds in fine wire mesh, digging the edges of the mesh into the soil. This also prevents birds from eating the seed. Cattle, goats, pigs, dogs and chickens must be completely excluded from the nursery by constant maintenance of the fence or wall.

18.3.9 Fungal diseases control

Two fungal diseases are important in nurseries in Nepal: damping-off and brown needle disease. The latter only affects pines. It is discussed in Forest Seed and Nursery Practice in Nepal.

'Damping-off' affects young seedlings. It may be caused by many different fungi which are always present in soils. Good nursery management involves stopping them from killing seedlings. There are three types:

- pre-emergent damping-off, in which the fungus attacks the seed and the newly developing root before the shoot emerges from the soil. It can easily be confused with poor germination that is due to the seed having poor viability.
- post-emergent damping-off, in which the fungus attacks the base of the stem or roots after the seedling has emerged from the soil. The plant falls over and rots quickly. This usually occurs within 2 - 3 weeks of germination, while the stem is still soft. It is easy to recognise, but can be confused with insect damage to roots and the seedling stem-base. It often occurs in patches on the seedbed, with the most recently affected plants at the outside of the patch. It can spread very rapidly unless corrective action is taken as soon as it is noticed; all the plants in a seedbed can be killed within 48 hours.
- root rot is not always regarded as damping-off although it is often caused by the same fungi. It affects older seedlings than the other two types. The first signs are yellowish (chlorotic) foliage, usually in the upper leaves. This is followed by the wilting, discoloration and death of the shoot, after which the lower leaves may show signs of secondary fungal attack. Some of the roots will be seen to be soft and rotten or already dead. A good test is to see if the outer root layer can easily be pulled away from the inner core. Also, when healthy roots are broken a sharp snap should be heard, but this will not happen if they are affected by root rot. Unfortunately, the first visible symptom of root rot, chlorosis can be caused by many other problems such as a shortage of nutrients, too much or too little watering, or insect or nematode damage.

In small bioengineering nurseries, where soil sterilization and extensive use of fungicides are not practicable, prevention and control of damping-off depends on good nursery techniques. Damping-off fungi thrive in warm, moist, shady conditions and the most common cause is excessive moisture. This is something which can be controlled and the naike should prevent damping-off by:

- not over-watering.
- removing shade as soon as it becomes unnecessary.
- not sowing seed too deep.
- where possible, sowing in the dry season.
- ensuring free air circulation over the beds.
- keeping the nursery free of weeds and old undamaged seedlings.
- not including compost or fertilizers in the sowing medium.
- using a well drained, sandy medium
- using pure sand as a seed cover
- avoiding transplanting damage by always handling seedlings carefully by the cotyledons or leaves, not by the stems or roots and where possible by sowing seed directly into polypots or stand-out beds.

If damping-off occurs, reduce watering, remove shade, and if possible protect the plants from rain by moving the seed trays under cover, or covering the beds with plastic sheets, during heavy showers. Once the disease is established it is very difficult to control. Try to prevent it altogether, but if it does happen, act quickly to prevent it spreading.

If fungicides are available, they can be used to help prevent damping-off spreading to other plants but they will not have much effect once it is well developed. Mix 25 g of Blitox (a blue colored powder) with 5 liters of water, and apply to the affected plants with a watering can twice a week.

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Assessing bioengineering site
Maintenance requirements and selection of plant species

This exercise involves devising a maintenance strategy for a site which has been treated with bioengineering. Assume that you have just started a project and have been given the task of undertaking bioengineering site maintenance. You need to plan what you will do on your site. In this exercise you will work in a group and spend half an hour on a thorough site investigation. You will then return to the Training Centre and, after a break, you will have an hour for preparing a presentation of the site and its maintenance requirements. You will be given 5 minutes to present your findings and another 5 minutes for discussion.

The main things to look at on your site are as follows.

19.1 Site history

- What is the material?
- What external factors are or were, affecting the site?
- What was the original cause of failure/erosion?
- What were the actual erosion processes at work in each part of the site?
- How long ago was it treated?
- What were the treatments? Are there signs of anything which has failed?
- What was successful in terms of stabilization/erosion control?
- How appropriate were the bioengineering treatments?
- Are the civil structures strong enough? Are they too big? Could they have been reduced and more bioengineering used? If so, how?
- Site characteristics like slope angle, aspect, rainfall, altitude and stoniness to calculate the draught factor.

19.2 Site maintenance requirements

- What needs to be done now? Identify any outstanding requirements to achieve the best possible bioengineering results.
- What are the maintenance requirements?
- What needs to be done urgently?
- What needs to be done to civil structures?
- What needs to be done to the vegetation structures?
- What will need to be done on a routine basis?
- What recurrent problems are likely to need tackling?

19.3 Selection of plant species

- what are the factors that are to be considered in your case
- What are the local plant species
- What are the plant types selected
- Observations , limitations and constraints

Estimating and costing

In this exercise you will make a quick estimate of work requirements and the costs involved in site works. Working in four groups, you have been assigned sites in the instability mapping session which requires some treatment works. Using the Rate Analysis Norms for Bioengineering Works you will then carry out the tasks of estimating and costing.

The exercise consists of:

a. calculating the quantities of materials required;
b. building up the rates;
c. estimating the costs for the site operations.

Make a quick estimate of the site dimensions and bioengineering requirements. Assume the site has not yet been bioengineered. Keep your proposals simple because there is not much time, but try to introduce a range of techniques to build up a more varied estimate of the site.

Use the forms for the Calculation of Quantities and Abstract of Costs given on the next pages. These are based on the standard Department of Roads forms for these purposes.

Use the item rates for civil Engineering works as in your practice. Use the Interim Rate Analysis Norms for Bioengineering Works.

Table 20.1 : Calculation of quantities

S. Nol.	Description of item	No	Length	Breadth	Height	Quantity

Table 20.2 : Abstract of cost

S. Nol.	Description of item	Unit	Rate	Quantity	Amount

Bioengineering programming works

21.1 Introduction

Bioengineering programming works are very important as the activities directly depend on the seasonal characteristics. In the other hand, financial obligation regulates the implementation of the work. The GoN financial system is clear that the fiscal year starts from Shrawan which is the prime time for bioengineering activities. Every institution must have a system, which regulates its expenditure. However, often it seems to hinder technical operations. We must know how to work within the system if we are to carry out bioengineering works effectively.

A better programming ensures efficiency, effectiveness and economy by utilizing scarce resources as minimum as possible and by producing as more output as possible. Programming is the advance planning. Scheduling is an important task in the process of programming. There are various types of schedules. Some of them are Construction schedule, Equipment schedule, Material schedule, Labor schedule, Financial schedule, etc.

21.2 Construction schedule

Before preparing a construction schedule, various calculating operations involve in the construction project like estimation of quantity, abstract of cost etc. It shows a clear picture of the project. An example of construction schedule is given below:

Project No. .... **Year ....**
Name of the Project .... **Location ....**

S. No.	Activities	Quantity	Unit	Rate per week	Total time required	Baishakh							
						1		2		3		4	
						e	a	e	a	e	a	e	a

Note: e = estimated a= actual

21.3 Equipment schedule

It shows the complete list of equipment required for the project on different dates and also their duration. It helps planning the equipment required for the project in advance.

Project No. .... **Year ....**
Name of the Project .... **Location ....**

S. No.	Equipment	Total nos. required	Baishakh				Jestha				Ashadh			
			1	2	3	4	1	2	3	4	1	2	3	4

21.4 Material schedule

In order to deliver materials to the site well, in advance and not far in advance or delaying material schedule is prepared.

Project No. .... **Year ....**
Name of the Project .... **Location ....**

S. No.	Description of materials	Total quantity	Baishakh				Jestha				Ashadh			
			1	2	3	4	1	2	3	4	1	2	3	4
1.	Cement													

21.5 Labour schedule

On the basis of construction schedule, labour schedule is prepared. It shows the required types of labour, their numbers and period of involvement.

Project No. .... **Year ....**
Name of the Project .... **Location ....**

S. No	Classification of labours	Total nos.	Baishakh				Jestha				Ashadh			
			1	2	3	4	1	2	3	4				
1.	Carpenters													

21.6 Financial schedule

It is important to prepare the financial schedule for the proper planning of the financial activities. In the absence of the schedule, there will be the dilemma of both the expenditures and receipt. As per the budget allocation practice in Nepal, the whole budget for the year is disbursed in three four monthly segments. The financial programming, hence, has to be prepared accordingly.

Financial Programming as per Budget Allocation
Project No. .... **Year ....**
Name of the Project .... **Location ....**

S. No.	Particulars	Total Quantity	Total Amount	Work for the Year			I			II			III			Remarks
				Q	A	%	Q	A	%	Q	A	%	Q	A	%	

Financial Programming as per Expenditure Requirement
Project No. .... **Year ....**
Name of the Project .... **Location ....**

Week after starting	Construction Activities	Expenditure per week	Cumulative Expenditure	Remarks

21.7 Bar chart

It is a simple and easily understood tool, used for construction planning and controlling. It is a graphical representation of various activities showing the duration, starting and the completion dates of the construction projects. On a chart by means of the horizontal bars, different activities are represented. The length of each bar indicates the duration required for the completion of the operation. By using an extra dark bar parallel to the bar already shown on the chart, progress of the activity also can be noted down.

Table 20.3 : Summary annual calendar of bio-engineering works

Month	Main activities	Comments
Shrawan Jul-Aug	Site plantation works: all grass slips and seedlings; all shrub and tree seedlings and hardwood cuttings; all remaining direct seeding Observation of newly planted sites and maintenance as required	
Bhadra Aug-Sep	Observation of newly planted sites and maintenance as required.	
Aswin Sep-Oct	Observation of newly planted sites and maintenance as required Conduct post-monsoon survey of roadside slopes, prioritise problem areas and begin planning for remedial works. Make initial assessment and order for jute netting. Carry out coppicing and pollarding of large trees.	
Kartik Oct-Nov	Preparation for seed collection: final establishment of quantities required and planning of seed sources. Compost and mulch making	
Mangsir Nov-Dec	Seed collection, treatment and storage Preparation for physical site works: planning, programming, contracting, etc. Compost and mulch making	
Poush Dec-Jan	Seed collection, treatment and storage Begin to prepare nurseries for operations in the spring. Preparation for physical site works: planning, programming, contracting, etc.	
Magh Jan-Feb	Preparation of nurseries for operations in the spring Low altitude nurseries start seed sowing Site works: slope trimming, start of construction of civil works, Seed collection, treatment and storage Carry out pruning and thinning of large trees.	
Falgun Feb-Mar	Main period for starting nursery production. Sowing of seeds Site works: slope trimming, civil works construction, etc. Carry out pruning and thinning of large trees.	
Chaitra Mar-Apr	Nursery operations in full swing Site works: slope trimming, civil works construction, etc.	
Baishak Apr-May	Nursery operations in full swing Site works: slope trimming, civil works construction, etc. Application of jute netting on site	
Jestha May-Jun	Nursery operations in full swing Final physical site works Final preparation of materials for site planting Direct sowing of shrub and tree seeds on site Direct sowing of grass seeds on gentle slopes or under mulch	
Ashad Jun-Jul	Nursery operations continue Site plantation works: all grass slips and seedlings; all shrub and tree seedlings and hardwood cuttings; all remaining direct seeding	

