



Civinnovate

Discover, Learn, and Innovate in Civil Engineering

1. Introduction to Bioengineering

1.1 Glimpses of landslides and scenario of soil erosion in Nepal

Nepal is Himalayan country where about 87% of the land is covered by the sloppy land and rest 13 % is Terrain. Civil engineering sites are very unstable and instability is further increased by rain, haphazard construction activities, and seismic activities. As a result soil erosion, landslide, and rock toppling or in general mass wasting activities are increasing. It is estimated that 800 MT/ha/yr. of soil is lost as result of mountain road construction, about 3000-9000 m³ of landslide per km during construction of road. Civil engineering construction without slope is unthinkable. During construction activities of roads, buildings, bridges, railways etc. civil engineers faces from gentle slopes to steep slope.

1.2 Identification of problems in Nepal

In the slopes, mainly following problems arises;

- Rolling of materials down the slope
- Waters percolates into the slope and liquefy the slope material
- Loose state of material
- Tendency of outward and downward movement of slope
- Slipping of overlying strata in stratified soil
- Accumulation of water

Causes of Instability

The main causes of are described as follow;

1) Surface water

Surface Water is that water which is found available either through heavy rainfall or from other water resources travelling from one place to another through the general surface. This gives the rise to erosion and soaking of water to cause shallow sliding. The water gets infiltrates from the surface. The failures are mainly shallow and there evidence of source and presence of water.

2) Ground Water

Ground water is that water which is being under the surface of the ground can cause the increased pore water pressure at the depth. This gives rise to a failure plane deeper than surface water failures. Water percolation through ground from terrace (paddy khet) and irrigation canal (kulo) major effect on the long way down the slope.

3) Weathering

Weathering is the process of constant action of temperature, air and water like agent and reducing the strength of rock. The bonds between the rock constituents are weakened or broken resulting to the failure of plane through those weakened plane. The weathering process may take place over a long period to result in failure.

4) Under Cutting

Under cutting is the process of slope under by flowing river or stream or by opening of road cutting which can cause the major slope failure. Incision (down cutting) or lateral scour by streams is a major cause of slope failure the initial failure can work rapidly up slope.

5) Added Weight

Added weight is the process of sliding material or dumping of spoil or debris from one plane to another causing the new failure in added place due being unable to bear the new extra load.

6) Earth Quake

Earth quake causes many complex failures.

Mechanism of Instability

The mechanism of instability are as follows

1) Erosion

Erosion is the process of removal of the particles from the surface mainly by flowing water. The removal of particles may vary from depth of 25 mm to several meters. The following types of erosion occur.

2) Planner failure

These are the most common types of slides in Nepal. In this a slab of material of more or less thickness slides off the surface. Translational slides are typically rectangular in plan, with a straight head scar and straight sides running parallel down the slope. They are frequently quite shallow (≤ 1 m). They can be caused by ground water pore pressure along a slide plane or by weathering or undercutting the slope. They can be shallow or deep according to the structure of the superficial layers.

3) Shear failure

The rotational movement of material occurs forming a spoon shaped scar on the hillside which is roughly circular in plan. The debris forms a bulge near toe. Slumps are commonly caused by high ground water pore pressure deep in the hillside and the slip circle usually goes several meters deep. The cause of shear failure is the movement of the materials in the slope by process of slide, slump, flow caused by surface water, ground water etc.

4) Debris flow

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

1.3 Engineering functions to be performed

To address the above problems in slope, the following engineering functions are to be performed;

- Catch

- Armor
- Reinforce
- Support
- Anchorage
- Drain

1.4 Materials to be used for slope protection and stabilization works

The control measures are those techniques which fulfill the specific engineering functions to solve the problems of instability and erosion on slope. The engineering function fulfilled by plants and civil engineering structures are show below.

Based on how these engineering function are fulfilled, the control measures introduced in Nepal are;

