LANDSCAPE TECHNIQUES FOR EROSION CONTROL AND SLOPE STABILIZATION

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI GHANA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE (M.Sc. LANDSCAPE STUDIES) DEGREE.

BY

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DECLARATION

I hereby declare that except for reference to other people's work, which have been duly acknowledged, this write-up submitted to the School of Graduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi, is the result of my own investigation and has not been presented for any degree elsewhere.

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DEDICATION

This work is dedicated to my caring and loving parents, Mr & Mrs E. A. Asiedu

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ABSTRACT

Increased population growth has led to increased demand on land resources mostly for economic activities. This has led to the destruction of resources such as vegetation cover, which protect the land surface against erosion and slope failure. Generally, slopes may become unstable and fail when they are exposed to the environment. Erosion and instability of slopy areas have thus become a problem in both urban and rural areas.

A brief is taken of erosion and unstable slopes, factors causing them and their effects on development. This is followed by a discussion of some of the conventional and indigenous methods used in stabilizing unstable slopes and controlling erosion. The discussion then considers the weaknesses and strong points of both systems of control, emphasizing on landscape methods used in solving such environmental problems.

This write-up also seeks to identify the contributions / roles of the landscape practice in solving the problem of slope instability and erosion control and ends with a summary and recommendations.

Although no single method could be recommended as ideal for all situations, a combination of some of them could be used as means to control erosion, stabilize slopes and enhance the environment. It is recommended that physical development on all sloping areas should

be controlled and monitored by strict supervision of the District/ Metropolitan assemblies in consultation with the Town and Country Planning Department, and Research Institutions like the Environmental Protection Agency, Building and Road Research Institute, and the Ghana Institute of Engineers who have direct interest in the environment.

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CHAPTER 1

1.0 INTRODUCTION

Protection of land from the ravages of erosion and adverse effects of utilization are very important aspects of human and land use activities and has to be given the utmost attention. This has become more important in developing countries like Ghana where crude forms of land utilization are in vogue - as in mining, farming, and urban development - resulting in vast expanse of land being exposed to erosion by water and sometimes by wind (Kundu and Ghose, 1997).

Soil erosion can, without reservation, be regarded as the most destructive environmental process threatening human existence. It is a social phenomenon, the main cause of which is economic activity; particularly agro-industrial production. It is a critical environmental problem and threatens long-term agricultural production and also causes the depletion of the greatest natural resource to man, soil (Medvedev and Bulygin, 1997). In the developed countries, its effect although controlled within the city environment by using modern engineering materials and techniques is very much felt in the countryside (Clouston, 1990). However in developing countries like Ghana the situation is worse both in the cities as well as in the countryside.

Intensive agricultural production, deforestation, poor management and inadequate public education have encouraged accelerated soil erosion. There is a general lack of appreciation for any conservation effort. It is estimated that 2 million tonnes of fertile soil are lost each year in Moldova, mostly through agricultural activities (Hill *et al.*, 1997). In the U.S.A., Hargett *et al* (1982) also reported annual losses of soil on recently cultivated cornfields of 359t per acre.

In Sub-Sahara Africa, a 20 fold increase in soil loss through erosion has been reported for the last three decades as more and more people are forced to move out of the good bottom-lands and unto the fragile hillsides (National Research Council, 1993).

Erosion is not considered destructive in all cases. Cunninghams and Barbara (1990) noted that erosion is a disaster only when it occurs in the wrong place, at the wrong time. However, sometimes when the results of erosion are spectacular enough, they are enshrined in national parks. An example is the Grand Canyon in the U.S.A. Another is the Damango National Park in the Northern Region of Ghana where spectacular geological scenes form an important aspect of the landscape. Also where erosion has worn down mountains and spread soil over the plains or deposited rich alluvial silt in river bottoms, it is gladly farmed.

The level of erosion in any area is directly related to the slope. Preece (1991) reported that most sloping areas become unstable as a result of increased surface run off leading to erosion. Cultivation of fragile hillsides for agricultural activities, their use for housing and other urban oriented development projects, have resulted in the exposure of hilly areas to serious stresses making them unstable and dangerous for human activities.

In Ghana a lot of development is being carried out on hilly sites as found in the Akuapim area, Obuasi, Cape Coast, Secondi-Takoradi, some parts of Accra, and Kumasi, etc., (Plate 1). There is the need therefore to develop mechanisms by which such places could be used effectively without any hazard to life and property.

Hillsides and other sloping areas when stripped of their protective covering of vegetation rapidly erode; depositing huge amounts of silt into downstream reservoirs, river valleys, artificial waterways, roads, etc. In some cases these lead to over- saturation of the soil resulting in colluvial creeps and mass wasting (Carpenter and Theodore, 1990; Thorne and Chang-Shan, 1990).

Plate 1: Housing Development in sloping areas

1.1. THE ROLE OF THE LANDSCAPE PROFESSION IN EROSION CONTROL AND SLOPE STABILIZATION

Landscape practice has an essential role to play in reducing the adverse effects of erosion and unstable slopes on the environment. This can be done through designing an appropriate system and choosing the right materials for both short and long term effectiveness; which should comfortably merge into the surrounding landscape. The practice can also through consultancy services advise on the choice of the right system to meet particular needs. Such services will be most important to local authorities as well as other interest groups.

Landscape practice can also help to educate the public on issues concerning the environment by involving the public in the designing and in ensuring that there is a significant learning process taking place which shape the minds of those involved as well as the space (Blackhurst, 1998).

1.2 AIMS AND OBJECTIVES

a. A critical assessment of the factors contributing to erosion and unstable slopes.

b. Evaluation of the indigenous methods of erosion control and slope stabilization in the face of their shortcomings and inadequacies to meet present demands.

c. Discussion on the effects of erosion and unstable slopes on development

d. Identification of the role and contributions of the landscape profession to erosion control and slope stabilization, and

e. Case studies of erosion control and slope stabilization based on landscape techniques.

1.3 SCOPE OF STUDY

The study examines relevant information related to erosion and slopes in both urban and rural areas.

It also examines the technical factors with regard to erosion control and slope stabilization based on indigenous and conventional principles and also on landscape techniques.

Finally conclusions and recommendations are made based on observations and comparative analysis of information gathered from various experts.

CHAPTER 2

DEFINITIONS AND PROCESSES OF EROSION

2.0 DEFINITIONS

Soil erosion is defined as a group of processes whereby earth or rock material is loosened or dissolved and removed from any part of the earth's surface (Van, 1986). It is a natural process; the redistribution of the products of geologic weathering and is part of both soil formation and soil loss (Cunningham and Barbara, 1990).

Hudson (1986) defined soil erosion as a smoothening or leveling process with soil and rock particles being carried, rolled or washed down by forces of gravity. Selby (1982) adds that it is an inclusive term for the detachment and removal of soil and rock by the action of running water, wind, waves, flowing ice and mass movement.

2.1 THE EROSION PROCESS

Soil erosion is a hazard traditionally associated with agriculture in the tropics, usually resulting from the mismanagement of agricultural production systems; and in the semi-arid areas where it tends to occur on land devoted to forestry, transport and recreation (Morgan, 1995).

Soil erosion is considered a two-phase process consisting naturally of the detachment of individual soil particles from soil masses and then their transportation by erosive agents, which deposits them when sufficient energy is not available to transport them any further.

The corresponding soil characteristics that describe the ease with which soil particles may be detached and transported are soil detachability and soil transportability. In general soil detachability increases as the size of the soil particles increases, but transportability increases with a decrease in soil particle size. Hence while clay particles are less difficult to detach than sand, they are less easily transported (Schwab *et al.*, 1981; Morgan, 1995).