Table 20.4: Bioengineering: general works annual program

		FISCAL YEAR: 2072/73											
No.	**Work activity**	**Shrawan**	**Bhadra**	**Aswin**	**Kartik**	**Marga**	**Poush**	**Magh**	**Falgun**	**Chaitra**	**Baishak**	**Jestha**	**Ashad**
1	Complete 2071/72 site planting												
2	Seed collection: grasses												
	other species												
3	Seed treatment												
4	Seed storage												
5	Site assessment												
6	Planning civil/site preparation												
7	Tendering and arranging contracts												
8	Implementing civil/preparation												
9	Planning bio-engineering needs												
10	Bio-eng stock production												
11	Final site preparation												
12	Placement of jute netting												
13	Bio-engineering site works:												
	grass seed sowing on site												
	shrub seed sowing on site												
	brush layering												
	grass planting												
	tree/shrub planting												
14	Programming for FY 2053/54												
	Routine activities												
15	Protection												
16	Monitoring												
17	Maintenance												

Table 20.5 : Bioengineering: low altitude nursery annual program

		FISCAL YEAR: 2052/53											
No.	**Work activity**	**Shrawan**	**Bhadra**	**Aswin**	**Kartik**	**Marga**	**Poush**	**Magh**	**Falgun**	**Chaitra**	**Baishak**	**Jestha**	**Ashad**
1	Seed collection: grasses												
	other species												
2	Soil and sand collection												
3	Compost: making turning												
4	Purchase of polypots and other items												
5	General preparation of nurseries												
6	Polypot filling												
7	Shade repairing												
8	Grass stock: plant out												
	respace												
9	Seedlings: seed sowing												
	pricking out												
	respacing												
	root pruning												
10	Prepare stock to leave nursery												
	Routine activities												
11	Weeding												
12	Protecting												
13	General maintenance												

21.8 Fitting operations into the Nepal financial calendar

The **GoN** financial system is clear and logical. Every institution must have a system which regulates its expenditure. However, often it seems to hinder technical operations. We must know how to work within the system if we are to carry out bioengineering works effectively.

21.9 Restrictions on bioengineering works imposed by the GoN Fiscal Year

There are many difficulties for bioengineers and the main ones are those which affect the annual programming of bioengineering works and the management of contracting. They are as follows:

- The Fiscal Year ends in the middle of our main working period (i.e. the rainy season).
- Unspent budgets are frozen.
- Programs have to be made well in advance and it may be difficult to alter them later;
- Any changes in either the program or the site location require a lot of file chasing in Kathmandu.
- At the end of the FY, there is much work to be done completing the accounts; this distracts from technical work.
- Funds for the new FY are often not released by the Ministry of Finance for several months due to delays in approval of the work programs by the National Planning Commission.
- The quotation system for employing local contractors is restricted by GoN's regulations;
- Civil engineering works are generally finished at the very last moment in the Fiscal Year, not leaving any time for bioengineering works.

21.10 Ways of working within the GoN system to reduce financial problems

There are several ways of overcoming these problems.

- If a budget has been proposed for bioengineering works in the Fiscal Year just started, up to one sixth of the annual budget may be used per month for the works. This needs to be requested by the Project Manager.
- If you are using contractors for the site works, contract packages can be arranged so that there is a defects and liabilities period of six or twelve months after the end of the Fiscal Year. If the contractor does not complete the works, then he will forfeit the retention money or performance bond.
- In exceptional cases, you can apply to the Director for use of money from the Deposit Account or from the Maintenance Fund. The Maintenance Fund is a separate revolving account and can be used for any road maintenance activities.
- In dire circumstances, you can apply for emergency funds (or again, from the Deposit Account). This would normally be for works resulting from a landslide or erosion of a serious nature which has occurred unexpectedly during the monsoon, i.e. soon after the start of the new FY.

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Monitoring and quality control works

It is a basis for determining what has been achieved when work is carried out. For this purpose all the works are to be judged based on the work specification.

22.1 Work Specifications

Specifications are required as

- Organisations need to standardise their works.
- We need to be precise about the specifications in all aspects of engineering works.
- We need to have sound information on which to base contracts.

Specifications of the work indicate the nature and the class of the work, materials to be used in the work, workmanship, etc. and are very important for the execution of the work. The cost of a work depends much on the specifications. Specifications should be clear, and there should not be any ambiguity anywhere. From the study of specifications, one can easily understand the nature of the work and what the work shall be.

While writing specification, attempts should be made to express all the requirements of the work clearly and in a concise form avoiding repetition. As far as possible, the clauses of the specification should be arranged in the same order in which the work will be carried out. The phrases 'shall be' or 'should be' are used while writing the specification. Specifications depend on the nature of the work, the purpose for which the work is required, strength of the materials, availability of the materials, etc.

22.2 Types of Specifications:

Specifications are of two types:

1. General specification or Brief Specification
2. Detailed Specification

(i) General specification or Brief Specification

General specification gives the nature and class of the work and materials in general terms, to be used in various parts of the work. It is a short description of different parts of the work specifying materials, proportions, qualities, etc. General specifications give general idea of the whole work or structure and are useful for preparing the estimate. For example, 1:2:4 Plain cement concrete, Plastering with 1:4 Cement Sand mortar, Random Rubble Stone Masonry with 1: 6 Cement sand mortar, etc. are general specifications for some items of work.

(ii) Detailed Specification

The detailed specification is a detailed description and expresses the requirements in detail. The detailed specification of an item of work specifies the qualities and quantities of materials, the proportion of mortar, workmanship, the method of preparation and execution and the methods of measurement. The detailed specifications of different items of work are prepared separately, and describe what the work should be and how they should be executed and constructed. The detailed specifications are arranged as far as possible in the same sequence of order as the work is carried out. The detailed specifications, if prepared properly, are very helpful for the execution of the work.

22.3 Criteria for assessing the quality of bioengineering works

The following are some simple rules for assessing the quality of bioengineering works. They are not fully comprehensive, but give some indicators to look for. Most of them refer to site works, but there are also quality checks for nurseries.

Individual plants should be:

- a bright, healthy colour.
- showing no signs of wilting;
- well proportioned (i.e. not stunted or very tall and thin).
- growing fast, with a number of long new shoots.
- without signs of discoloration on the leaves.
- without signs of insect attack on the leaves or shoots (e.g. holes eaten in the leaves).
- without any obvious signs of disease.
- undamaged.
- not yellowed, except in the later part of the dry season.

Grass lines should be:

- complete, with plants at the spacing specified within the rows.
- in the right distance between the rows, according to specification.
- even, with no gaps or poor plants in them.
- straight, according to specification.

Brush layers should be:

- complete, with the right number of cuttings per running metre.
- the right distance between the lines, according to specification.
- even, with no gaps or dead cuttings.
- straight, according to specification.

Fascines, which will need some minor excavations to check, should be:

- complete, with the right number of cuttings per running metre.
- the right distance between lines, according to specification.
- straight, according to specification.

Whole sites should be:

- completely treated, with no gaps or areas missed out.
- evenly covered.
- fully tidied up, with no loose debris on the slope.
- showing no signs of instability.
- stable enough to survive the early rains while plants get established.
- generally looking good, complete and healthy throughout.

Nurseries: quality checking

Grass beds (slip and rhizome cuttings, and grass seeds) and hardwood cutting beds should be:

- composed of good, fertile, well aerated soil.
- kept moist at all times.
- showing even growth.
- well weeded.
- kept with a porous, uncapped soil surface.

Grass plants should be:

- a healthy green colour.
- growing vigorously, with a number of long new shoots.
- showing no signs of wilting;
- without signs of discoloration on the leaves.
- without any obvious signs of disease or insect attack.

Shrub and tree seed beds should be:

- composed of good, fertile, well aerated soil and fine, clean sand.
- kept moist at all times.
- well shaded.
- showing even growth.
- well weeded.

Polypot seedlings should be:

- a bright, healthy colour.
- showing no signs of wilting.
- growing fast, with long new shoots.
- kept with roots pruned.
- kept moist throughout the soil cylinder.
- well weeded.
- without signs of discoloration on the leaves.
- without signs of insect attack on the leaves or shoots (e.g. holes eaten in the leaves).
- without any obvious signs of disease.
- undamaged.

Whole nurseries should be:

- kept tidy and clean.
- weeded throughout.
- well maintained.
- protected properly at all times.

22.4 Survival rates of plants

Grasses propagated by slip should give a survival rate of almost 100% in the nursery and about 95% on site. If there are significantly more failures than this, you should investigate the possible reasons. The most common reason is that the slips were allowed to dry out at some stage during the transplanting process. Grasses propagated by rhizome cuttings have a slightly lower survival rate. However, this should still exceed 95% in the nursery and 90% on site. Failures greater than these, should be investigated. Where grasses are grown from seed, it is almost impossible to estimate the survival rate. However, if the standard application rates are used, there should be a thick, even cover of grasses. If this does not occur, the usual causes are from sowing too early or from seeds being washed off the surface. Shrubs and trees have to be considered separately. In nurseries, it is normal to plant more cuttings or to sow more seeds than are required because no matter how good the nursery staffs are, there will inevitably be significant losses. The processes of taking from cuttings or germinating, transplanting and growing on, all take a toll on the young plants.

It is normal practice to allow four times the amount of seed for the final number of seedlings required. It is normal practice to grow up 25% more seedlings than will be required, and to discard the poorer plants when they leave the nursery. Therefore, for every 100 seedlings used on site, 400 seeds will have been sown and 125 seedlings will have been grown up.

On site, the survival rates for shrubs and trees can vary considerably depending on the biophysical harshness of the site, the quality of the plants and the quality of the planting works. In forestry plantations in Nepal, the survival of only 80% is considered acceptable, although it should be much more. The same rate should be used for bioengineering works. If less than 80% survive, a thorough investigation should be made. The usual causes of casualties are from careless handling and planting on site, and subsequent grazing damage.

22.5 Monitoring over different time frames

The following table gives an example of the frequency of monitoring for different works. This is based on general rules only and is not definitive for individual sites. In practice, you should devise your own frequencies of monitoring for your own area of working. This may be similar to the 'intervention periods' of many standard road maintenance programs. Add your own specific requirements in the spaces provided.

What to monitor	Supervisor/*Naike*	Overseer	Engineer	Which months
Site works				
Site preparation	Throughout execution	Daily	Weekly	Poush - Baishak
Site planting	Throughout execution	Daily	Weekly	Jestha - Ashad
Initial survival	-	Once off	Once off	Bhadra
Growth of plants	-	Monthly	Monthly	Year round
Later survival	-	Twice yearly	Twice yearly	Baishak + Kartik
Signs of damage	Daily (first monsoon)	Weekly in monsoon	Monthly in monsoon	Jestha - Aswin
Nurseries				
Planting & sowing	Throughout execution	Daily	Weekly	Falgun - Chaitra
Care of plants	Continuous	Daily	Weekly	Falgun - Ashad
eneral maint.	Continuous	Weekly	Monthly	Year round
Main seed collect.	Throughout execution	Daily	Weekly	Mangsir - Poush
Other seed collect	Throughout execution	Daily	Weekly	As it occurs

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Application of the standard norms and specifications cost estimation for bio engineering

23.1 Task to be performed

a. Write-up of detailed assessment of the site.
b. Preparation of bioengineering proposals.
c. Estimation of materials/resources required.
d. Costing works, including plant production.
e. Scheduling of all works for preparation and implementation.
f. Preparation for presentation in Session 26.