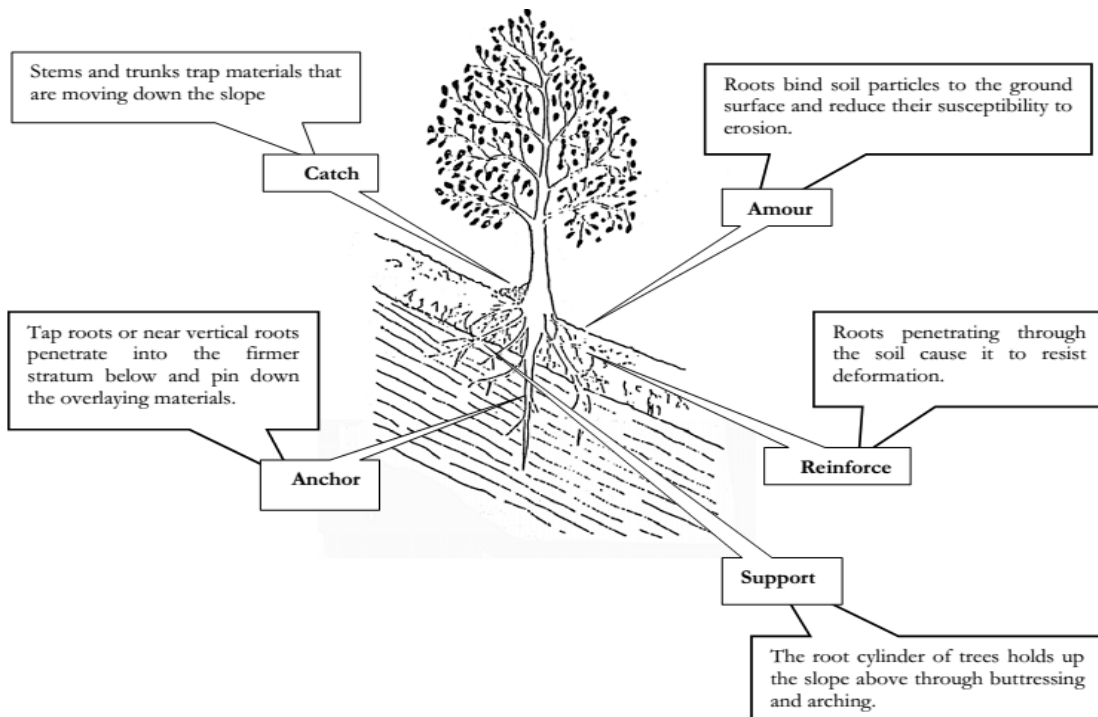
- 1) Using Civil engineering structures (rigid structures) only
- 2) Using Vegetative (flexible) systems only
- 3) Using Bio-engineering techniques

Civil engineering structures are those rigid structures which are constructed to full fill the engineering functions to control instability and erosion on slope. This technique is widely used in road constructions in Nepal. These structures includes: retaining wall, revetment wall, prop/support wall, dentition wall, check dam, surface and sub-surface drain, stone pitching, wire bolster etc.

Vegetative system is the use of different grass, shrubs and trees to fulfill engineering functions to control instability and erosion on slopes. But in reality use of vegetative system is inefficient because a plant takes months to years to fully grow and fulfill engineering function. During its' growth period it should be protected from grazing of animals and washing away due to landslide, erosion, slumping etc. as it can't function at its initial stage and for that we need assistance of civil engineering structures in small scale (by size, cost and technology) and gives rise to what is now called "Bio-engineering techniques" which is the optimization of civil and vegetative systems in terms of cost, strength, economy and performance. The vegetative system alone refers to different techniques to plant seeds, seedlings and cuttings of grass, shrubs and trees. Few of them are: grass planting, seeding and turfing, shrub and tree seeding and planting, large bamboo planting, brush layering, palisades, fascine, live check dam, live wattle fence etc.

1.5 Use of vegetation as slope stabilizing material

The control measures are those techniques which fulfill the specific engineering functions to solve the problems of instability and erosion on slope. The engineering function fulfilled by plants and civil engineering structures are show below.



1.6 Definition of Soil Bioengineering

- Bio-engineering is the use of living vegetation either alone or in combination with civil engineering structures and non-living plant materials to reduce the shallow seated instability and erosion on slope.
- Bio-engineering can be used to protect all most all slopes and reduces the instances of shallow seated planner sliding.
- It is also used to improve the surface drainage and reduces slumping.

1.7 Justification of Bioengineering

- By observation
- By calculation
- By estimation
- By interviews with local people
- By case studies
- By field visits

1.8 Field of application and scope

Scope:

- ◆ Mining and reclamation
- ◆ Highways and railways
- ◆ Construction sites for buildings, tunnel dams, power house, bridges ,etc
- ◆ Waste disposal and public health
- ◆ Airfields and helipads

- ◆ Waterways
- ◆ Land drainages
- ◆ Reservoir and dams
- ◆ Coastal and shoreline protection (River training works)
- ◆ Buildings
- ◆ Recreation
- ◆ Pipelines
- ◆ Site appraisal (to evaluate the type of soils)
- ◆ Water disposal and public health
- ◆ Agricultural Sites-agro tourism

Applications:

- Slope stabilization
 - Embankment
 - Cutting
- Erosion control
- Water course and shoreline protection (River training and bank protection)
- Wind erosion control
- Vegetation barriers
 - Shelters
 - Noise reduction
- Surface protection and trafficability
- Control of run offs in small catchments
- Plants as indicators

1.9 Advantages and limitation

Advantages

- Low-cost and lower long-term maintenance cost than traditional engineering methods.
- Environmental benefits to wildlife habitat, water quality, and aesthetics
- Improved strength over time as the root system develops and increases structural stability
- Compatible with environmentally sensitive sites or sites with limited access
- Socially and economically advantageous to local communities, use of local resources (material, manpower)
- Physical flexibility
- Versatility in application
- Protects almost all slope against erosion

- Reduces the shallow seated instability
- Improves surface drainage and reduces slumping
- The only solution to some problems

Limitation

- Not able to function in its initial stage
- Chocking of waterways with plant growth
- Needs after care, regular repair and maintenance
- Root penetration in foundation and growth of vegetation in structure causes adverse effect.