During a rainstorm, part of the rain falls directly on the land either because there is no vegetation or because it passes through gaps in the plant canopy (a component called 'Through fall'). Part of the rain is intercepted by the canopy from where it is either returned to the atmosphere by evaporation or finds its way to the ground by drippings from the leaves; a process termed 'leaf drainage'. It can also run down the stem as 'stem flow'. The actions of direct through fall and leaf drainage produce rain splash erosion (Morgan, 1995).

The water that reaches the ground may be stored in small depressions on the soil surface or may infiltrate the soil. When the soil is unable to take in more water the excess water moves down the slope within the soil as sub-surface flow or inter flow. It may contribute towards runoff on the soil surface resulting in erosion by overland flow.

Rain splash is an important detaching agent. On a level ground raindrop splash is not serious but may cause the soil to be detached and the increased sediment reduces the infiltration rate by sealing the soil pores (Schwab *et al.*, 1981 and Morgan, 1995). This may subsequently result in erosion. The raindrop impact on the soil not only causes splash but also decreases soil aggregation and causes deterioration of the soil structure. The subsequent washing out of fine soil particles results in the so-called erosion pavements; the result of an accumulation of coarse particles or rock fragments on the surface. Areas where loose topsoil overlies tight subsoil are most susceptible to this phenomenon (Schwab *et al.*, 1981).

A well-structured soil surface exposed to successive spells of rain is subject to a series of processes that can lead to the formation of surface seals that form a crust upon drying. These crusts reduce the infiltration rate and may induce erosion by increasing runoff when it rains (Bissonnais and Arrouays, 1997). Infiltration rate is the rate at which water passes into the soil, and exerts a major control over the generation of runoff and depends upon the characteristics of the soil and the nature of its surface (Morgan, 1995).

2.2 TYPES OF EROSION

It has been reported that soils of the semi-arid and semi-humid areas of the world are more vulnerable to erosion, especially in China, India, Western USA, etc, than soils of the tropics, which according to Hudson (1983) have good resistance to erosion. This is however at variance with Hill's (1995) observation that erosion is considerably more serious in the tropics due to high rainfall and thin soils.
Hudson (1986) described two types of erosion common to all climatic zones – Normal or Natural or Geological erosion, which results from the forces of nature and Accelerated erosion which is a process influenced by the activities of man such as removal of vegetation cover for constructional or agricultural purposes. Wills (1962), Schwab *et al* (1981), and Morgan (1995), however recognized wind and water erosion as the main types of erosion. Three main agents of soil erosion are thus recognized, namely water, wind and man (Korem, 1976). The agents, water and wind have formed the basis for two types of erosion – water and wind erosion.

2.2.1. <u>Wind Erosion</u>

This is a form of erosion brought about by wind. It is important in areas with dry windy conditions, often devoid of vegetal cover as a result of indiscriminate burning, crop harvesting or natural phenomena. It is common on sandy soils, which are very poor in organic matter (Korem, 1976); also it may be prevalent on sloping or flat exposed land (Hudson, 1986) where soils are dry and winds are strong (Cunningham and Barbara, 1990).

2.2.2. Water Erosion

This is erosion caused by water, mostly rain splash from rainfall. As a result of raindrops striking a bare soil surface, soil particles may be dislodged, thus setting the process of soil erosion in motion. Continuous exposure to intense rainstorm considerably weakens the soil (Morgan, 1995) and may lead to one or more of the following types of soil erosion.

2.2.2.1 Sheet Erosion: This is the removal of a uniform layer of soil by water from sloping land (Korem, 1976). Also called overland flow or sheet flow, it is described as consisting of rain splash, and surface runoff in the form of shallow flows of infinite width. Its effect is gradual, and removes the topsoil over a wide area leaving the lower soil, which is mostly infertile and cannot support any good plant growth (Wills, 1962 and Schwab *et al.*, 1981)

2.2.2.2 Rill Erosion: This is the removal of soil by water from small but well defined channels or streams when there is a concentration of overland flow. Erosion occurs when these channels have become sufficiently large and stable to be readily seen (Schwab *et al.*, 1981). Rills are small enough to be removed by normal tillage operations. This type of erosion is common on sloping areas and more serious at the lower ends of farmed fields. It is also found on loose shallow top-soils and in areas where intense rainfall occurs.

2.2.2.3 Gully Erosion: This is an advanced form of rill erosion (Schwab *et al.*, 1981) producing deep channels of 30cm deep or more (Korem, 1976), which are larger than rills and cannot be obliterated by tillage (Schwab *et al.*, 1981). The main cause is too much water, a condition that can be brought about by either climatic changes or alterations in land use.

Thus a climatic change like increased rainfall and alterations in land use such as burning of vegetation, over-grazing, deforestation, may result in increased run off, leading to gully erosion.

2.2.2.4 Stream Channel Erosion: This form of erosion consists of soil removal from stream banks or washing away of soil from the banks of established streams, creeks or rivers. This occurs as a result of removing trees and bush along such water bodies and by cattle damage to the banks (Cunninghams and Barbara, 1990).

2.3. EFFECTS OF EROSION ON DEVELOPMENT IN GHANA

2.3.1 Erosion in Ghana

The commonest form of erosion in Ghana is the type aided by man with water as the dominant agent. Wind erosion is of limited extent occurring mostly along the coast and some parts of the northern region.

Wills (1962) did not consider erosion as a serious problem in Ghana, since the traditional forms of agriculture practiced were all adapted to the local environmental conditions. However recent findings seems to contradict this. For instance continued bush fires and cultivation have left most land barren of vegetation and exposed to erosion (Vance and Gray, 1984; Morgan, 1995).

Increased population growth around settlements is also cited to have intensified the problem of erosion in Ghana, an observation made by Wills (1962) around such settlements as Kusasi and Frafra in the extreme Northeastern part of Ghana (Upper East), as well as Tamale and Yendi in the Northern part of Ghana.

Generally, poor planning, lack of coordination amongst landowners, city authorities and service providers have increased erosion problems in Ghana.

2.3.2 Effects on Development

2.3.2.1 Weakening of Roads, Bridges, Buildings and Other Structures: Despite efforts to control erosion, soil loss on some highways continues;

resulting in the development of gullies, which sometimes cut through roads. In some cases, parts of the road may be carried away (Korem, 1976; Hargett *et al.*, 1982).

In newly developed areas of most cities and towns, development has been without properly constructed roads and other facilities like lanes, walks, and proper water supply lines; at best these are introduced after the area is developed. Many roads are thus not properly structured and may not have drains to carry away surface water and therefore tend to encourage erosion (Boateng, 1999). Atonso Agogo and Gyinyase are typical suburbs in the Kumasi metropolis, which have developed without such facilities.

In areas of high surface runoff, gullies have developed that have affected the overall stability of slope structures (Ayetey, 1989 and Preece, 1991). Building bases and foundations are undermined (Troeh *et al.*, 1980) literally raising buildings above their surrounding ground.

Boateng (1999) attributed such situation to lack of adequate drainage facilities in building projects in the towns and cities. Where individual property owners have endeavored to protect their immediate surroundings, open spaces between buildings usually used as walkways are left unprotected, with gullies soon developing.

2.3.2.2 **<u>Lost Land and Reduced Productivity of Land</u>**: Soil erosion is a quiet crisis and the changes it brings are often irreversible. Erosion leads to the loss of topsoil (Korem, 1976), which eventually retards plant growth (Mahli *et al.*, 1994). Topsoil loss in tropical red soils is reported by Chleq and Hugues (1988) and Barrow (1991) to be associated with iron-pan formation, which in the transitional zone of Ghana is known to turn arable land into useless waste-lands.