Use the following formats for the calculations:

Table 23.1 : Rate analysis format:

S. No.	Particular	Details		Unit	Quantity/ No.	Rate	Total	Remarks
		Man Power	Skilled					
			Unskilled					
		Materials						
		Tools and equipment						
Total								
Taxes, overhead or service charges if any @ of..........%								
Grand total : In Words:								

Table 23.2 : Calculation of quantities

S. No.	Description of item	No	Length	Breadth	Height	Quantity

Table 23.3 : Abstract of Cost

S. No.	Description of item	Unit	Unit rate	Quantity	Amount

Table 23.4 : Bioengineering: general works annual program: project: ....

		FISCAL YEAR:											
No.	**Work activity**	**Shrawan**	**Bhadra**	**Aswin**	**Kartik**	**Marga**	**Poush**	**Magh**	**Falgun**	**Chaitra**	**Baishak**	**Jestha**	**Ashad**

Table 23.5 : Material/Resource Requirements

			Resources								
S.no.	Work Description	Unit	Labour			Construction Materails			Equipement		
			Level	Unit	Quantity	Type	Unit	Quantity	Type	Unit	Quantity

Introduction to nursery

Nursery is a factory that produces the plants when required, quantity required and at an affordable cost with the specified quality. For the establishment and operation of a nursery the following points should be taken in to account.

24.1 Components of a nursery

The main components of a nursery are as follows:

General: Compound wall or fence

Office *Chowkidar*'s hut

Vehicle access and turning area, pathways to all parts of the nursery, working area

Storage: Nursery store, soil and sand stores, compost bays

Water: Water tank and accessories, drainage systems

Beds: Seed beds, stool cutting beds, bare root plant beds, Grass beds, bamboo beds standout bds for polypot seedlings, shades for beds

24.2 Other areas and corners for perennial grass and hardwood stock plants:

24.2.1 Nursery site selection

The selection of a suitable nursery site is the most important decision affecting the efficient production of good quality plants for bioengineering. Before you start to select a site carefully define the objectives of the nursery, including:

- the number of plants of each species to be produced each year.
- the type and size of plants.
- the location of the planting sites to be supplied.
- the expected life of the nursery.

You must choose the site at least six months before the first seed is to be sown. You should carefully consider the district's bioengineering site plans over the next few years. Nurseries need to be as close as possible to the sites they will serve but at the same time the location must be technically suitable. You will rarely be able to get everything just right, so the final selection should be based on evaluating the relative advantages and disadvantages of three or more possible sites after you have thoroughly inspected the area.

24.2.2 Water supply

A reliable, adequate water supply is essential for all Bioengineering nurseries. Ideally, it will come from a perennial stream located above the site and close to it. Water may be available from an existing irrigation canal.

Whatever the source of the water is, check that it is available throughout the year, especially the flow in the driest months: March, April and May. Also see who else uses the supply and if, for example, it is cut off at times to water winter crops. You can only discover this by discussing fully with local people. If there are other users, you must make sure they clearly understand the effect that nursery requirements will have on the supply. Conflict over water use easily occurs even though there may be sufficient for everybody. All users must clearly understand each other's needs, especially with regard to quantities and the times when water is required. You may be able to combine the Description of a water supply for a new nursery with an improved supply for a project camp or even a nearby village. Again, you must obtain clear agreement on water use and make careful estimates of supply and demand before the nursery in established.

In the Terai, if the site is not close to a stream or irrigation canal, you may need to sink a well and install a hand pump. Check to see if there are other wells in the area and how deep and efficient they are before starting to sink a new one.

A guaranteed supply of 1,000 liters (1 m^3) of water per day is needed for a nursery of 20,000 plants watered with a watering can. Surface irrigation requires considerably more.

24.2.3 General location

The site should be as close as possible to the center of the area to which plants will be supplied and near to the road.

24.2.4 Physical features

Aspect is very important. North facing slopes are cooler and more humid and are better for nurseries at lower elevations, whereas nurseries above 1200 m are better on warmer southern slopes. Make sure this benefit on a south-facing slope is not lost by shading in the morning or evening by adjacent ridges. This is most important in nurseries at higher elevations. In the hills, you will usually have to be built nurseries on terraces. However, if the land is too steep, making terraces that are wide enough for a bed and working space alongside it will be difficult. Moving in the nursery and gaining access to it will be also difficult. Avoid land, which is too steep. At lower elevations and it the terai flatter sites are likely to be available. A slope of 2-3% is necessary to allow water to drain off without causing erosion. If the nursery has to be built on a completely flat site, you have to build a drainage system to prevent waterlogging.

Consider natural hazards. Avoid areas threatened by landslides, flooding or strong winds. At higher elevations, avoid sites that are particularly liable to frost. These include valley bottoms and other places where the downward flow of cold night air is interrupted either by topography or other obstructions such as dense belt of trees or shrubs below the site.

24.2.5 Availability of materials and labour

If the plants are to be produced in beds you should select a location with a deep loamy soil, if possible with good content of organic matter (2 %), on a well-drained site. In nurseries, where plants are grown in polypots you will need large quantities of soil. This has to be carried to the nursery, so you need a large source of sandy loam or loam soil, preferable forest topsoil, as close as possible to the proposed site. If only heavy soils such as clays are available, they will have to be mixed with sand. Pines also require mycorrhizal soil. See, if there is an area nearby where foliage and litter can be collected for compost making. The soil at the nursery site itself is not so important except that is should be well drained.

The quantity of soil required is often under-estimated. A nursery with a target of 20,000 usable plants would fill 25,000 pots. For 10 – 17.5 cm (4" – 7") pots, this would require 12.25 m3 of potting mixture. For a 2:1:1 soil:sand:compost mixture you would need about 6.2 m3 of soil and 3.1 m3 of sand, which would weigh about 9 and 5.5 metric tonnes. If sieving was done in the nursery, you need 15 % more soil and 5 % more sand.

Easy access to stone for building the nursery wall and beds as well as other items, such as a water tank, a shed and a compost bin, is also an advantage. A lot of labor is required for constructing the nursery and later on for tasks like carrying soil and pot filling. You should locate the nursery where it is possible to obtain labor without difficulty at most times of the year. Siting a nursery near a village also increases awareness of it and enable the naike to carry out their extension work more easily.

24.2.6 Land ownership

If possible, nurseries should be on land owned by project. If the project does not own enough suitable land, it will have to be purchased or other government-owned land assigned for the project use. Make sure this assignation is guaranteed at least for ten years.

Table 24.1 : Design requirements of the physical components of nurseries

Component	Design features	Reasons for design
Compound wall or fence	Secure against all animals Strong and long lasting Built using local materials Simple but effective gate	To protect the nursery As cheap as possible Effective Show people it is private

Nursery store/ office/ *Chowkidar's* hut	Secure against all unwelcome people Strong and long lasting Big enough for all its functions Built suing local materials Good quality to stay there	To look after tools, seeds, etc. safely To give the *chowkidar* a reasonable place to stay As cheap as possible to be

Component	Design features	Reasons for design
	Efficient layout	effective
Vehicle access and turning area	Beside safest and easiest road access point Adequate space for turning and unloading (if space is limited, vehicles may reverse in)	Easy transport of goods in and out of the nursery
Soil/sand store	Adequate size for storing all soil and sand Space for working in during set weather (optional)	As cheap as possible to be effective
Working area	Big enough for all operations Big enough for more labourers to work in at peak times Hard, well drained surface If possible, shaded by a large tree	To enable efficient performance of all operations
Water tank and accessories	At highest part of nursery Permanent good water source Well built tank Tank of large capacity Good taps Hose pipes reaching every bed in the nursery	Water is most essential for plants. It must be guaranteed at all times of the year. Water must be easily available in all parts of nursery.
Drainage system	Must prevent erosion in the nursery Must prevent erosion in the nursery Keep paths and working areas hard and dry	To keep the nursery in good condition all year round As cheap as possible to be effective
Pathways to all parts of the nursery	Well made so they last a long time Drained so they are good during rains	To allow easy access As cheap as possible to be effective
Compost bays	Strong and long lasting Big enough for all the nursery's needs Built using local materials	To provide compost for the nursery on an annual basis As cheap as possible to be effective

Table 24.2 : Design requirements of nursery beds

Component	Design features	Reasons for design
Grass slip beds	Well drained Good quality soil Sufficient depth Enough space	To give good growing conditions for maximum productivity To produce enough slip, including reserves
Seed beds	Best available soil Finely prepared bed Well shaded Very well drained	To give young seedlings the best possible chance of survival

Standout beds for polypot for polypot seedlings	Well drained base Strong frame to support pots Removable shades	To support polypots and prevent damage
Bamboo culm beds	Good quality soil Dug to at least 50 cm depth Well shaded Plenty of water available	Bamboo culms need very damp, shady conditions in which to sprout
Bare root plant beds	Well drained Good quality soil Carefully constructed	To give good growing conditions for delicate plant parts
Stool cutting beds	Well drained Good quality soil Carefully constructed	To give good growing conditions for delicate plant parts
Shades for beds	Made from local materials Easily removable	To be as cheap and effective as possible
Other areas for perennial grass and hardwood stock plants	Well drained Cultivated Stones removed Water available at times	To use spare land for additional grass stock reproduction

24.3 Types of nursery beds

24.3.1 Grass slip beds

Grass slips are very strong and resistant; as a result, you do not need to take as much care over the construction of beds for grass slip multiplication as for most other nursery plants. However, the soil should be fertile and either a loam or sandy loam in texture. Use the following procedure for making the beds:

a. cultivate the original ground throughout the area and heap the soil into mounds to form beds. Mark out the beds using line string and shape the mounds. Cut pathways between the beds and heap the soil on the beds, so they are will drain;
b. if the soil has a high clay content, add sand to make it into a loam or sandy loam.
c. If the soil is not very fertile, lay 15 cm of forest soil and washed sand, in a 3:1 ratio, on the top of the bed; and
d. once the bed is shaped off, it should be no more than 30 cm high and no more than 120 cm wide at the top.

24.3.2 Grass seedling beds

Grass seedlings produced in the nursery are raised in 25 cm high beds made as follows;

a. compact and flatten the original ground, leaving a slight camber to facilitate drainage.
b. lay 5 cm of washed gravel on the compacted ground.
c. follow this by 5 cm of compost and forest soil mixed in a 1:1 ratio.
d. finally lay 15 cm of forest soil and washed sand, in a 3:1 ratio, and flatten the bed off. The bed should be no more than 120 cm wide at the top.

24.3.3 Beds for sowing tree and shrub seeds

These need to be made most carefully, as the seeds are often very small and young seedlings can be extremely tender. Seed sowing beds should b a minimum of 15 cm high and 100 cm wide. Make the bed up with the following layers from bottom to top:

a. 5 cm of washed gravel of facilitate drainage.
b. 5 cm of unsieved forest soil.

c. 5 cm of a 1:3 mix of sieved forest soil and washed medium fine sand.
d. 1-3 cm layer of washed sieved and sterilized sand.

Cover the bed using a shade made from bamboo slats and plastic sheeting. It should be between 80 and 100 cm high. Surround the bed with an edging of bricks, bamboo or stone.