3. Basic aspect of vegetation

3.1 Plant types, plant form, and structures

There are different types of plants found in Nepal. They are:

1. Trees

The plants most of which grow from a single upright main trunk with branches in the upper part to form a crown and has the height of 3m or above are called trees. The growing habits of trees can vary considerably. So tree can be taken as woody plant of large structure.

2. Shrub

The plants having fairly dense, woody, perennial growth, with many well branched stems are called shrubs. Some of them are quite low growing whereas some of them can grow to over 2m; it is a woody plant of substantial structure smaller than a tree but some overlap with this group.

3. Grass

It is a member of distinct botanical family, widely utilized by people; includes ruddes, sudes and reeds; non-woody usually short lived individuals which can withstand tamping and grazing. The grasses are the wide spread and versatile family of plants, widely used by people for a variety of purposes. The most important factor in the growth habit of grasses is that the main growing points are at ground level. Grasses spread vegetatively by tillering, i.e. by producing new stems from the bases of the existing ones. The new fillers either cluster at the base of the existing plant forming large clumps of densely packed plants or they form rhizomes or stolons to produce a spread sward.

4. Herbs

Herbs are broad leaves plants of which the above ground parts are generally non-woody. They include what are generally referred to wild flowers and weeds together with cultivated and forage plants such as legumes (e.g. pea, clover, vetch and lupin). Growth habits vary from upright single stemmed or multi-stemmed individuals to spreading, creeping individuals.

5. Bamboo

Basically bamboo are tall grasses. But, because of its specialized role on bio-engineering and special growth characteristics, it is taken as a separate type of plant. Bamboo serves not only as material for bio-engineering but also as a living plant material.

Considerable parts of plants

- Roots – for anchoring, absorbing water and nutrients.
- Stem – to perform catch function

- Leaves –to interact with sunlight for manufacturing the carbohydrate and interruption of rain drops,
- Flowers –to use for propagation

Root Architecture

- Tap Root
- Plate Root
- Heart Root

Root Structure System

- Strong, vertical and horizontal growth
- Shallow growth parallel to surface
- Parallel and horizontal growth
- Strong horizontal growth
- Strong vertical orientation
- Profuse massive growth
- Deep branched rooting

Classification of plants depending upon

A) Root system

- | | |
|--------------------|---------------------|
| ▪ Fine and fibrous | ▪ Deep |
| ▪ Branched systems | ▪ Heart root system |
| ▪ Shallow | ▪ Plate root system |

B) Stems

- Single stemmed –spreading upright
- Multiple

On the basis of flexibility, stem can be classified as

- Resilient
- Buried
- Weak

C) Leaves

- Narrow/Long
- Small
- Large/ board

3.2 Vegetation and plant community

- Progression
- Regression
- Climax
- Succession

Plant Community

A plant community is an established group of plant living more or less in balance with each other and their environment. The group can be natural or managed. The community is usually dominated by the main species of trees, but also contains lower plants such as shrubs, grasses and herbs. An ideal plant community for bio-engineering contains a carefully planned variety of different plants which together meet the engineering needs of site. The following things are to be considered for managing plant communities in bio-engineering:

- Where possible, mixture of plants should be used in the initial planting. If relied on only one species this may fail, and there may be a complete loss of planted material.
- It should be started with pioneer species. For example, with a damp and north facing slope utis and some under storey grasses should be introduced.
- A balance of plant species in the community should be planned. Generally grasses, shrubs and trees should be included (but the exact balance is determined by the engineering requirements of the site).
- Dominant plants such as utis must be replaced or thinned out within five to ten years. Otherwise the under storey plants will be overshadowed and eradicated completely, allowing erosion to start under the tree canopy.
- The plants should be thinned out properly to maintain a balance.
- Weeds should be cleared to reduce competition.
- Gaps should be re-planted

3.3 Basic requirements of plant

Plants require the following for their living:

- A. Air (25%)
- B. Water 25%
- C. Nutrient 45% , Organic matter 5%

Major Nutrients

- Nitrogen(87%) – for greenery and fast growth of the plant
- Phosphorus – strengthen stem and flowering
- Potassium – act as disinfectant

Minor Nutrients

- Sulphur
- Calcium
- Magnesium
- Sodium

Trace Mineral

- Iron
- Magnesium

- Boron
- Copper

Acidic soil lacks:

- Nitrogen
- Phosphorus
- Potassium
- Sulphur

Alkaline soil lacks:

- Phosphorus
- Iron
- Manganese
-

- Zinc
- Molybdenum

- Copper
- Zinc
- Boron

- Copper
- Zinc
- boron

D. Soil organism

- Earthworms
- Soil fungi
- Actinomyces
- Bacteria

E. Nitrification

F. Sulphur oxidation

G. Nitrogen fixation

Compost

- ✓ Improves soil structure
- ✓ Stimulates activities of soil organism
- ✓ Adds nutrients to soil

Ingredients/ Requirements

- ✓ Plant materials
- ✓ Soil organism
- ✓ Good environment for the activities of soil organism

Mineralization is the process of the cycle in which inorganic minerals are taken up by plants and a subsequently returned to the soil as organic matter when they die and minerals in this organic matter become available to the plants again when they are decomposed by micro-organism.