2.3.2.3 **<u>Silting-up of Water Ways:</u>** (Silted Reservoirs, Irrigation Works, Canals, etc) Sedimentation or silting-up is recognized as a contributor to water pollution and about half of all such silt originates from agricultural lands (Miller and Aarstad, 1983). In Ghana surface mining activities also contribute significantly to this (Boateng, 1997).

Sedimentation has been described in terms of sediment yield as the quantity of **sediments removed by erosion from a unit area of ground surface in a** given time (Clark *et al.*, 1990; Strahler and Strahler, 1992).

The effect of sedimentation is seen in unceasing flooding as a result of silting up of storm water drains. This is a serious problem facing city authorities who are responsible for maintaining such drains (Boateng, 1999). Sedimentation affects water storage schemes, for example water reservoirs and dams, by reducing their capacity and useful life (Clark *et al.*, 1990). In the Ashanti region the Owabe and Barekese dams are known to suffer from sedimentation.

2.3.2.4 **Loss of Wetlands**: Wetlands serve as sponges or filters to storm water and are home to aquatic life and other wildlife. They also serve as avenues for recharging ground water resources (Kundu and Ghose, 1997). Construction works, mining and farming activities when carried out within 100m of wetlands can lead to sedimentation (Gary, 1997), which tends to fill up wetlands and could change unique aquatic habitats into terrestrial ones (Troeh *et al.*, 1980). Boateng (1999) attributes the recent flooding experienced in some parts of the city of Kumasi to the loss of its wetlands.

CHAPTER 3

STABLE AND UNSTABLE SLOPES AND THEIR EFFECT ON THE ENVIRONMENT

3.0 INTRODUCTION:

Slopes developed along the sides of valleys and at the margins of hills, are in many respects the most important of all landforms (Small, 1989). They add immensely to the interest and apparent size of the landscape, and determine the use to which different parts of topography can be put (Crowe, 1986, and Laurie, 1986).

Ollier and Pain (1996) reported that as more and more slopes are brought into use their natural stability is affected. This has resulted in failures ranging from mild inconveniences to serious catastrophic consequences. Watson (1983) however believed that the physical environment itself is naturally unstable and has thus led to long-term changes in it.

Watson (1983) asserted that though nothing or little can be done to influence the basic geological processes involved, like weathering, erosion and sedimentation, their effect may be mitigated by the monitoring of potentially dangerous development and by intelligent planning for potential engineering and land use activities.

Bowen (1984) defined stable slopes as slopes that show no tendency to slide. Small (1989) described it in terms of slope equilibrium; as a condition, which tends to develop on most natural slopes between the rate of weathering and the rate of transport. Thus a 'stable slope' may be described in terms of a factor of safety F, where

$$F = \frac{\text{Sum of resisting forces}}{\text{Sum of driving forces}}$$

Where the forces prompting stability (resisting forces) are exactly equal to the forces prompting instability (driving forces) F is equal to one (F=1) and the slope is said to be stable and in equilibrium (Selby, 1982).
An unstable slope has a gradient steeper than can be supported by the inherent strength of the material of which it is composed. Such a slope according to Clouston (1990) will fail, because it is not in a stable state of equilibrium.

3.1 CAUSES OF INSTABILITY

One of several causes or a combination of them, may trigger off instability in slopes. These include undercutting of slopes (Foster, 1983), overloading of slopes, removal of vegetation, weathering, ground water and type of geology (Bowen, 1984; Ayetey, 1989; Ali, 1999). Changes in moisture content of soil, changes in gradient, climate and environment also affect stability of slopes.

3.1.1. Undercutting of Slopes

Instability in natural soils may be caused by such external disturbances as undercutting the foot of an existing slope or digging an excavation with unsupported sides (Terzaghi and Peck, 1967).

3.1.2. Moisture Saturation of Upper Layers of Soil

This is considered to be the most important single cause of slope instability. Moisture plays a key role by reducing the strength and coherence of unconsolidated material or by lubricating potential slip surfaces. This is common in soils with high pore fluid pressure and impermeable layers, which obstruct ground water flow and provide lubricated slip surfaces (Watson, 1983). Terzaghi and Peck (1967) had earlier observed that on slopes that have been stable for many years, a temporary increase in pore-water pressure might cause instability and eventual failure. Hudson (1986) explained this to be due to both greater weight and reduced resistance to deformation. Thus an earth bank which is stable when dry can become unstable when wet, thereby lessening the internal cohesion of the over burden (Foster, 1983). This situation occurs when topsoil is placed on embankments without due regard to the continuity of the soil profile or the behavior of percolating water (Clouston, 1990).

Instability of a slope due to moisture content may also be related to the effect of erosion or rain-wash transport. Scour and erosion of a slope surface during and after heavy rainfall as observed by Korem (1976), Ayetey (1985), and Clouston (1990), can cause reduced stability of sloping areas. Preece (1991) explained that this can lead to increasing sequence of gully formation, which in bad cases can become deep enough to affect the stability of the overall slope structure.

3.1.3. Vegetation Cover

The destruction of plant cover is considered by Watson (1983) as one of the causes of instability, especially with regard to deforestation. Small (1989) observed that a thick forest cover would by its root system help to stabilize the regolith (soil) and maintain slope stability. By contrast, where the vegetation cover is sparse, dislodgement and transport of soil particles by rainfall and runoff can be more active, leading to instability.

Vegetation helps to control the moisture level in the soil largely through interception by the leaves and also evapo-transpiration through the leaves. The principal effect of this on stability is by reducing the length of time that a soil remains saturated.

Forest removal by stumping reduces soil strength due to rooting not beginning until about 3 years following removal. This is when there has been significant decay of rooting systems (Coates, 1976), thus creating a state of instability. Foster (1983) however reported a contrary view that vegetation could not have any positive influence on the stability of slopes, since there has been examples where very large trees or even forests have moved as part of landslides. Yet Ayetey's (1989) observation that the presence of vegetation on hillsides made of un-weathered rock material reduced the stability of the slope, seems to support this.

3.1.4. Weathering

The rate at which physical and chemical changes occur may range from a few days to many years, and can affect both the long term and short term stability of a slope. Short term in this case refers to stability over the duration of a contract period, for example, while the long term refers to the engineering life of a scheme (Blyth and deFreitas, 1984).

In Ghana slopes that are cut steep and stable initially are observed to loose their stability over time as the slope material begins to weather. This situation has been observed to be particularly true of the Voltaian formations (Ayetey, 1989 and Ali, 1999).

3.1.5. Climate

Climate affects the stability of slopes by influencing greatly the type and rate of weathering and hence the thickness of slope regolith. Differences in slope forms have been observed between slopes of the humid and temperate regions and those of the arid and semi-arid landscapes. Those in the former tend to be smooth curving while those in the later are irregular and often steeper (Small, 1989; McGeary and Plummer, 1992).

3.1.6. Earth Vibrations

These may be the result of natural or artificial conditions. Foster (1983) and Watson (1983) showed that vibrations from earthquakes or explosions that break the bonds holding a slope in place may cause slope instability.

Vibrations may result in shock that liquefies the soil beneath the slope and cause instability (Terzaghi and Peck, 1967).

Singh and Singh (1995) also observed that artificial vibrations or blasting, which are uncontrolled, might result in rough uneven contours, overhangs, extension of tension cracks, and opening of various discontinuity planes. All these can result in loss of cohesion between surfaces and lead to instability.

3.1.7. Overloading of Slopes

Foster (1983) observed that overloading of slopes so that they cannot support their weight has been another factor causing slope instability.