24.3.4 Standout beds for polypots

Stand out beds are prepared for plants that are raised in polypots. Make the beds 100 cm wide and as long as is convenient. Build a frame 15 cm high made of bricks, stone or bamboo to support and protect the seedlings. Compact the original ground well, and place a 5 cm thick layer of gravel on the soil to facilitate drainage. Place shades made from bamboo-stacked covers that can easily be rolled up 100 - 120 cm above the beds.

24.3.5 Beds for bare root seedlings and stumps

Some species of tree are raised as bare root seedlings or stumps because they grow more quickly, develop better rooting systems after planting, are easier and cheaper to transport of site and are cheaper to raise that containerized seedlings. They require different forms of management and care which must be provided if this type of production is to be successful.

Prepare beds as follows:

a. compact the original ground leaving a slight camber to allow for drainage; if available, bamboo sheaths placed on the ground are useful to prevent roots growing into the original ground;
b. place 2-5 cm of washed gravel as a drainage layer.
c. prepare a mixture of forest soil, fine compost (or gobar) and sand in a 2:11:1: ratio and out a 20 cm thick layer on top of the gravel.
d. place a 1:1 ratio of sieved soil and washed fine sand in a 20 cm thick layer on top.
e. after the seed has been broadcast sprinkle on sand, to the same thickness as the seed being sown.

After you have sown the seed, cover the bed with hessian jute until the seed germinates. Erect bamboo shades 100 to 120 cm high with a bamboo-slatted cover that can be rolled on or off. Gradually remove the shade over several weeks, exposing the plants to increasing amounts of sun each day.

24.3.6 Stool beds for cuttings

Stool cuttings are made by growing seedlings, cutting off the top and roots and planting them. These are used with species such as sisoo, kimbu, poplar and rudrakshya. It produces vigorous plants. Beds are generally prepared with the following instructions which go:

a. dig the soil to a depth of 30 cm; add a doko of compost for every 5 m^2 of bed to the soil and mixed it in well;
b. mix forest soil and fine compost (or gobar) in a 2:1 ratio and place a layer 20 cm thick on top of the original dug material;
c. add a 1:1 ratio mix of sieved soil and washed fine sand in a 10 cm layer on top;
d. use bamboo shades 100-120 cm high with a bamboo slatted rollable cover over the bed in the first weeks after planting the cuttings. Place the cuttings at 50cm centers. Weed thoroughly and occasionally give a handful of compost to encourage growth. Take the first cuttings after the second monsoon growth.

24.3.7 Beds for bamboo culm cuttings

Bamboo culms must be kept very wet. Therefore, bunds and complete shade with hessian jute are important. Beds are prepared as follows:

a. dig the original ground to a depth of 50 cm and lay 2-3 cm of gravel in the base. Mix the soil with forest soil in a ratio depending on the quality of the original soil.
b. lay 10 cm of unsieved forest soil on top of this.
c. follow this by 20 cm of sieved forest soil on the top.
d. bund the edges of the bed to help retain water.

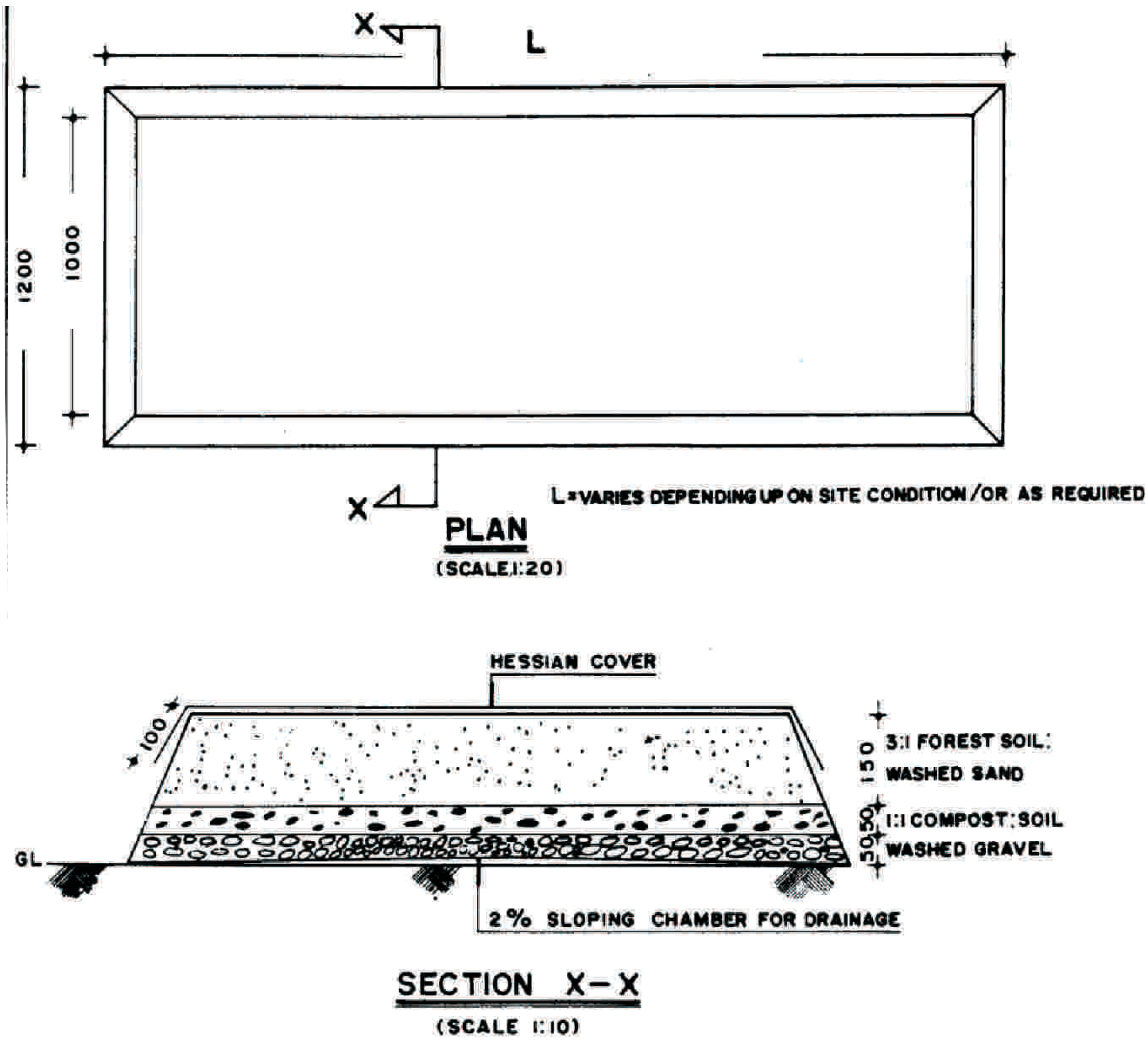

Fig. 24.1 : Details of grass bed.

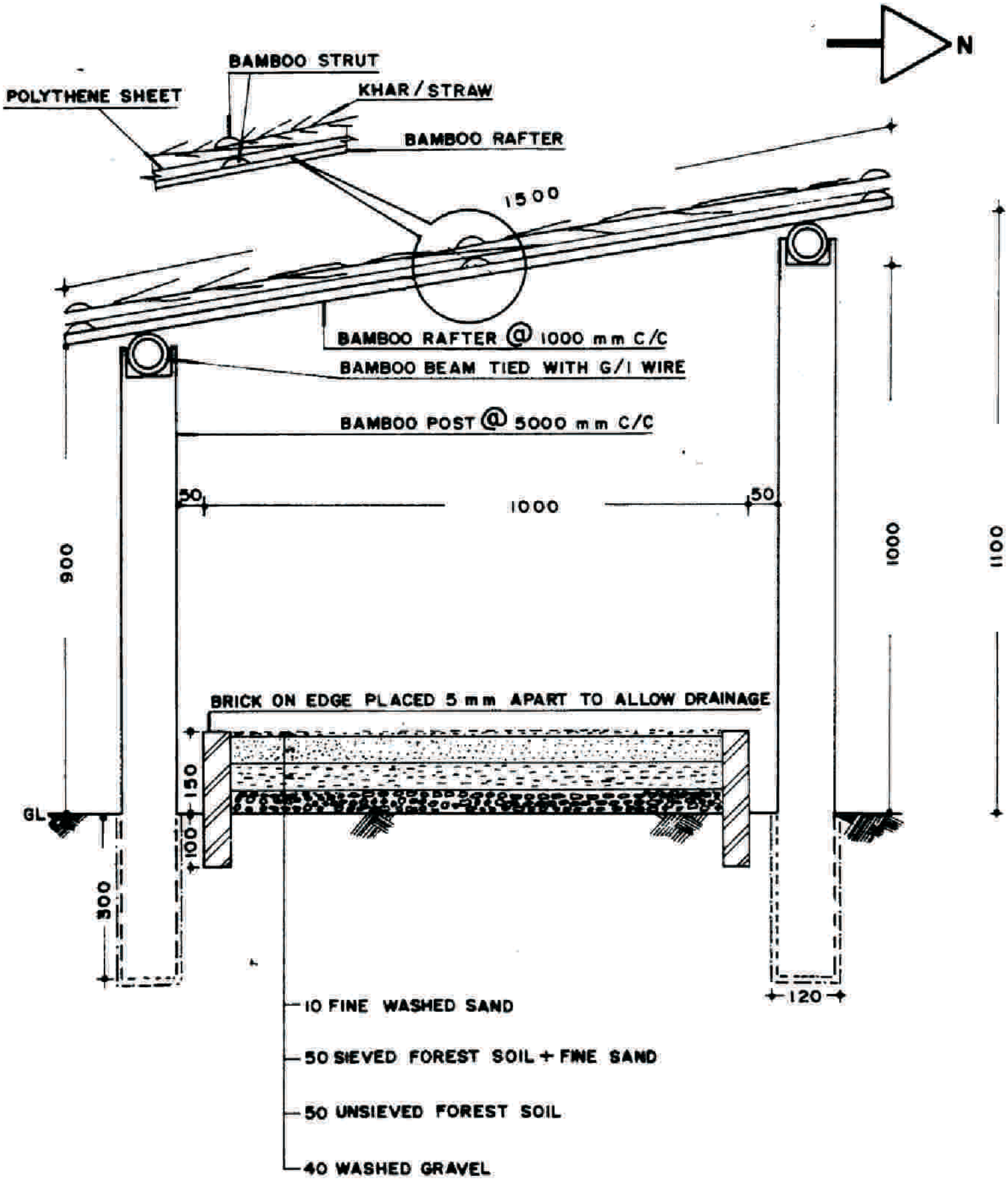

Fig. 24.2 : Typical cross section of tree/shrub seed bed.