Plants and Soil

Physical properties of soil:

- Texture

- Soil structure
- Rooting potential
- Soil water capacity
- Permeability and water acceptance
- Ion exchange capacity
- Erodibility
- Ease of cultivation

Soil structure

- It is the characteristics which describes the arrangement and size of components of the soil.

Field capacity

- Moisture content remaining when a soil is drained under gravity.

Permanent Wilting Point

- The moisture content at which the plants will not normally recover if soil moisture is further reduced.

Available Water Capacity

- It is the difference between field capacity and the permanent wilting point.

Typical Soil Wetness Classification

- a) Marshy and baggy
- b) Poorly water drained – water logged for most of the year (water table less than 4m)
- c) Moderately drained, seasonally water logged (WT in between 0.4m and 0.7m)
- d) Well-drained
- e) Drought

4. Role of Vegetation

Vegetation acts on slopes through a complex series of mechanical and hydrological processes. There are beneficial as well as adverse effects of vegetation on slope. The same factors beneficial at one site may not be suitable at another site. Some of the mechanical and hydrological functions are given below.

A) Mechanical Functions

a) Roots bind the soil and permeates the soil resulting in followings:

- Trapping of material moving down the slope
- Restraints of soil movement reducing the erosion

This function is good for engineering purposes

b) Tall growth of tree result the weight surcharge on slope increasing the normal and downward slope components. This is advantageous in gentle slope but disadvantageous in medium and steep slope

c) Vegetation exposed to wind, the dynamic forces are transmitted into the slope which is generally considered good.

d) Stem and leaves cover the ground surface so that impact of traffic is absorbed which is not good.

B) Hydrological Functions

a) Foliage intercepts the rainfall causing the reduction in the kinetic energy of rain drops and thus less erosive which is of good effect.

b) Roots permeate the soil leading to opening up of surface and increased infiltration. This effect may be good or bad depending upon the site condition.

The Role vegetation also can be explained in another way as follows:

1. Modification of surface water regime

- Interception
- Surface water runoff
- Infiltration
- Sub-surface drainage

2. Surface Protection

- Rain drop impacts
- Surface water erosion
- Mechanical role
- Soil insulation
- Soil restraint

3. Modification of Soil water properties

- Evapotranspiration
- Soil water balance
- Soil moisture depletion
- Soil weight reduction

4. Modification of Soil Mechanical Properties

- Root reinforcement of soil
- Anchorage, Arching, Buttrussing

5. Modification of Air Flow

- Change in direction
- Change in velocity
- Change in the content
- Change in the impacts

Soil Strength (Shear Strength) Incensement

The shear strength of the soil is increased by the following expression:

$$\Delta S = tr (\sin\theta + \cos\theta \tan\phi) \dots\dots\dots (i)$$

Where,

ΔS = Increase in Shear Strength

ϕ = Angle of Internal Friction of soil

θ = Angle of Shear distortion in the shear zone

tr = Modified tensile stress of root fibers per unit area of soil = $Tr(A_r/A)$

T_R = Root tensile strength

$$(A_r/A) = (\sum n_i a_i) / A$$

$$T_R = (\sum n_i a_i T_i) / (\sum n_i a_i)$$

Generally the value of expression (i) is found as,

$$\Delta S = 1.2 T_R (A_r/A) \quad \text{i.e. } (\sin\theta + \cos\theta \tan\phi) = 1.2$$

The strength is give by

$$T_R = n D^m \dots\dots\dots (ii)$$

D = Diameter of root (mm)

n and m are empirical constants for given species

$$m = (-0.76) - (-0.45), n = 29.1 - 8$$

$$L_{min} = T_R \cdot D / 4 T_b$$

Where,

$$T_b = z \cdot \gamma \cdot (1 - \sin\phi) f \cdot \tan\phi$$

D - Root diameter

T_R - Root tensile strength

T_b - Limiting Bond

f - Coef. of friction between root fibre and soil

Root Strength

$$T_R = n D^m$$

Where,

T_R → root tensile strength

D → root diameter

n and **m** → empirical constants for a given plant species

n=29.1-87

m=(-0.76)-(-0.45)

Strength loss with time following cutting

$$T_{rt} = T_{ro} e^{-bt}$$

Where,

T_{rt} → Tensile strength of root wood sampled from live trees

T_{ro} → Tensile strength of roots sampled from stumps cut 't' months before sampling

b → probability of decay

t → age of stump (time between felling and sampling)

e^{-b} → expression of strength decay rate

Quantification of Soil Arching

$$P_r = 0.5 K_o \gamma H_z^2 (D+B) - \rho B H_z$$

$$P_p = \frac{(\gamma H_z \cos \Phi (m \sin \beta - m \cos \beta \tan \Phi - K_o \tan \Phi) - (C_1 m + 2C \cos \beta))}{2 K_o \cos \beta \tan \Phi}$$

Where,

B – clear spacing between trees

H_z - vertical thickness of yielding soil stratum

K_o – coef. of lateral earth pressure at rest

γ – unit weight of soil

ρ – average lateral earth pressure in opening between piles trees on a slope

d – diameter of the embedded section of tree

$$m = B/H_z$$

$$n = X/B$$

X – row to row distance between trees

5. Selection of Bioengineering Plant Species

Factors governing the distribution of vegetation in Nepal

In Nepal, vegetation bands are related broadly to altitude. The main factors, which govern the distribution of vegetation are:

- Altitude
- Aspects
- Rainfall distribution
- Geology and soil (relatively minor scale)

In Nepal, 10,010 species of plant are found in Nepal.