3.2 EFFECTS OF SLOPES ON THE LANDSCAPE

The slope, a measure of the vertical drop over a given horizontal distance (Skinner and Porter, 1987), is a very important feature of the landscape. It determines the quality of the landscape and the use to which different parts of the land can be put. The slope thus helps to separate the different parts of a landscape (Laurie, 1986).

Slopes as integral part of mountains add immensely to the interest and apparent size of a landscape. It may be formed, among others, as a result of granitic intrusions (e.g. Inselbergs); or uplifts – which are consequences of vertical earth movements that is responsible for the formation of highlands (e.g. the Voltaian plateau). Folding, which result in continuous range of mountains (e.g. Akuapim-Togo range), also produce slopes (Asiedu, 1999).

The presence of these slopes on the landscape makes interesting contrasting scenery. The Akuapim –Togo range shows a beautiful panorama presented by natures' arrangement of the ridge, contrasting with the nearby Accra plains.

Other features created by slopes on the landscape are the waterfalls some of which may be found in Boti near Koforidua, Bukuruwa near Kwahu and others near Hohoe and Begoro (towns in the Eastern and Volta Regions of Ghana).

The nature of slopes reflects an intricate relationship between the rocks that underlie them and the presence of weathering and transport helping to shape them.

Blyth and deFreitas (1984) added that the effect of slopes on the landscape may be determined by the nature of the slope and the materials covering the surface.

Some slopes may be rocky with steep sides of about 45° or more and may not be able to retain any debris accumulated on the surface as a result of weathering. Such rocky slopes may give a hard or smooth rugged effect; and depending on the effect of cloud cover and sunlight on the surface, may have a harsh or soothing effect on the environment.

The steep slopes of the South Voltaian Plateau (Kwahu escarpment) give a good example of a rocky slope. The plateau is a prominent feature trending southeast to southwest from Koforidua in the eastern region to Kintampo in the Brong Ahafo region. The part of this plateau near Nkawkaw is very impressive (Plate 2) declaring some of the architectural wonders of nature. The close observer appreciates the fine laminations and bedding planes of its steep sides showing the perfectly structured mass of horizontal bed of shale.

Plate 2: View of Kwahu scarp from Nkawkaw

Most slopes are gentle, sloping less than 5°, but a few may slope more than 45° (Foster, 1983). Tropical slopes may however be steeper ranging between 35-55° (Ollier and Pain, 1996; Tsidzi, 1996). These slopes allow debris to accumulate to a considerable thickness masking the bedrock (Small, 1989).

The nature of materials covering the surface of the slope influences its effect on the landscape. Mounds of mines spoils, for instance, are usually bare of vegetation (Troeh *et al.*, 1980), and provide most uncomfortable or uninteresting contrast to the well-vegetated hill slopes of the surrounding landscape. On the other hand, Granitic domes (inselbergs), which are equally bare (Photo 3), rather produce sharp and interesting contrast to the well-vegetated surrounding landscape (Asiedu, 1999). An example is the quiet prominent granitic dome at Nkurakan near Koforidua and Tetekasum on the Suhum – Asamankese road in the eastern region of Ghana.

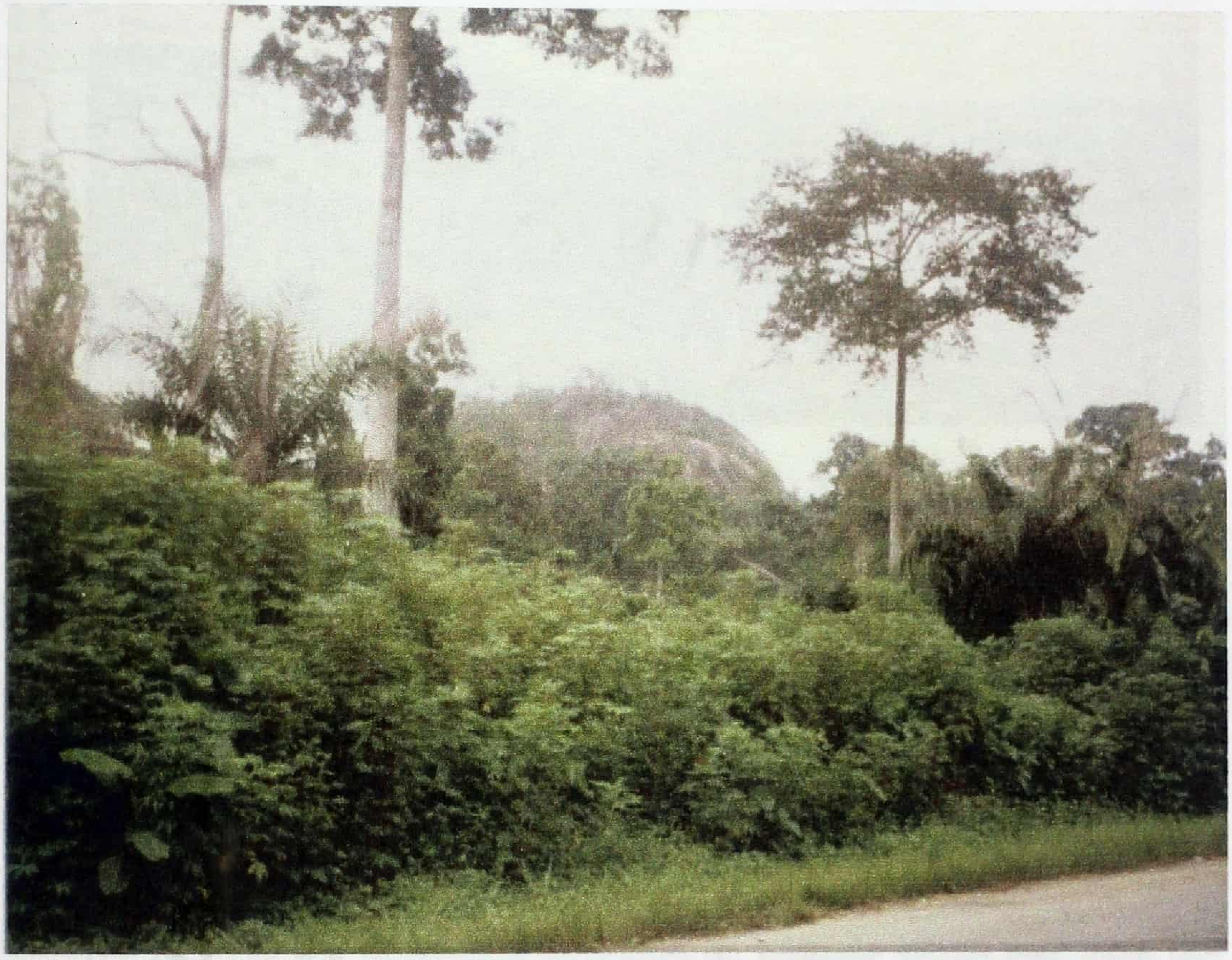


Photo 3: Granitic Dome (Inselberg) near Suhum along Suhum – Asamankese road

Again the panoramic view produced by tree-covered surfaces of mountains (Plate 4), like the Akuapim-Togo range of mountains, presents another interesting view to the observer especially when viewed from such strategic spots as the south and north facing slopes.

Some of the slopes too, especially, in the temperate regions, may be covered with ice. This gives it a wonderful effect as the surface radiates a dazzling brilliance from the sun's reflection. This is most common in the high altitude areas.