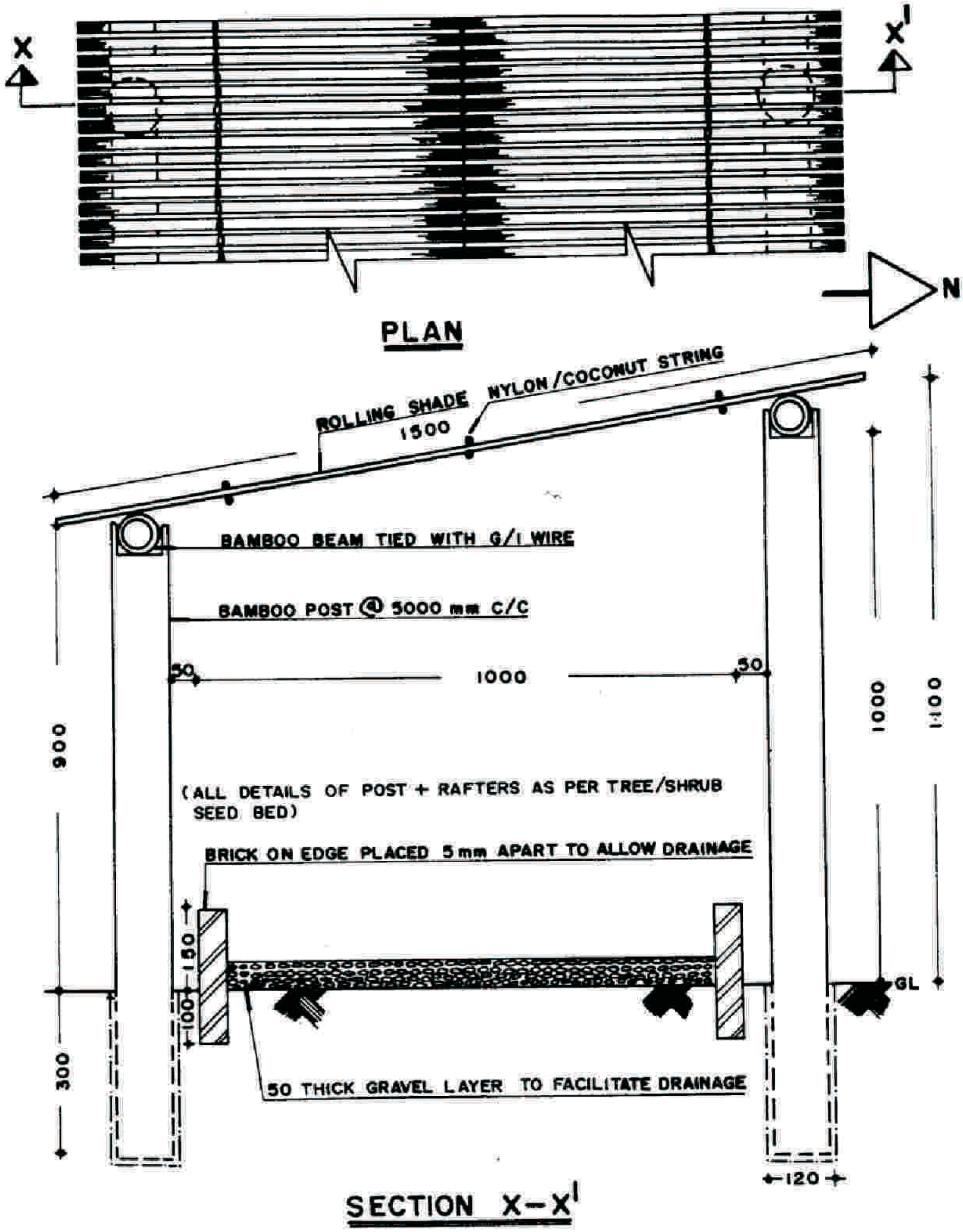

Fig. 24.3 : Tree/shrub standout bed.

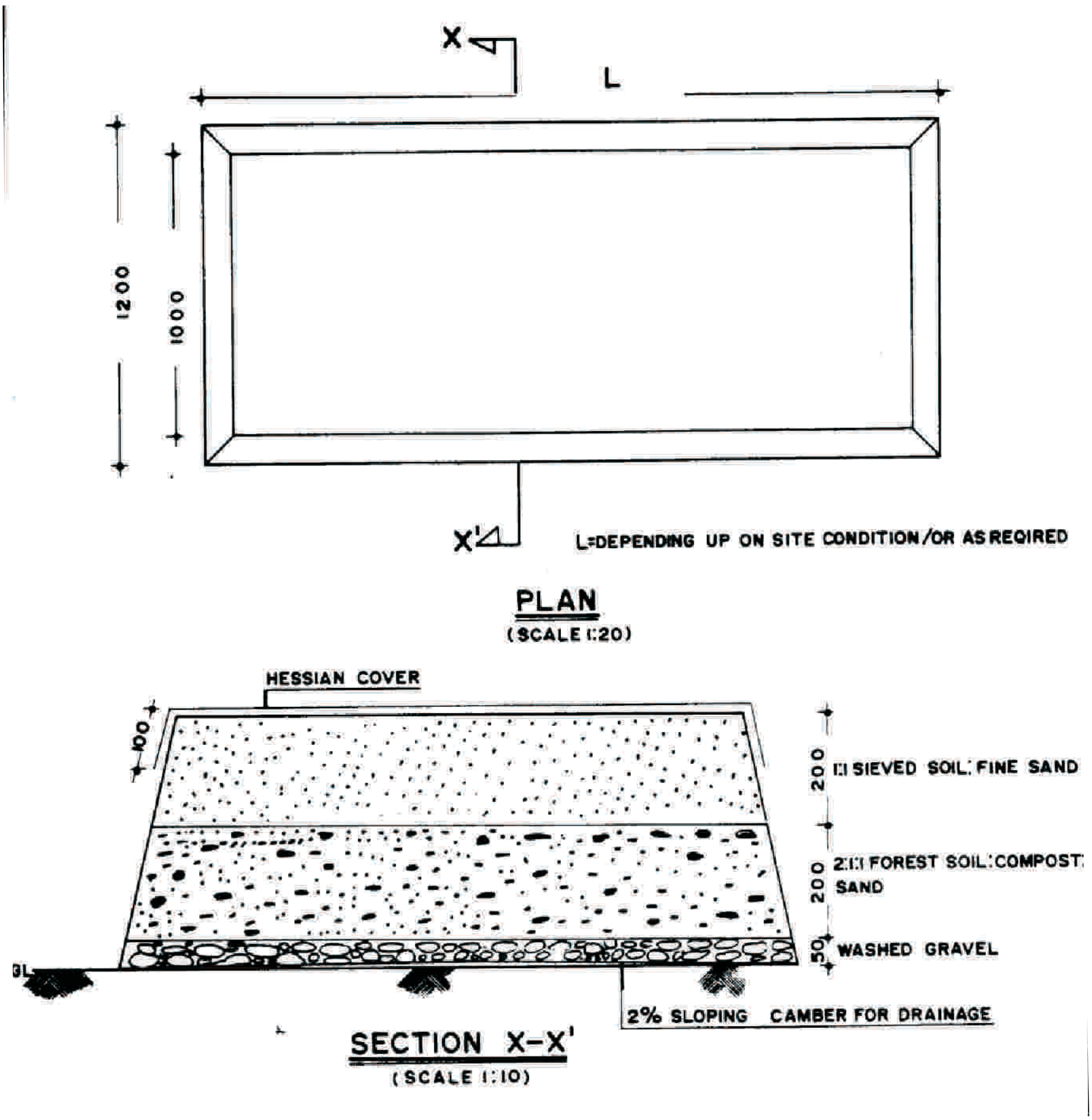

Fig. 24.4 : Details of bare root plant bed.

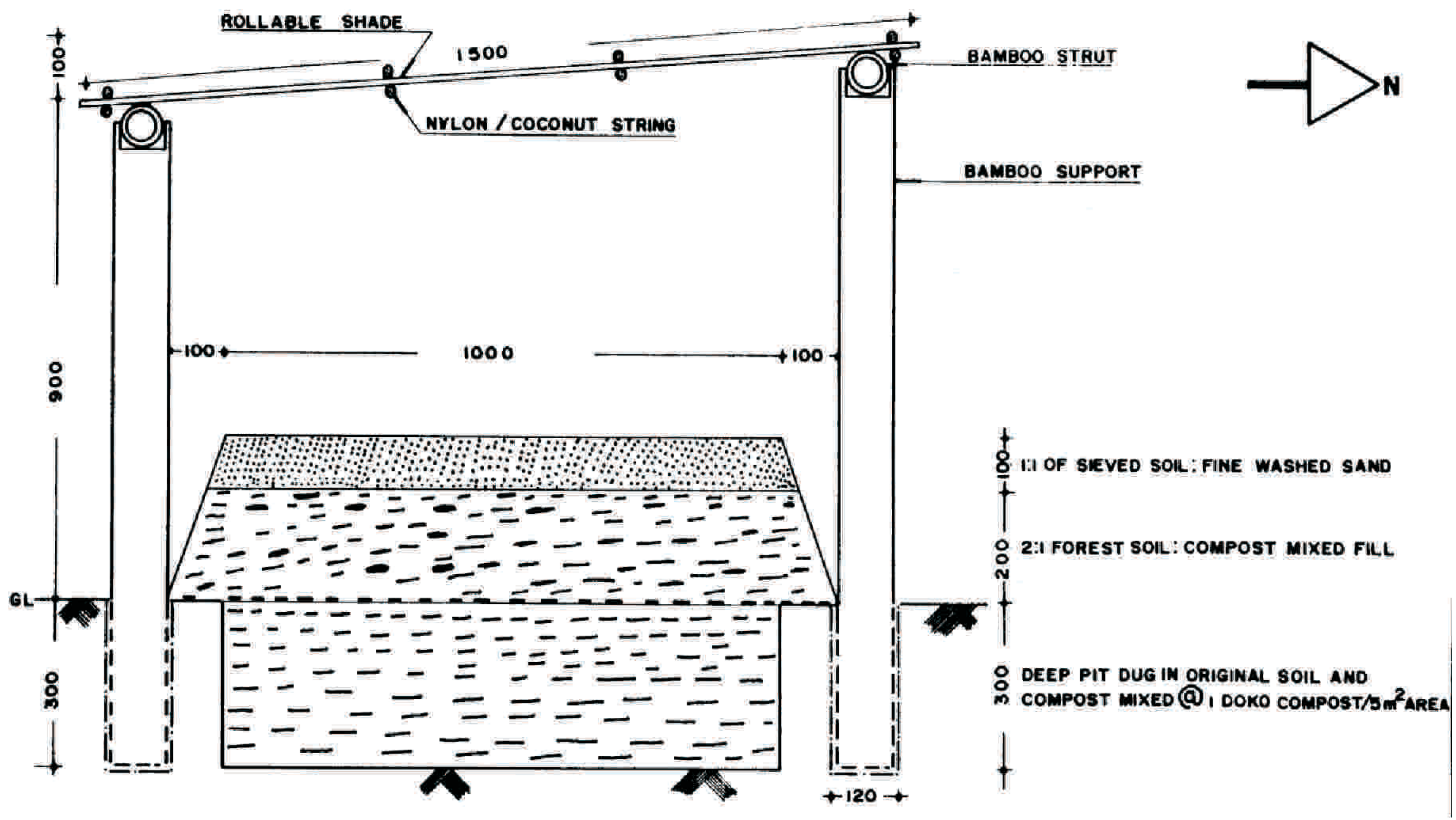

Fig. 24.5 : Typical cross section of stool bed.