6500 species of plant found everywhere in Nepal.

350 species of plant are used for bioengineering purpose.

1. Ecological zones of Nepal

Nepal can be divided into six ecological zones, with one of them divided into two zones:

- I. Terai
- II. Chure
- III. Inner Terai
- IV. Lower Himalaya
- V. Higher Himalaya
 - a) Mahabharat Range
 - b) Mid lands
- VI. Trans Himalaya

2. Vegetation Zones

Distribution of vegetation depends on altitude but there might be contain marginal area where plants of two vegetative zones may be encountered. According to this factor, vegetation can be divided into:

- I. Tropical zones
 - Upper boundary at about 1000m
 - Sal forest
 - Khayer and sisam forest
 - Other riparian forest
 - Grass land
 - Asana forest (Terminalia spp.)
- II. Sub-tropical zones
 - Range 1000-2000m in the west and 1000-1700m in the east

- Khote salla
- Chilaune + katus
- Utis
- Riparian forest (tooni + siris)

III. Lower temperate zone

- Range 2000-2700m in the west and 1700-2400m in the east
- Khatas
- Gobre salla
- Lower temperature mixed broadleaf forest
- Banjh

IV. Upper temperate zone

- Range 2700-3000m in west and 2400-2800m in the east
- Banjh
- Gurans
- Upper temperature coniferous forest (Gobre salla)
- Upper temperate broadleaf forest

V. Sub-alpine zone

- Range 3000-4200m in the west and above 3000m in the east
- Basically forest species are found growing in the cool desert area having rainfall of less than 300mm/year. Small spiny shrubs are found in the Mustang and Dolpa. Species include gurans, Gobre salla, dhupi

VI. Alpine zone

- Above snowline
- Species include Gurans, thorny plants and shrubby species.

3. Selection of plant species depending upon moisture availability

Some plants love moisture whereas some can be grown in drought condition. Some of the grass species that can be grown in the moist area: Dhode, Amresho, Shito, Fhurke, etc. but in the drought area: Bhabiyu, Kash, Dhode can be introduced. Plants type like sitaria, mushe kharuke, kush, nepiyan, khar are some species that can be introduced in moderate sites.

4. Selection of plant species depending upon land mass meeting

Based on the source of migration, the vegetation are scattered whether in the eastern or western part, therefore it has to be considered whether the specific species can be grown in specified area. E.g. 'Chilaune' are not found in the western part of Nepal whereas 'banjh' are not available in eastern part. Border line can be taken as Tinau khola.

5. Selection of plant species depending upon plant community

Site condition (unstable, infertile, dry)

- Pioneer plants
- Dominant plants
- Associated plants
- Improvement (Leguminous plant)
- No colonizers

Other factors to be considered for plant type selection:

- Local species
- Morphological characteristics
- Establishment and persistence
- Fast growth and vigor
- Ease of propagation
- Availability

Selection of plant species depending on drought factor

1) Slope angle

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

2) Stoniness (% of fines)

Fines	Score
>25%	1
20-25%	2
15-19%	3
10-14%	4
5-9%	5
<5%	6

(Note: fine- 0.075mm ; sometimes 0.02mm)

3) Altitude

Altitude (in meter)	Score
>2500	1
2000-2500	2
1500-1950	3
100-1450	4
500-950	5
<500	6

4) Aspect

Aspect	Score
North	0
North-East	2
North-West	4
East	6
West	8
South-East	10
South-West	10
South	12