Plate 4: Slopes create interest on the Landscape-panoramic view along Accra-Dodowa road

3.3. EFFECT OF UNSTABLE SLOPES ON THE DEVELOPMENT OF PHYSICAL STRUCTURES

The development of physical structures on unstable slopes may have far-reaching consequences. For instance, the construction of motorways or dams on unstable areas can initiate phases of persistent land slipping (Watson, 1983). An example is along the Yamoransah-Anwia Nkwanta highway, where roadside cuttings and embankments created during construction have resulted in increased rock fall and landslides. This has necessitated the erection of road safety signs along the road to warn drivers and other road users (Plate 5).

Plate 5: Rock-fall along Yamoransah-Anwia Nkwanta highway

Increasingly, estate developers are moving to the hilly, fragile areas of our towns and cities. This is common in places like Akuapim, Obuasi, some parts of Accra, Kumasi, Cape Coast, and Takoradi, etc. This is causing a lot of disturbances to the already unstable slopes in such places. In most cases, measures have been taken to curb slope failure (Plate 6), but these measures have not been sympathetic to the environment (Acquah, 1997). That is to say, the measures have not been properly integrated into the surrounding environment.

Marsh (1987) has observed that, buildings and related facilities placed on unstable slopes often increase the likelihood of disaster from slope failure. Such structures act as stimuli, especially where construction is carried out on soils made up of sensitive clay and quick sand - materials that liquefy in response to small stimuli and can flow on slopes of only a few degrees.

The occurrence of soil creep in some areas has also been observed to be a major nuisance. Although not very common in Ghana, it can become a very serious problem in places of increased development on hill slopes.

Photo 6: Unsympathetic Slope Stabilization in a Residential area

This danger becomes apparent in the field when there is accumulation of soil on the upslope side of fences, walls, bulging of embankments and retaining walls, dams, and breaking of mains of services like gas and electricity (Watson, 1983 and Small, 1989).

3.4. INSTABILITY OF SLOPES IN GHANA

Slope failure due to instability occurs throughout Ghana. Although there has been no serious or very little research on slope instability, occurrences of slope failure in recent times have led to initiation of research into this area. Research has been concentrated in two areas: namely, slope instability, which can be controlled and instability that can neither be controlled nor corrected (Ayetey, 1985, 1989, 1991).

Slope failure occurs mainly in the rainy season and generally after heavy rains. An example is the Agona – Akim mile 7 road failure, which was attributed to heavy rains (Ayetey, 1989). Slope failure has also been linked to the geology of an area. For instance, instability has been noted to be more pronounced on Voltaian formations of Paleozoic age as compared with the Pre-cambrian metamorphic and granite rocks.

Soil type also affects stability of slopes. Ayetey (1989) noted that lateritic soils – rich, reddish cultivated soils in the tropics, hold up well on slopes but soprolitic soils fail easily. Soprolitic soils are soils with high clay and water content.

Other factors, which have been reported to affect slope stability, are, weathering, and vegetation. Both slope failures reported along the Kumasi-Ashanti Mampong and Kumasi-Lake Bosomtwi roads are attributed to weathering. Ayetey (1989) and Ali (1999) explained that this is because rock slopes loose their strength and become unstable when they decompose.

The presence of vegetation on rocky slopes also leads to slope instability. This is due to the large roots of trees which penetrate into rock joints, acting as wedges and with time widening the joints enough to cause a failure (Ayetey, 1989). This report contradicts observations made by Coates (1976), Watson (1983), and Small (1989) who noted that the presence of vegetation enhances stability of slopes.

CHAPTER 4

EROSION CONTROL AND METHODS OF SLOPE STABILIZATION

4.0. INTRODUCTION

Soil may be valuable where it is, but may be dangerous to the neighbour if it should escape. Thus soil carried from one place to the other through erosion may lead to silting-up of water ways resulting in flooding in most cases; in covering-up of road ways etc, and in laying waste whole tracts of land. Control measures will thus preserve the land and protect other land use resources as well (Kleine, 1997).

Some of these control measures in use including measures based mainly on landscape techniques and problems associated with them are discussed. Some of these control measures are also centered on reduced tillage of land to reduce rate of destruction of soil structure. Others are, introduction of cover crops, agro-forestry, fertility management programmes and effective crop residue management (National Research Council, 1993 and Hill *et al.*, 1997).

Retaining residue and humus *in situ* is currently considered to be a very important control measure. This could be by the decay of animal matter, leaves and other vegetative material as they fall to the ground, a process which ensures that important ecological processes in the soil are sustained (Constantini *et al.*, 1997; Miller and Aarstad, 1983).

Kleine (1997) also suggested structures like terraces, lined channels, contour ploughing, strip cropping, windbreaks, hedgerows, and buffer strips as means of control. The use of inert materials like rubbles in rubble walls, bamboo stripes, and earth bunds also exist.

Hudson (1983) suggested the enactment of legislations to support control measures. This gives legal support to establishments like the Environmental Protection Agency (EPA), Green Earth Organization (a Non-Governmental

Organization), and other bodies whose activities seek to control destruction of the environment.

4.1 PROBLEMS ASSOCIATED WITH CONTROL

Generally, most methods of control implemented, have been without any effective system of monitoring. Monitoring determines whether planned control efforts have been implemented the way they were designed. It also checks the effectiveness of the design and helps validate or otherwise the assumption upon which the control measures were based (Heveran *et al.*, 1997).

Another problem area is the enactment of laws to protect the land as suggested by Hudson (1983). It is well known that soil erosion does not win votes; hence politicians show less concern in matters to do with conservation. They are more concerned with how to increase food production than any long-term conservation plans.

In areas where the productivity of the soil and other inherent characteristics of the soil limit the use of plants, inert materials have been suggested to help stabilize the soil surface. Hargett *et al* (1982) however, observed that these structural measures might be expensive and less sympathetic to the environment.

The popular use of terraces in sloping areas to reduce the length of slope and thus stabilize slopes has been found to be equally expensive and labour intensive. In some cases poor maintenance of the terraces had yielded devastating results (Hudson, 1983; Pope *et al.*, 1983; Bell, 1993; Zurayk, 1994).

Contour cropping, which involves ploughing along contours and planting on the contours to control erosion, is also widely used (Schwab *et al.*, 1981; Pope *et al.*, 1983; Bell, 1993; Agus *et al.*, 1997). However, Schwab *et al* (1981) cautioned that although the measure reduced surface run off by impounding water in small depressions, under conditions of high rainfall intensity low breaks may release the stored water causing serious cumulative damage.

4.2 METHODS OF CONTROL

4.2.1 The Environment and Soils

There are set procedures for assessing a site for its potential for vegetation growth. The assessment serves as a basis to determine the extent of erosion and slope stability. It considers the functional qualities of plants that will be required to solve the problem. Such information will help determine the need for any short-term control measure or protection during the period of plant establishment (Clouston, 1990).

Consideration of the soil environment is an extension of what will be normally good for plant growth on the site (Clouston, 1990). In most cases topsoil is absent or very sparse and hence requires particular attention. This attention can be in remedial treatment to support rapid establishment. In a situation where enormous variations exist in soil fertility within a particular area, a standard specification for soil treatment can be adopted, for instance, importation of topsoil.

Soil preparation for vegetation establishment, especially, should ensure good root permeability and good soil fertility. The soil should be cultivated to improve infiltration and remove compaction. Tillage operations should, however, be limited to prevention of erosion (Pope *et al.*, 1983).

On slopes the ease of cultivation will depend on the gradient. Gentle slopes of up to 4 % (about 2°) are always easy to work and have good drainage as compared with slopes of up to 30°. Such slopes require special equipment to work (Laurie, 1986 and Clouston, 1990).