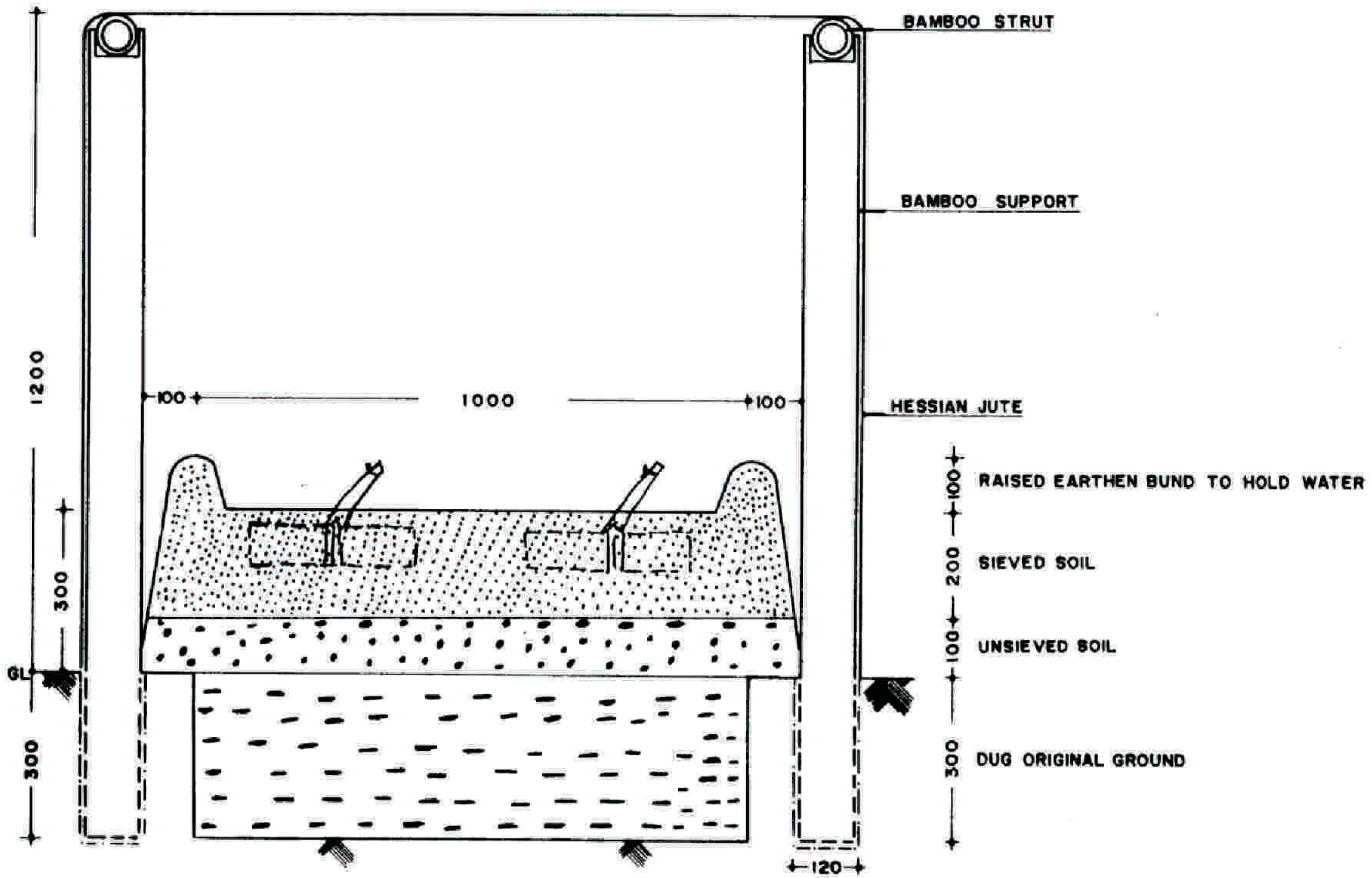

Fig. 24.6 : Typical cross section of bamboo propagation bed.

24.4 Seed collection: choice and location of plants

Seed collection

Seed provenance is important. Provenance means a place where the seed plants grow. You need to know something about this because seedlings usually grow best when planted on sites that are similar to those of the seed plants. Ideally you should collect seed locally from natural stands near the proposed planting site, with similar altitude, rainfall, soil and aspect. If there are no seed sources, you may have to order seed, through the seed suppliers, or from a project with a sizeable bioengineering component, or from the Department of Forests. When ordering, give as many details as possible about the planting site (altitude, rainfall, soil) and also how many seedlings will be needed. Ask the supplier to match these considerations as closely as possible.

Good quality natural tree stands or plantations can be managed, by selective heavy thinning, so as to improve their genetic quality and increase their production of seed. If you know of such stands, you should ask Department of Forests for advice.

Keep a register of all seed sources within your working area, with details of the species, area of the stand (or number of plants), and location. This register helps you plan seed collections.

Keep seed from very different sources, e.g. sources that are several kilometers apart. Never mix new collections with seed from previous years. Label every seed coat properly with species name, date of collection, location, and the number of seed plants. Always label seed that you send to the nurseries, so that the nursery naike knows exactly which species have been sent, and from where it was originally collected.Keep seed from very different sources, e.g. sources that are several kilometers apart. Never mix new collections with seed from previous years. Label every seed coat properly with species name, date of collection, location, and the number of seed plants. Always label seed that you send to the nurseries, so that the nursery naike knows exactly which species have been sent, and from where it was originally collected.

Which plants to collect seed from

Seedlings grow to be like their parents. Therefore, seed should only be collected from plants with the characteristics that are wanted by the eventual planters. However, you should remember that the majority of our plants are cross-pollinated and you are selecting on the basis of only one parent. All seed plants should be healthy and growing vigorously. Whenever possible, a seed lot should contain a mixture of seeds from ten or more seed plants. Avoid collecting from only one or two plants that happen to have a lot of seed. If a species usually grows in groups, do not collect its seed from very isolated plants, as they may not be fertile. Do not collect seed from very young plants that have only a few fruit; they may not be fertile.

How to collect seeds

Some of the following points relate specifically to collecting seed from trees, but others apply to collecting seeds from the range of types of plants used in bioengineering.

Climbing must be done carefully, so as to avoid accidents. Local methods can be safe if properly supervised. Follow these guidelines for safety:

- only employ seed collectors if they like climbing.
- only use strong and healthy collectors.
- collectors should work in twos, then if one needs help, the other can go and get it.
- only healthy trees with strong branches should be climbed.
- the climber should tie himself to the tree whenever possible while picking fruits.
- proper fruit cutting tools with long handles should be used, so that there is no need to cut off large branches.

Only collect ripe fruits. If fruits are collected too early, the seed may be immature and weak. If you delay collection too long, the seed may be eaten by birds, or attacked by insects or fungi. Pick fleshy fruits just as they turn from green to their ripe color. Pick dry fruits that open just before they open. Test the ripeness of seed by cutting the fruit open and looking at the inside of the seeds. They should be firm and white, and completely fill the seed coat. The seed coat should usually be dark and hard.

Do not collect fruits that are unhealthy or attacked by insects. For this reason, avoid fruits that have fallen to the ground, though they are sometimes suitable. Check them carefully.

Harvest the fruits without damaging the tree, so that it can produce again in the following years. Whenever possible, take only the fruits or the small twigs bearing them. Try not to tear them off, but cut or break them cleanly. Unless it is absolutely necessary, do not allow seed collectors to cut whole branches with a khukuri or sickle (hasiya).
Suitable seed collection tools include the following:

- a hook for bending branches towards the collector. Tie or nail a metal hook to a wooden handle 2 m long. Provide a 2 m length of rope so that the climber can tie the hook and the branch to himself, so that he has both hands free to pick the fruits and put them in the collecting bag. A strongly made hook can also help in climbing the tree.
- if it is necessary to break off the ends of branches with the fruits attached, a 'wedge knife works well. This can be made in Kathmandu. It should be bolted or tied with wire to a light, long wooden or bamboo pole (up to 4 m). The collector places the tool over the branch end and pulls it. The branch may slice off easily, but if it is woody, the knife may have to be twisted to snap the branch.
- a collecting bag can be made from a strong hessian sack which has been made shorter and has a draw string to close the mouth easily. When full, the bag is closed and thrown to the ground.

The best material for long handles is one-inch aluminum tube with thick walls which can be purchased in Kathmandu. Otherwise, use well dried wooden or bamboo poles.

If it is difficult to gather the fruits by hand in the tree, they can be allowed to fall to the ground and be gathered by an assistant. Clearing the ground of vegetation may help. The assistant should wear a strong hat as protection from falling fruit and twigs. It may be safer to wait until the climber has finished his work.

Transport and storage of fruits

Fruits should be stored and transported in cloth or hessian sacks. Do not put them in polythene bags, as they get warm and moldy very quickly, spoiling the seeds inside. Always store the sacks of fruit in the shade, where it is cool and dry. Keep them off the ground by placing them on planks of wood, or hang them from hooks.

When to Collect Seeds

You need to know the dates for seed collection in order to get good results. Details are given in the tables below, as far as they are known for the main bioengineering species. Every month, you should check which species are due to ripen so that arrangements can be made for collection. Before collecting season of a species starts, the nursery naike should keep a regular check on how the fruits are ripening. In some years, fruits will ripen earlier than usual, and in other years they may ripen later. As a general rule, fruits tend to ripen later in the west than in the east, and also later at higher altitudes.

Table 24.3 : Seed collection times for grasses

Local name	Botanical name	Seed collection	Local name	Botanical name	Seed collection
Amliso	Thysanolaena maxima	Mar-Apr	Khus	Vetiver zizanioides	Sep-Nov
Babiyo	Eulaliopsis binata	Jan-Feb	Kikiyu, thulo dhubo	Pennisetum clandestinum	Use cuttings
Banso ghans	Eragrostis tenella	Dec-Jan	Kudzu	Pueraria lobata	Use cuttings
Blue panic grass	Panicum antidotate	Use cuttings	Molasses	Melinis minutiflora	Use cuttings
Buffalo grass	Cenchrus ciliaria	Use cuttings	Musekharuki	Pogonatherum paniceum (?)	Use cuttings
Clover	Trifolium species	Use cuttings	Napier	Pennisetum purpureum	Use cuttings
Dangre khar	Cymbopogon pendulus	Dec-Jan	Narkat	Arundo clonax	Nov-Jan
Desmodium	Desmodium distortum	Use cuttings	NB21	P. Purpureum × typhoides	Use cuttings
Desmodium greenleaf	Desmodium intortum	Use cuttings	Padang bans	Himalayacalamus hookerianus	Use cuttings
Dhonde	Neyraudia reynaudiana	Dec-Jan	Phurke	Arunduella nepalensis	Dec-Jan
Dhubo	Cynodon dactylon	Use cuttings	Rato kans	Frianthus rufipilus	Dec-Jan
Dhungre	Unknown	Dec-Jan	Salimo khar	Chrysopogon gryllus	Dec-Jan
Dhus	Unknown	Dec-Jan	Setaria	Setaria anceps	Jul-Aug
Jaughans	Unknown	May-Jun	Sito	Neyraudia arundinacea	Dec-Jan
Kagati ghans	Cymbopogon citratus	Nov-Dec	Stylo	Stylosanthes guianensis	Use cuttings
Kans	Saccharum spontaneum	Nov-Dec	Thulo kharuki	Capipedium assimile (?)	Dec-Jan
Khar	Cymbopogon microtheca	Dec-Jan	Tite nigalo bans	Drepanostachy um intermedium	Use cuttings