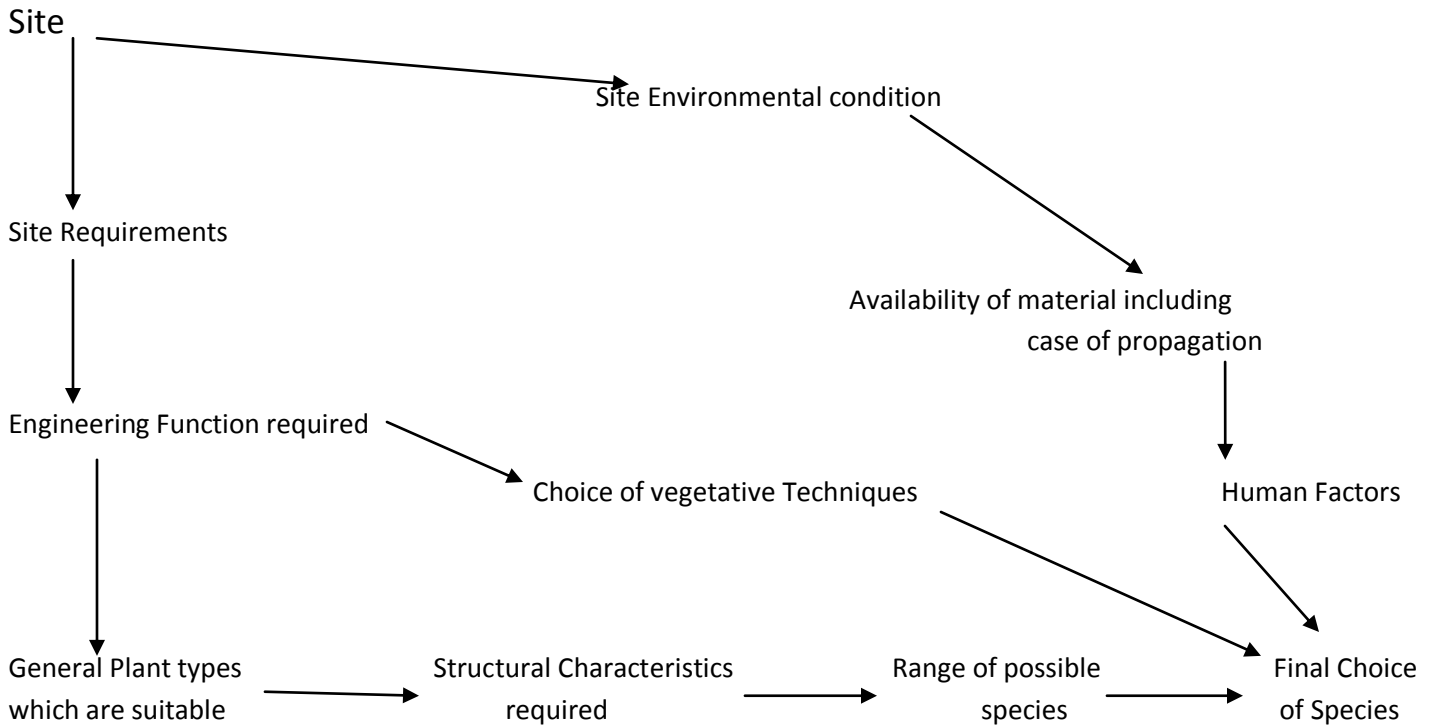
5) Annual rainfall

Rainfall (in mm)	Score
>2500	1
2000-2490	2
1500-1990	3
1000-1490	4
500-990	6
<500	8

CLASSES OF THE SITES ACCORDING TO ABOVE SCORES

Score	Class	Definition
<6	I	Cool and Moist sites
6-11	II	Damp sites
12-17	III	Moderately Dry sites
18-23	IV	Warm and Dry sites
24-30	V	Very Hot and dry sites
>30	VI	Very Severely Hot and dry site

Selection of plant species for Bio- Engineering



6. Vegetative engineering techniques

Bio-engineering is the engineered combination of living plants. It is the use of living plants to perform the engineering functions. E.g. tree plantation above retaining walls.

Bio-engineering systems can be developed by the use of following techniques:

- Seeds
- Sapling
- Cutting of plants
- others

Use of Seeds(Seeding)

The seeding consists of the mainly following techniques:

a) Seed Sowing

b) Seed Broadcasting

The techniques of the seeding depend upon the following factors:

a) Slope Angle

- Steep land :Sowing
- Plain land : Broad casting

b) Seed Size

- Large Size : Sowing
- Small Size : Broad casting

c) Cost (Availability)

- Low cost : Broad Casting
- High Cost: Sowing

d) Soil Type

- Debris : Broadcasting
- Other : Sowing

Sapling (plantation)

A) Grass Plantation (GP)

Grass seedlings or rooted cuttings are planted in line on slope. They will protect slope with their roots by providing a surface cover, reinforcement and catch. Lines can be made in angles in order to:

- Reduce the speed of runoff.
- Give rapid drainage.
- Give combination of both.

According to the configuration of line of planting, they are classified as:

a) Horizontal Line Pattern

This is done only when soil is sandy in steep slope. The Dimensions of the patterns are as given below:

Slope Angle	<30°	30°-45°	>45°
Row-Row	1m	0.5m	0.3m
Plant-Plant	10cm	10cm	10cm

b) Vertical Line Pattern

This Pattern is made in clayey soil in any slope .The row to row distance is made 0.5m and that for plant to plant is 10cm.

c) Diagonal line Pattern

In this, grasses are planted in lines running diagonally across the slope. They armor the slope with their roots and by providing a surface cover. The main engineering functions are to armor and reinforce with secondary function to catch and drain. This is done in mixed of clayey and sandy soil type with the same pattern dimension of vertical pattern.

d) Chevron Pattern

This pattern is made in ridge of slope.

e) Herring Bone Pattern

This pattern is made is in valley of the slope.

f) Random Pattern

Grasses are planted at random on a slope to an approximate specified density i.e. generally 10cm of row to row and plant to plant. They armor and reinforce the slope with their roots and by providing a surface cover. They also have a limited function of catch debris.