Clouston (1990) added that although the use of vegetation may be a principal soil erosion control factor, certain conservation measures like limiting the length of slope or ridging can be adopted to reduce the risk of erosion or slope failure. These can be done before the vegetation becomes established and functional.

a. **Limiting the length of slope**: This is done by interrupting long slopes with ditches or narrow berms to intercept overland flow of water and divert it from the slope. It may also be in the form of terraces (Selby, 1982 and Zurayk, 1994).

b. **Ridging (Planting or scarifying across slope)**: This increases surface roughness, infiltration and thereby reduces surface water flow (Luiz *et al.*, 1997). The use of crop residue as surface mulch (to control erosion till the plants are established) is another way of increasing surface roughness (Miller and Aarstad, 1983).

When spreading soil as a surface covering, a proper continuity should be established between each layer and underlying compacted soil. This will reduce susceptibility to erosion and prevent slope failure (Schwab *et al.*, 1981).

4.2.2 The Role of Vegetation

A close vegetation cover reduces surface run off velocity considerably, giving a virtually complete protection to the soil (Selby, 1982). Thus lands that are covered with well-maintained vegetation will be less likely to experience instability than land not that vegetated (Kato *et al.*, 1997).

Ayetey (1991) cautioned that vegetation cover may help to stabilize slope provided the right type of vegetation is used. If the vegetation is made up of hug trees with deep taproots, they tend to widen rock joints, shatter rocks and cause slope failure.

4.2.2.1. Use of Grasses and Herbaceous Plants: Grasses and herbs are very cheap and versatile materials that have positive effect upon soil stability, given their rapid colonization of eroded areas (Weddle, 1979; Hill, 1995).

Grasses have very dense but shallow root systems concentrated towards the surface (40-60% in the top 25mm of topsoil) but a low density below the upper soil layers. Grasses are useful in surface protection and reinforcement, but have little effect below 100mm. Clouston (1990) considered the creeping type, which spread by either rhizomes or stolons as the most effective surface protectors. He added that regular cutting encourages fast tillering and colonization.

Two types of grass may be used; the ornamental and the tall wild types. The tall types can be used in informal or semi-natural or wild settings whilst the ornamental types may be used for mostly formal settings. This will provide soft surface out-door living space for public use. Some of the ornamental grass types in common use in Ghana are *Paspalum notatum, Axonopus compressus, Cynodon dactylon.* The Vetiver grass (*Vetiveria zizanoides* (Lim) Nash), a tall grass, has been suggested as the most effective in slope stabilization and erosion control (National Research Council, 1993).

Herbaceous plants have a wider application for slope planting. Clouston (1990) observed that herbaceous plant species have more extensive root systems and achieve better slope reinforcement than grasses. Walker (1991) added that herbaceous plants are best used in areas with steep slopes. They also add texture and colour to the area, which help to improve the aesthetic value of the site.

4.2.2.2. <u>The Use of Woody Plants</u>; Woody plants tend to provide long term plant cover and form the climax vegetation of majority of habitat types (Clouston, 1990). They also provide a close cover, which gives a virtual complete protection to soil (Selby, 1982) and provide effective long-term stability on slopes. Their extensive roots reinforce the soil profile and tie the slope together across zones of weakness (Bache and Machskill, 1984). It must be added however, that most of the woody vegetation found on slopes in Ghana today are from volunteer growth. Some of these woody plants are *Azadirachta indica* (Nim), *Dialium guineense* (Velvet Tamarind), *Griffonia simplicifolia* (Kagya), *Mangifera indica* (Mango), *Mallotus oppositifolius* (Satadua), *Zanthoxylum xanthoxyloides* (Kanto), etc.

4.2.2.2.1 **Slope Fascines:** This is a landscape technique used to stabilize topsoil in relatively deep soils. Fascines are made from long straight branches of living woody material of at least 10mm diameter (Fig 1). They are bound together with wire in bundles so that the cross section at any point contains at least 5 branches. They can either take discrete lengths of up to 5m or of continuous bundles intended to run without a break for the whole length of the slope to be stabilized.

Parallel ditches of several intervals are dug in the slope, either horizontally with gaps to allow for drainage or continuously at an inclination of up to 30°. This will aid and control surface water runoff. The prefabricated fascines are laid in the ditches and covered completely with earth.

The method though quick and easy to maintain, gives only short-term stability and relatively shallow protection (Clouston, 1990). It can however be combined with woody plants to give long-term stability.

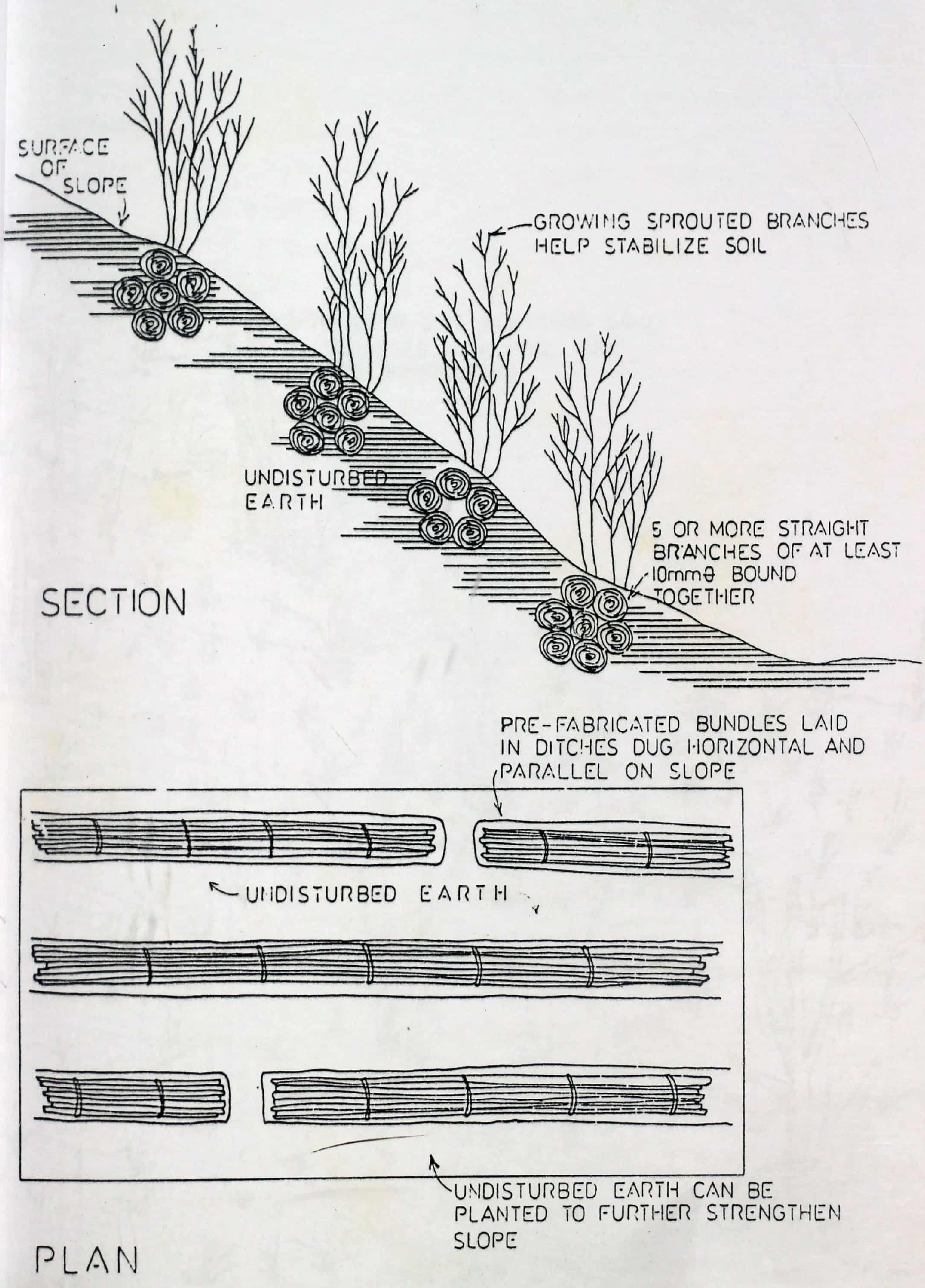
4.2.2.2.2 **Branch Layers:** This method is most effective for rapid stabilization of cut and fill slopes as well as rocky hills (Bache and Machskill, 1984; Clouston, 1990). Trenches or terraces are cut, into which are placed live branch cuttings of between 2-7m long in a criss-cross fashion in horizontal courses.