Table 24.4 : Seed collection times for shrubs/small trees

Local name	Botanical name	Seed collection	Local name	Botanical name	Seed collection
Aak	Calatropha giganteum	Feb-Mar	Gahate	Unknown	—
Ainselu	Rubus ellipticus	Nov-Dec	Ghangaru	Pyracantha crenulata	Use cuttings
Alainchi	Elettaria cardomomum	—	Ghurmiso	Leucosceptrum canum	Use cuttings
Amala	Phyllanthus emblica	Sep-Jan	Hasna/hasua	Cestrum nocturnum	—
Amba/ ambak	Psidium guajava	Aug-Oct	Imili	Rumex natatus	Mar-Apr
Aparajita	Clitoria ternatea	—	Kanda phul	Lantana camara	Use cuttings
Areri	Acacia pennata	Nov-Dec	Kera	Musa paradisiaca	Use root suckers
Argali	Unknown	Use cuttings	Kettuke	Agave americana	Use cuttings
Arile kanda	Caesalpinia decapetala	—	Keraukose	Indigofera atroturpurea	Nov-Jan
Armalito, seabuckthorn	Hippophae salicifolia	Nov-Dec	Khirro	Sepium insegne	Use cuttings
Assuro	Adhatoda vasica	Use cuttings	Kimbu	Morus alba	Use cuttings
Bainsh	Salix tetrasperma	Use cuttings	Kunyelo	Trema orientalis	Use cuttings
Bains	Unknown; not Salix	Use cuttings	Lalupate	Poinsettia pulcherrima	Use cuttings
Bagamkali/ baramase phul	Bougainvillea spectabilis	Use cuttings	Mesquite	Prosopis juliflora	May-Jun
Ban chutro	Berberis aristata	—	Namdi phul	Unknown	Use cuttings
Ban silam	Elsholtzia blanda	—	Nil kanda	Duranta repens	Use cuttings
Bayer	Zizyphus mauritiana	Dec-Mar	Pate siuli	Opuntia ficus indica	—

Local name	Botanical name	Seed collection	Local name	Botanical name	Seed collection
Bhimsenpati	Buddleja asiatica	Use cuttings	Rahar	Cajanus cajan	—
Bhui katahar	Ananas comosus	Use cuttings	Rato chulsi	Osbeckia stellata	—
Bhujetro	Butea minor	Nov-Jan	Saruwa/ bihaya	Ipomoea fistulosa	Use cuttings
Bilaune	Maesa chisia	—	Sajiwan	Jatropha curcas	Use cuttings
Bokshi ghans	Mimosa rubicaulis	Use cuttings	Simali	Vitex negundo	Use cuttings
Chiya	Camellia sinensis (and other species)	Use cuttings	Sisal	Agava sisalana	Use cuttings
Chutr	Berberis asiatica	Mar-Apr	Siuli/sihundi	Euphorbia royleana	—
Coffee	Coffea arabica	Aug	Tara phul/kochu	Helianthus tuberosus	Use cuttings
Dhanyero	Woodfordia fruticosa	Mar-Apr	Thakal	Phoenix humilis	Feb
Dhusun	Colebrookea oppositifolia	Mar	Tilka	Wendlandia species	Feb-Mar

Table 24.5 : Seed collection times for large trees

Local name	Botanical name	Seed collection	Local name	Botanical name	Seed collection
Acacia	Acacia auriculiformis	Mar-Apr	Kagati	Citrus aurantifolia	Sep-Nov
Amp/aap	Mangifera indica	May-Jul	Kaju	Anacardium occidentale	—
Ashare phul	Lagerstroemia parviflora	Jan-Feb	Kalki phul/ bottlebrush	Callistemon citrinus	Oct-Feb
Babul/kikar	Acacia nilotica	Dec-Feb	Kalo siris	Albizia lebbeck	Nov-Jan
Badahar	Artocarpus lakoocha	Jun-Jul	Kangiyo	Grevillea robusta	Jun-Sep
Bakeno	Melia azedarach	Nov-Mar	Kapur	Cinnamomum camphora	Sep-Nov
Bange kath	Populus ciliata	Use cuttings	Kavro	Ficus lacor	Mar-May

Table 24.7 : Seed collection times for shrubs/small trees

Local name	Botanical name	Seed collection	Local name	Botanical name	Seed collection
Banghi	Anogeissus latifolius	Dec-Mar	Khanyu (khosro)	Ficus semicordata	Jul-Oct
Birendra phul	Jacaranda mimosifolia	Feb-Mar	Khari	Celtis australis	Oct-Dec
Champ	Michelia	Aug-Nov	Khasru	Quercus semecarpifolia	Jun-Aug
Chilaune	champaca	Jan-Apr	Khayer	Acacia catechu	Jan-Feb
Chiuri	Schima wallichii	Jun-Aug	Koiralo	Bauhinia variegata	Mar-May
Chuletro	Aesandra butyracea	May-Jun	Kutmero	Litsea monopetala	Jun-Aug
Dabdabe	Brassaiopsis hainla	Jun-Sep	Lahare pipal	Populus × euramerica	Use cuttings
Dar/githi	Garuga pinnata Boehmeria	Oct-Jan	Lankuri	Fraxinus floribunda	Sep-Jan
Deshi katus	rugulosa Castanea sativa	Oct-Nov	Lapsi	Choerospondias axillaris	Oct-Jan
Dhale katus	Castanopsis indica	Oct-Nov	Makadamia	Macadamia tetraphylla	?
Dhupi salla	Cryptomeria japonica	Oct-Nov	Mashala	Eucalyptus camaldulensis	Jul-Sep
Dudhilo	Ficus neriifolia	Jun-Aug	Mayal/mel	Pyrus pashia	Nov-Jan
Ghobre salla	Pinus wallichiana	Oct-Nov	Musure katus	Castanopsis tribuloides	Oct-Nov
Gliricidia	Gliricidia sepium	—	Nebharo	Ficus auriculata	Mar-May
Gogan	Saurauia nepaulensis	Mar-Apr	Nim	Azadirachta indica	Jun-Jul
Golainchi/ goila	Plumeria acuminata	—	Okhar	Juglans regia	Sep-Dec
Gulmohar	Delonix regia	Mar-May	Painyu	Prunus cerasoides	Oct-Nov
Ipil ipil	Leucaena species	Nov-Jan	Patle katus	Castanopsis hystrix	Oct-Nov
Jamun	Syzygium cumini	Jun-Jul	Phalant	Quercus lamellosa	Oct-Dec
Kadam	Anthocephalus chinensis	Oct-Jan	Phaledo	Erythrina species	Nov-Mar
Rajbriksha/ amaltas	Cassia fistula	—	Seto siris	Albizia procera	Dec-Jun
Rani (khote) salla	Pinus roxburghii	Jan-Mar	Sisau	Dalbergia sissoo	Feb-May

Local name	Botanical name	Seed collection	Local name	Botanical name	Seed collection
Rato siris	Albizia julibrissin	Sep-Feb	Suntala	Citrus chyracarpa	Dec-Jan
Ritha	Sapindus mukorossi	Sep-Feb	Tanki	Bauhinia purpurea	Nov-Apr
Sahijan/ shobhanjan	Moringa oleifera	Mar-Jun	Tendu	Diospyros malabarica	Apr-Jun
Sal	Shorea robusta	Jun-Jul	Tooni	Toona ciliata	May-Jun
Saur	Betula alnoides	Oct-Feb	Utis	Alnus nepalensis	Nov-Mar

24.5 Seed processing and storage

24.5.1 Seed processing following collection

Most seeds need to be removed from their fruits before sowing or storage. Separate them carefully to avoid damaging the seeds. Although they may look inert and tough, they can easily be damaged by heat, moisture, physical breakage, fungi, insects, etc. Try to extract the seeds as soon as possible after collection, unless recommended otherwise.

Spread out grass seeds to dry in sheltered, sunny places, on a clean concrete or hard earth floor. Separate them from stems and other unwanted parts in the ways normally used for grains. Since the seeds of bioengineering grasses are mostly very fine, take great care when winnowing. Once the seeds are thoroughly dry, place them in a hessian jute bag for storage. Instructions for processing tree and shrub seeds are given in the manual Forest Seed and Nursery Practice in Nepal.

24.5.2 Storing seed

If you are sowing the seeds immediately after processing (within a few days), put them in a cloth bag and keep them cool. Never use a sealed container such as a polythene bag, glass jar or tin. The seed will usually be too moist and will quickly get warm and moldy.

If you are keeping the seeds for more than a week (often several months or even a year may be required), store them properly to avoid loss of viability. Most species have seeds that store best if they are properly dried, and then kept dry and cool. These are called 'orthodox' seed. First dry them properly. Expose the seed to the sun on a sieve, nanglo or gundri that is raised off the ground on wooden strips or stones, so that there is plenty of air circulation above and below the seeds. If possible, spread them out thinly (one seed thick). If this is not possible because of lack of space, turn the seeds every hour during drying so that those on the bottom also dry out. Usually 2 - 3 days in the sun will be sufficient.

If the seeds were extracted from the fruits using the water method, they will be very damp and so let them dry for a day in the shade before exposing them to the sun. If moist seed is exposed to the sun's heat too quickly, it may be damaged.

At night, cover the trays with cloth or put them under a roof. Be careful to cover them well if there is any chance of rain. If there is not much sun, leave the seeds on the drying trays under cover until there is a dry and sunny period.

When the seeds have dried sufficiently, leave them in the sun until the afternoon. And then put them immediately into a container that can be properly sealed in order to keep them dry. Do not leave packing until the morning, as the seeds absorb moisture overnight.

The simplest container is a thick polythene bag, or two thinner ones, one inside the other. Squeeze out the excess air, and then tie the neck tightly with string or wire so that damp air cannot get in. It is often a good idea to put the bag in a tin box to protect it from being punctured and from rodents who may try to

Plastic or glass jars with a screw lid can be used for small quantities of seed provided that the lid forms a tight seal. Do not put unbagged seeds in tins with lids that press shut as the seal may not be sufficiently tight.

24.5.3 Label and number the containers of seed.

Keep the containers in a cool, dry room. The best place is a well-ventilated ground floor room on the north side of a two-story building. Keep the containers off the ground, preferably on shelves half way up the wall. Do not put them in the eaves of a roof, as this will become warm during the day or directly on a ground floor as this may be damp.

When you remove seed from a container, make sure it is sealed properly immediately afterwards. This is especially important if the container is opened on a wet day. If the container is left open the seed quickly absorbs moisture, and needs to be dried again.

Some species have seeds that must be kept moist if they are to remain viable. They are called 'recalcitrant'. If they are dried they quickly die. These seeds are often found in species that have fleshy fruits which do not dry out on the tree, and which are dispersed just before or during the rains. The following species used for bioengineering fall into this category:

Badahar	*Artocarpus lakoocha*
Champ	*Michelia champaca*
Chiuri	*Aesandra butyracea*
Dhale katus	*Castanopsis indica*
Chuletro	*Brassaiopsis hainla*
Khasru	*Quercus semecarpifolia*
Kutmero	*Litsea monopetala*
Musure katus	*Castanopsis tribuloides*
Okhar	*Juglans regia*
Patle katus	*Castanopsis hystrix*
Phalant	*Quercus lamellosa*

Always sow this type of seed as soon as possible. If it has to be stored for more than a week, use the following method. Extract the seed from the flesh. Do not dry it but mix it with twice its volume of damp sand. Put this mixture in a tin with a lid, whose sides and bottom have at least 20 small holes (2 mm diameter), made with a nail. Make sure several of the holes are in the bottom to allow for drainage. After putting in the sand/seed mixture, fill it to the top with damp sand. Dig a hole of 1m deep in a sheltered and well drained place. Check that the water table is not reached. Cover the bottom with a layer of damp sand and put the seed containers on it. Then cover with more damp sand and fill the rest of the hole with the excavated soil. Mark the spot with a stick. If it is on a slope, dig a drainage ditch above the hole so that water will not drain into it. When you require the seed, dig it out. Remove the seed from the sand carefully, as some of it may have started to germinate.