B) Tree/ Shrub plantation

Seedlings of shrubs and trees are planted on a geometric pattern in the slopes $< 45^\circ$ < 300 respectively. They perform engineering functions such as catch, reinforce, support and anchorage. The practice of the tree plantation is 1m X 1m (spacing) offset or staggered. The following techniques seedlings are adopted:

- a) Bare root Plant
- b) Containerized plant
- c) Stump

Implementation Procedure

- a) Site preparation by digging a pit 30cm dia. and 30 cm deep.
- b) After removing the polythene pot trim the root coming outside the soil cylinder (pruning).
- c) Loosen the soil cylinder slightly.
- d) Place the plant into the pit and fill the top organic soil and compact it gently.
- e) To have the site free from water logging, make a small heaving so that water will not get stagnant.
- f) Mulch it.
- g) If rain does not occur for 48 hours, irrigate it.

C) Bamboo plantation

It includes 3 types of plantation systems such as by **seedlings**, **rhizome cutting** and **Culm cutting**. Plantation by Culm cutting is more effective. Its primary function is catch and support too. They are planted in the dampest of sites (muddy) having critical slopes less than or equal to 45 degrees. In any particular locality, lower slopes where there is accumulation of the debris and moisture have been found best. For e.g. a line of bamboos along the top of a gabion wall keeps debris back and effectively raises the wall.

Implementation procedure

- a) Remove all loose debris from the site and prepare the surface well in advance of the planting day.
- b) Dig a hole and plant the rhizome (6 month to 1 year old and about 2m high)/ a Culm cutting (well matured, 3-5 years old, including 1 nod and 10-15 buds) either upright or perpendicular to the slope. Backfill the hole well and mulch it.
- c) Generally plant to plant spacing is 2m and planted in a single row.

Mulching

Mulch is made by cutting the stems and leaves of unwanted plants. It is placed around seedlings to keep the soil cool and moist, thereby enhancing growth. It is generally used in conjunction with another technique.

2.6.3 Use of Cuttings

The use of cuttings means the use of the followings for different types of plants:

- a) **Stems**(Branches)
- b) **Rhizomes** (Underground stem of like plants bamboo, ginger etc.)
- c) **Stolon**(Like Dubo)
- d) **Culm** (Like Sugarcane)

Different Bio-engineering systems Using Cuttings:

A) Brush Layering

Woody (hardwoods) cuttings are laid in trenches across a slope, usually following the contour, having critical slope 45 degrees.

- a) For consolidated site depth of cutting is 45cm
- b) For unconsolidated site Depth of cutting is 60cm.
- c) Width of trench = 30 to 40 cm
- d) Diameter of cutting=8-18mm

Implementation procedure:

- a) From 1m above the bottom of slope, a precise contour line should be marked. The layer spacing

Slope	<30°	30°-40°
Spacing	2m	1m

- b) Starting at bottom, trenches are excavated along the lines at 20% inclination downwards.
- c) Cuttings should then be placed into each trench at 5 cm centers at right angle.
- d) To maximum slope 2/3 depth of cutting is inserted to the trench.
- e) The trench should be then partially backfilled and another line of cuttings placed along the trench at 5 cm center. (Cuttings are laid in double rows). Line to line, the cuttings are placed in offset, staggered and criss-cross pattern. Generally the offset pattern is used so that cuttings will be at 2.5 cm centers in each brush layer (i.e. 40 cuttings per running meter)
- f) The trench is then completely backfilled and gently compacted.

Main function: Catch, reinforce and support

B) Palisades

Almost same as in brush layering, in this system, a vertical hole is dug and cuttings are inserted. It is started from top to bottom. They are used when trenches cannot be dug i.e. trench can't be dug.

C) Live staking

Like palisade but placed 1m apart between plant to plant and is single rowed.

D) Fascines

Fascines are bundles of live woody cuttings laid horizontally in trenches, and parallel to the line of the trench just below the surface having critical slope equal to or less than 45 degrees. It is started from bottom to top.

Implementation Procedure:

a) From 1m above the bottom of slope, a precise contour line should be marked out. The fascine spacing depend on slope:

Slope	<30°	30°-45°
Spacing	4m	2m

b) Starting at bottom, trenches (20cm depth) should be excavated along the lines.

c) Cuttings should then be laid along each trench so that they lie horizontally along the trench (4~8 cuttings). They must be overlapped so that no two ends coincide. The cuttings must then be tied using jute or coir (coconut fiber) string at 50 cm intervals to form a bundle.

d) The trench should be backfilled and gently compacted. The top of fascine should be 50 ~ 100 cm below the surface.

e) Any loose or excess material is cleared down the slope before the next line is planted.

Main function: Catch, support, reinforce.

E) Live check dam

Woody or hardwood cuttings are built to form a live check dam. They armor and reinforce gullies, and trap material moving downwards. It is a low cost structure to reduce erosion in smaller gullies. It is used in slopes equal to or more than 45 degrees. Spacing of the check dam should normally be at 3~5m centers.

Other Systems

A) Turfing / Sodding

A surface is covered with the sods of turf brought from elsewhere. It is implemented where the critical slope is 35 degrees. It gives complete and instant surface armouring. Pegging should be done at 250mm centers on slopes > 15 degrees. It is mainly used In Terai road embankment in Nepal.

B) Hydro Seeding

This is the process of jetting of seeds, mud and fertilizer in the conglomerate land by the machine.