The branches are placed with their lower ends in the soil at an angle of about 10° (Fig. 2). They are covered with layers of fill material so that between 1/4 -1/5 of their length protrudes from the face of the slope.

The method has the most deep-seated biological slope stabilizing effect (Clouston, 1990); however, it is not suitable for retaining topsoil (Bache and Machskill, 1984).

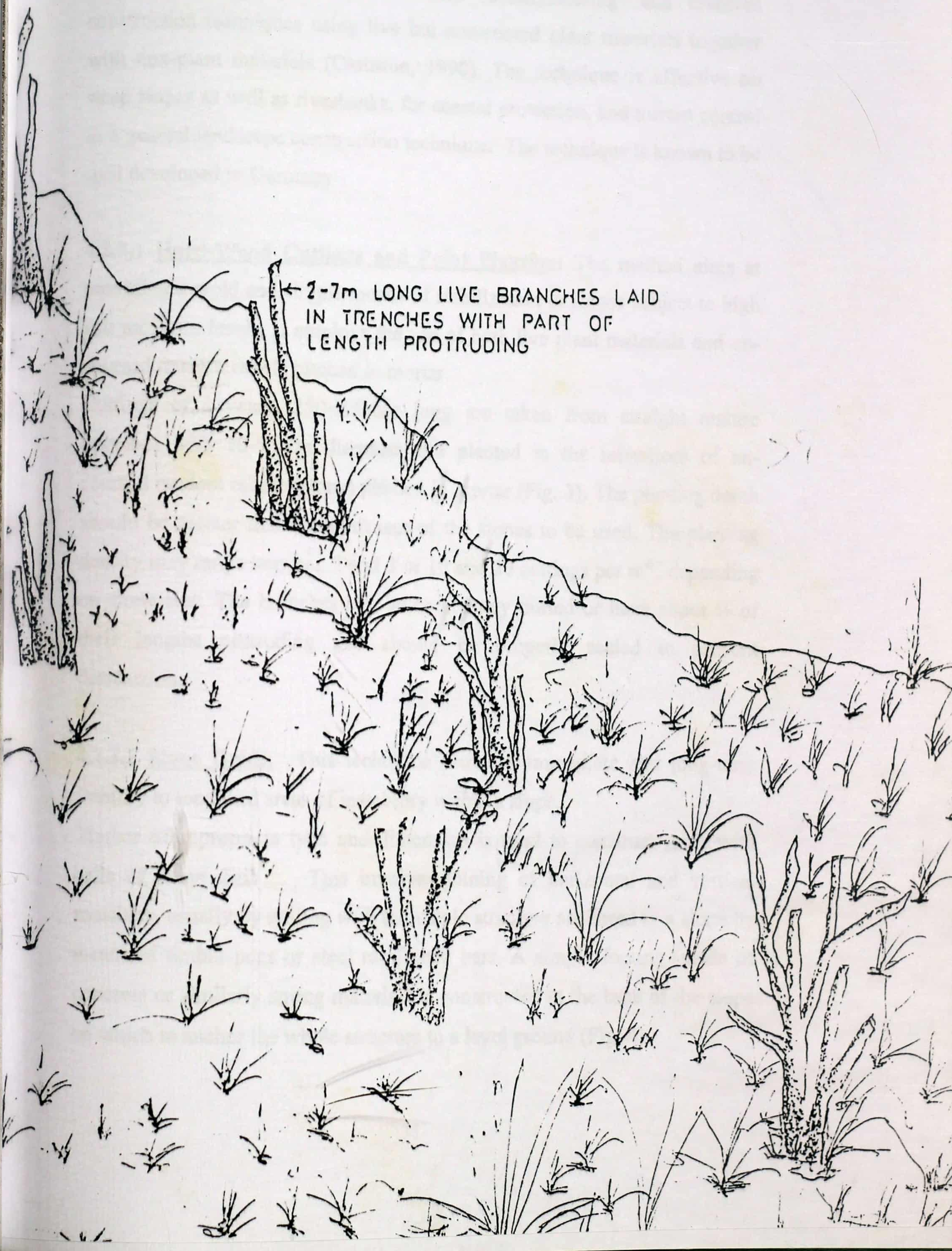
SLOPE FASCINES

(FIG. 1)



BRANCH LAYERS

(FIG. 2)



4.2.3. Mixed Construction

The use of combined vegetation and structural measures have been suggested as alternative methods to combat erosion and slope failure (Bache and Machskill, 1984). This is termed 'bioengineering' and involves construction techniques using live but non-rooted plant materials together with non-plant materials (Clouston, 1990). The technique is effective on steep slopes as well as riverbanks, for coastal protection, and torrent control as a general landscape construction technique. The technique is known to be well developed in Germany

4.2.3.1 Hard-Wood Cuttings and Point Planting: The method aims at providing a rapid and simple means of stabilization to slopes subject to high soil moisture levels. It employs the use of both live plant materials and un-coursed random rabble pitched in mortar.

Cuttings of between 250-600mm long are taken from straight mature branches with 10-50mm diameter and planted in the interstices of un-coursed random rabble (stone) pitched in mortar (Fig. 3). The planting depth should be greater than the thickness of the stones to be used. The planting density may range between 2 and 5 or 10 and 20 cuttings per m^2, depending on stone size. The branches can be completely buried or have about ¼ of their lengths protruding and should be properly sealed to prevent desiccation.

4.2.3.2 Slope Grids: This technique provides immediate and long-term stability to localized areas of instability within a slope.

Timber of appropriate type and dimension is used to construct grids with cells of about $2m^2$. This involves joining of horizontal and vertical members, usually by nailing with the whole structure anchored to a slope by means of timber pegs or steel reinforced bars. A simple footing (made of concrete or similarly strong material) is constructed at the base of the slope on which to anchor the whole structure to a level ground (Fig. 4).

The open spaces within the grid are back-filled with local soil and can be planted. The height of the slope grid should be between 10-20m.