24.5.4 Equipment

You can obtain storage tins and thick polythene bags from Kathmandu. The tin trunks available in most bazaars are ideal for keeping plastic bags of seed in. If thick polythene bags are not available locally, use two thinner ones, one inside the other. Plastic jars from bazaars are suitable, provided the lid is a tight fit. You can check this by filling the jar with water, screwing on the lid, turning it upside down and squeezing. Water should not come out.

Preparation for bioengineering project presentation

During this Course you have taken part in a number of Field Exercises. You have also looked at water movement and the various types of instability which we find. In connection with this you have mapped a landslide.

Your thinking then moved on to the study of civil engineering systems and bioengineering systems. Finally, considering the idea of the plants that we may use in bioengineering, you selected the plant species. You calculated the cost and prepared the programs. Now it is the time for the compilation of all these works and become ready for the presentation in the next session. The presentation will cover the following:

- site assessment.
- geological assessment.
- civil engineering measures.
- bioengineering measures.
- species selection.
- planning for plant provision.
- work programming.
- safety considerations.
- estimating, costing and budgeting.

Based on the topics mentioned above, the groups will present their findings in the next session. Therefore, work in groups by dividing the work among members. Remember that there is limited time, manage it accordingly.

■ ■ ■

Project presentation

26.1 Preparation of presentations at Training Centre

a. Write-up detailed assessment of the site.
b. Preparation of proposals.
c. Estimation of materials/resources required.
d. Costing works.
e. Scheduling of all works for preparation and implementation.
f. Preparation for presentation.

26.2 Presentation on each group's site

You had worked in four groups. Each group was given the same site to assess. Assume that you have just arrived in this office and that your group has been assigned the task of stabilizing your site. Establish what you need to do; assuming that budgets and targets are not a constraint

You have assessed your site in as much detail as possible and made some estimate of the area and volumes involved in treatment. Consider the items in this Presentation.

26.2.1 Site history

- What is the material?
- What are external factors, or were affecting the site?
- What was the original cause of failure/erosion?
- What are the active erosion processes at work in each part of the site?
- How long ago did it start to become unstable?
- What is the drought factor for the site?

Past stabilisation attempts (if any)

- Have there been any attempts to stabilise it so far?
- What were the treatments? Are there signs of anything that failed?
- What was successful in terms of stabilisation/erosion control?
- How appropriate were any bioengineering treatments?
- What are about the civil structures? Are they strong enough? Are they big?

The way forward

- What needs to be done now?
- How can the site be broken down into different segments?
- What treatment is needed for each segment?
- What preparation works are required?
- What resources will be needed to achieve this?
- What are the quantities involved?
- What are the costs of these works?
- How should the works be scheduled?
- Are these measures the best possible solution in terms of cost and effectiveness?

In preparing your group's presentation, you should note the following:

- The presentation must be for people who have not seen the sites.
- Each group must describe its site (with sketches).
- You should say what rehabilitation measures are proposed.
- You should define the materials and resources required.
- You should prepare a costing for the work?
- You should state the schedule for completing the works.
- Do not forget include the nursery preparation of pants for the bioengineering works.
- You must be ready to justify the proposal.

Mercy Corps , Nepal

.......................................Project

A ONE - WEEK TRAINING ON BIOENGINEERING
FOR
ENGINEERING TECHNICIANS

CLOSING CEREMONY

15:30	Welcome remarks	Mr/Mrs. .... Manager, ... Project.
15:35	Sum up remarks on the Training Program	Mr/Mrs. ...., Manager, ... Project.
15:45	Comments from the Participants	Mr/Mrs.................................. ...., ...Project
15:50	Comments from the organizer	Mr/Mrs.................................. ...., ...Project
15:55	Comments from the trainers	Mr/Mrs.................................. ...., ...Project
16:00	Certificate distribution and Closing remarks	Mr/Mrs.................................. ...., ...Project
16:25	Vote of thanks	Mr/Mrs.................................. ...., ...Project
16:30	Refreshments	

Mercy Corps Nepal

……………………….. Project

COURSE ATTENDANCE CERTIFICATE

This is to certify that

Mr./Mrs./Miss ....

attended and successfully completed the One Week Training Course
on

BIO-ENGINEERING FOR ENGINEERING TECHNICIANS

………………… to ……………20XX

……………………………………………………

………………………………………………………, 20XX

... | **..**

………………………………………… | **……………………………………………**

Chief Guest | **Training Co-ordinator**

………………………………………… | **……………………………………………**

……………… ....Project

Evaluation form

Please complete Sections 1 and 2 by entering a () in the appropriate columns according to the key and adding comments you wish to make.
Key: Relevance - 1 = Very relevant, 2 = Relevant, 3 = Not very relevant, 4 = Not at all relevant
Interest - 1 = Very interesting, 2 = Interesting, 3 = Not very interesting, 4 = Not at all interesting
Time allocation - A = Too much, B = About right, C = Too little

1 Classroom sessions

Topic area	Relevance to work in bio-engineering				Level of interest of topic area				Time allocation			Comments
	1	2	3	4	1	2	3	4	A	B	C	
Introduction to Bio-engineering												
Hill slope processes and Landforms												
Rainfall and water movement												
Slope and slope materials												
Causes and Mechanism of Failure												
Slope instabilities												
Instability mapping techniques												
Field work on instability mapping												
Small scale civil engineering structures												
Drainage and gully protection work												

Topic area	Relevance to work in bio-engineering				Level of interest of topic area				Time allocation			Comments
	1	2	3	4	1	2	3	4	A	B	C	
Field work on small scale civil engineering structures												
Vegetative engineering structures												
Compatibility of structures												
Field work on vegetative engineering structures												
Selection of bioengineering Plant Species												
Maintenance of vegetative system												
Field work on maintenance task and plant type selection												
Estimating and costing												
Programming work												
Monitoring and quality control												
Exercise on Rate analysis, Preparation of cost estimate												
and programming												
Introduction to Nursery												

Please add any further comments you wish to make about the training sessions in the space below.

3. Training methods

This course has been run as participatory training. This means that you were not simply given lectures, but were actively involved in the sessions through questioning, discussion and a variety of exercises. Please tick the appropriate boxes to show how much you agree or disagree with these statements about the training.

	Agree strongly	Agree	Disagree	Disagree strongly
a. I enjoyed the training approach				
b. I did not like the group work				
c. I feel that I learnt more this way				
d. I prefer to have lectures				

Please add any further comments you wish to make about the training approach in the space below.

---

4 The trainers

Please indicate your views on the trainers by ticking the boxes in the table below.

	Agree strongly	Agree	Disagree	Disagree strongly
a. I found the trainers friendly				
b. I could not understand the trainers				
c. The trainers were interested in me				
d. The trainers were well organised				

Please add any further comments you wish to make about the trainers in the space below.

---

5 Organisation and facilities

Please give your evaluation of the following items by ticking the appropriate boxes.

	Very good	Good	Poor	Very poor
a. The classroom				
b. Transport arrangements				
c. Course materials				
d. Equipment				
e. Residential accommodation				
f. Meals				
g. Advance information				
h. Administration of training				

6 Other comments

a. Best things about the block

Please note what you feel are the three best things about the block.

1. ______________________________

2. ______________________________

3. ______________________________

b. Weakest things about the block

Please note what you feel are the three weakest things about the block and suggest ways in which they could be improved.

1. ______________________________

2. ______________________________

3. ______________________________

c. Improvements to the block

Please note three improvements you think should be made to the block.

1. ______________________________

2. ______________________________

3. ______________________________

You can use the back of this page for any other comments that you wish to make about the training. Thank you for your help.

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Mercy Corps is an international, non-governmental humanitarian relief and Development agency that exist to alleviate suffering, poverty and oppression by helping people to build secure, productive and just communities. Mercy Corps was established in 1979, and has headquarters in the USA and UK. Since 1979, Mercy Corps has worked in over 100 countries. Mercy Corps currently works in 40 countries around the world focusing on countries in transition, where countries are in the midst of or recovering from conflict, economic collapse, or disaster; Mercy Corps sees these crisis situations as moments of opportunity to go beyond traditional boundaries of relief and catalyze lasting change. Globally, Mercy Corps implements programs in a range of sectors, including agriculture and food security; market development; emergency response; disaster risk reduction; climate change; health; conflict management; youth Engagement; and community mobilization/ governance. In Nepal, Mercy Corps began its operation in 2005 and focuses on the sectors of Agriculture and Food Security, Financial Services, and Disaster Risk Reduction with early warning and Youth Engagement, with the inclusion of women and disadvantaged groups as a cross cutting issue.

The Hariyo Ban Program, funded by USAID and implemented by a consortium of WWF, CARE NTN and FECOFUN with WWF as the lead, aims to reduce adverse impacts of climate change and threats to bio-diversity in Nepal. It works on 3 core interwoven components – bio-diversity conservation, sustainability landscape and climate change adaptation – with livelihoods, gender and social inclusion being important cross-cutting themes.

Mercy Corps is one of the resource partners for Hariyo Ban and is implementing a number of initiatives aimed at improving resilience to climate-induced disasters, with a particular emphasis on flooding, while at the same time decreasing the negative impacts on livelihoods, for flood-prone communities in the Terai region of Far Western Nepal. This document is part of Mercy Corps partnership with the Hariyo Ban consortium documenting successful approaches, identifying and recommending corrections for less successful approaches and helping chart forward an evidence-based course for scaling up climate change resilience of communities and ecosystems in Hariyo Ban areas through analyzing successful approaches in climate-induced disaster risk reduction and livelihood enhancement.

The Hariyo Ban Program is named after the famous Nepali saying 'Hariyo Ban Nepal ko Dhan' (Healthy green forests are the wealth of Nepal). It is a USAID funded initiative that aims to reduce the adverse impacts of climate change and threats to biodiversity in Nepal. This will be accomplished by working with the government, communities, civil society and private sector. In particular, the Hariyo Ban Program works to empower Nepal's local communities in safeguarding the country's living heritage and adapting to climate change through sound conservation and livelihood approaches. Thus the Program emphasizes the links between people and forests and is designed to benefit nature and people in Nepal. At the heart of Hariyo Ban lie three interwoven components – biodiversity conservation, payments for ecosystem services including REDD+ and climate change adaptation. These are supported by livelihoods, governance, and gender and social inclusion as cross-cutting themes. A consortium of four non-governmental organizations is implementing the Hariyo Ban Program with WWF Nepal leading the consortium alongside CARE Nepal, FECOFUN and NTNC.

Disclaimer: This guidebook is made possible by the generous support of the American people through the United States Agency for International Development (USAID). The contents are the responsibility of Mercy Corps and do not necessarily reflect the views of USAID or the United States Government.