09. Nursery

Defination

It is the factory that produces the plant and the plant materials of required quality when required, how much required and at an affordable cost.

Nursery Component

The main components of the nursery are:

General	Compound wall or fence
Office	Chowkidar's hut, Vehicle access, Working area, Pathways
Storage	Store for soil, sand, compost, pesticide
Water	Water tank and Accessories, Drainage system
Beds	Seed Bed, Stool Cutting, Bare Root Plant, grass, Bamboo, Standout for poiypot, Shades for bed

Material Checklist

- Soil, Sand and Seed
- Compost fertilizer
- Fungicide, Insecticide
- Heavy gauge polybags for storage
- Shed material (bamboo, hessian)
- Wire, nails, string, wire mesh
- Seed bed level
- Pen, pencil
- Poly pot (4"*7")
- Heavy gauge

Equipment Checklist

▪ Kuto, Kodalo, Kodali	▪ Doko
▪ Chuppi	▪ Watering can
▪ Hasia, khukur	▪ Flit gun sprayer
▪ Khanti, Shovel	▪ Paper punch
▪ Secateurs/Scissors	▪ Plant carrying tray
▪ Tin trunk with padlock	▪ First aid kid
▪ Tray	▪ Safety equipment kit
▪ Measuring tape	▪ Soil and Sand Sieves

Nursery Site Selection

Factors to be considered for the selection of a nursery site:

- 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;

- The site is chosen at least six months before the first seed is to be sown;

Land Ownership

- As far as possible, the nursery should be established in own land.
- Legal provision should be carried out for the rented land.

Water Supply

- A guaranteed supply of 1,000 litres ($1 m^3$) of water per day is needed for a nursery of 20,000 plants watered with a watering can. Surface irrigation requires considerably more.
- The water right should be registered in the Water Resource Committee.

General Location

- The site should be located as close as possible to the centre of the area to which plants will be supplied and near to road.
- Aspect is very important. North facing slopes are cooler and more humid, thus better for nurseries at lower elevations whereas nurseries above 1200m are better on warmer southern slopes.
- A slope of 2-3% is necessary to allow water to drain off without causing erosion.

Availability of Materials and Labour

- Deep loamy soil, if possible with good content of organic matter (2%), on a well drained site.
- A nursery with a target of 20,000 usable plants would fill 25,000 pots. For (4"*7") pots, this would require $12.25 m^3$ of the plotting mixture. For a 2:1:1 Soil : Sand : compost mixture, about $6.2 m^3$ of soil and $3.1 m^3$ of sand are required.
- It should be near to the peoples' access so that they could go to work and come back to their place in the evening.

Spacing Nurseries

- Nurseries should be established at intervals according to their needs.
- Each climatic area where work is to be carried out should be represented by at least one nursery.
- Ideally plants are produced in nursery immediately next to their eventual destination although this cannot be achieved in every case.
- On some mountain roads crossing much unstable terrain a wide variety of climatic zones, one nursery per 10km may be necessary. Elsewhere a distance of 25km between the nurseries may be adequate.
- Nursery need to be as close as possible to the sites they serve.
- The location must be technically suitable.

- The final selection should be based on evaluating the relative advantages and disadvantages of three or more possible sites.
- Permanent nurseries with a production capacity of less than 100,000 grass slips or 25,000 shrub or tree seedlings, are not usually economically viable.
- Small nurseries can be better than one large one.

Advantages of Small Nursery

- The risk is spread during the planting season: blockages of the road which disrupt transport are less likely to jeopardise the planting programme.
- The dangers of drought, disease or poor management in one nursery will affect only part of the total stocks.
- Transport of stock from nursery to site is minimized which saves money and reduces stress damage to the plants.
- Nurseries in each climatic zone will allow a wider range of plants to be produced.
- Each nurseries requires trained foreman(*Naike*), this allows a greater transfer of skills which is a development objective.
- Nurseries act as a focus for work in the local community.

10. Maintenance Tasks

1. Protection works

E.g. protection of the plants and planting sites from grazing, theft of firewood and timber and fire protection works

2. Plant treatment

E.g. weeding, mulching, trimming, pruning, grass cutting, thinning and training of plants

3. Repair to vegetation structures

E.g. repairs to palisade, fascines, brush layering, turfing and vegetation enrichment

4. Repairs to inert structures

E.g. repairs to revetment and prop walls, gabion walls, bolsters, jute netting and wire netting and sealing cracks

5. Geophysics

E.g. small slope trimming, small slip clearance, cleaning, sub-soil drain outlets

Frequency of carrying out maintenance activities

- Routine maintenance
- Recurrent maintenance
- Periodic maintenance
- Emergency maintenance

Caring of young plants

- Environment management
- Spacing out plants
- Polypot management
- Weed, pest and disease control

Environment Management

- Shading
- Nursery Irrigation System
- Watering

Spacing out plants

- for light, pass nutrients for plants.

Re-spacing grasses

- pricking out
- thinning
- pruning

- coppicing
- pollarding
- trimming

Polypot Management

- spacing out polypot seedlings
- root-pruning polypot seedlings

Weed, Pest and Disease control

- weeding
- insect and pest control
- fungal disease control



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