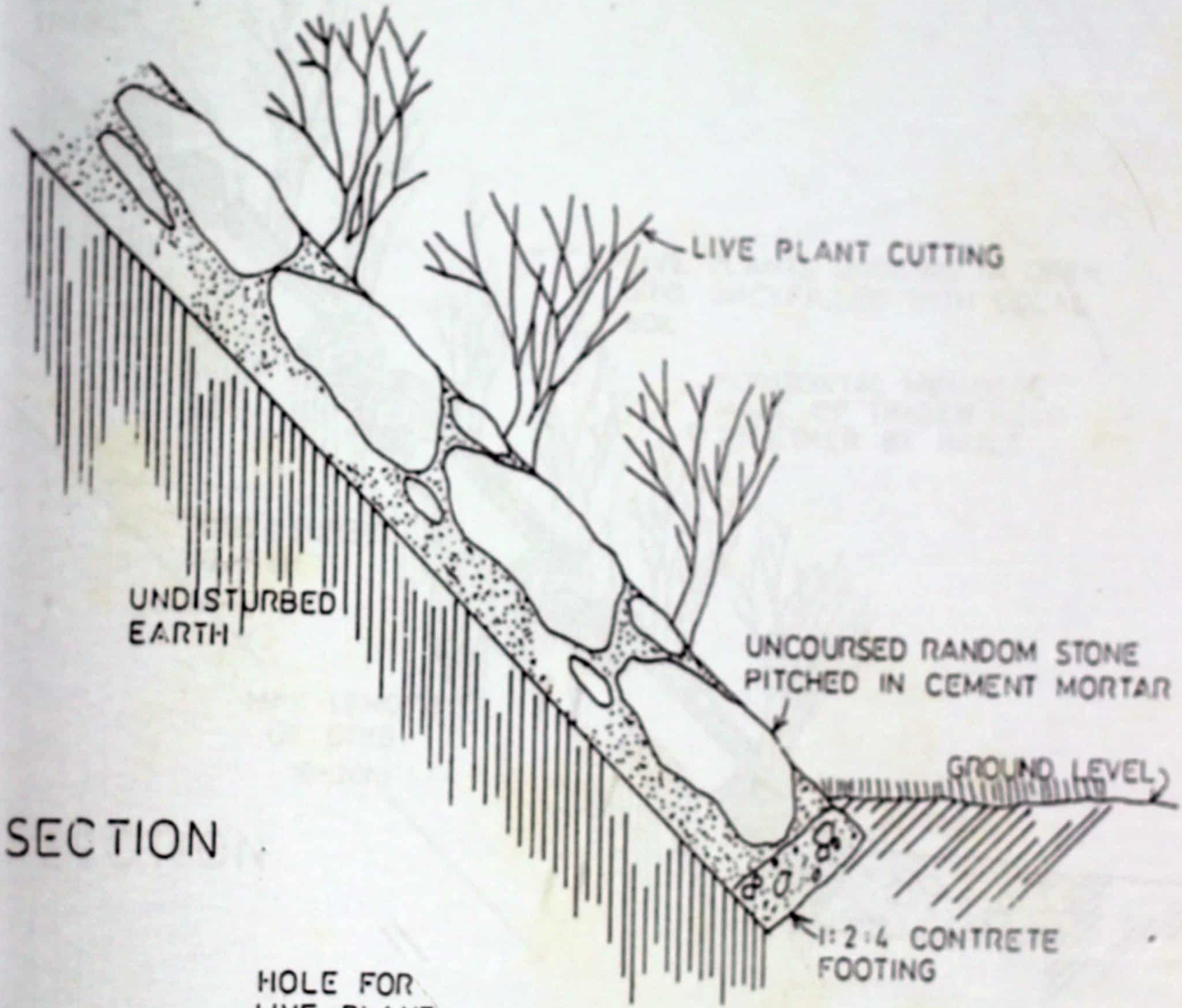
4.2.3.3 Live Crib Wall: These provide immediate stabilization and perform the same function as a gravity retaining wall. It may be situated at the base of the slope or at intervals up its sides, tied into the slope by headers or with steel anchors.

The crib wall consists of long header beams, which are laid horizontal and parallel to the face of the slope and shorter stretches (Fig. 5). The stretches run between the header beams at right angles back into the slope at an angle of at least 10° to the vertical. Materials used can be peeled timber, round or sewn wood and specially shaped pre-cast concrete elements.

Clouston (1990) suggested that at least half of the header beams must be driven back into the undisturbed slope. The void built up between the rows are then filled with fine material and planted.

HARDWOOD CUTTINGS AND POINT PLANTING

(FIG. 3)



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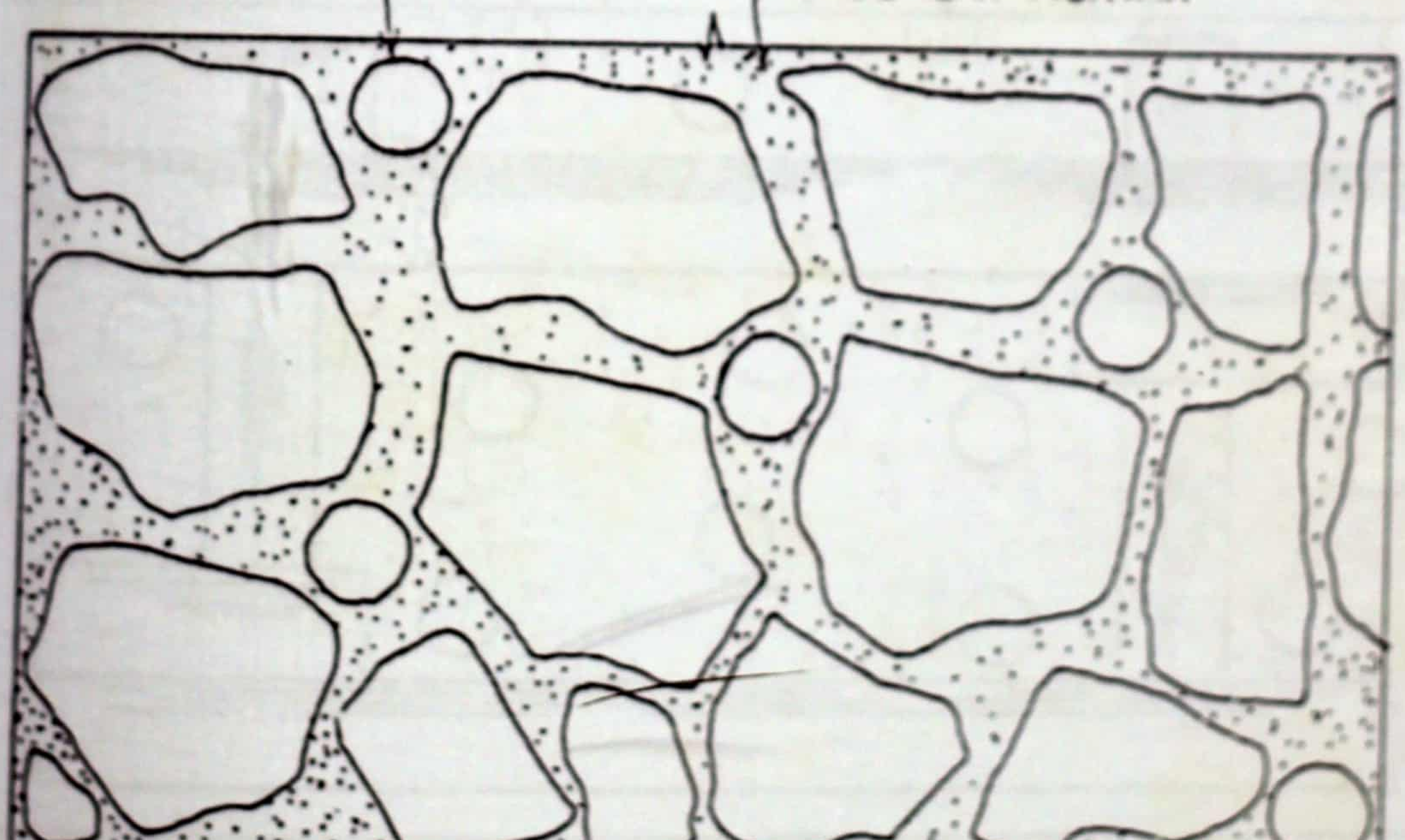
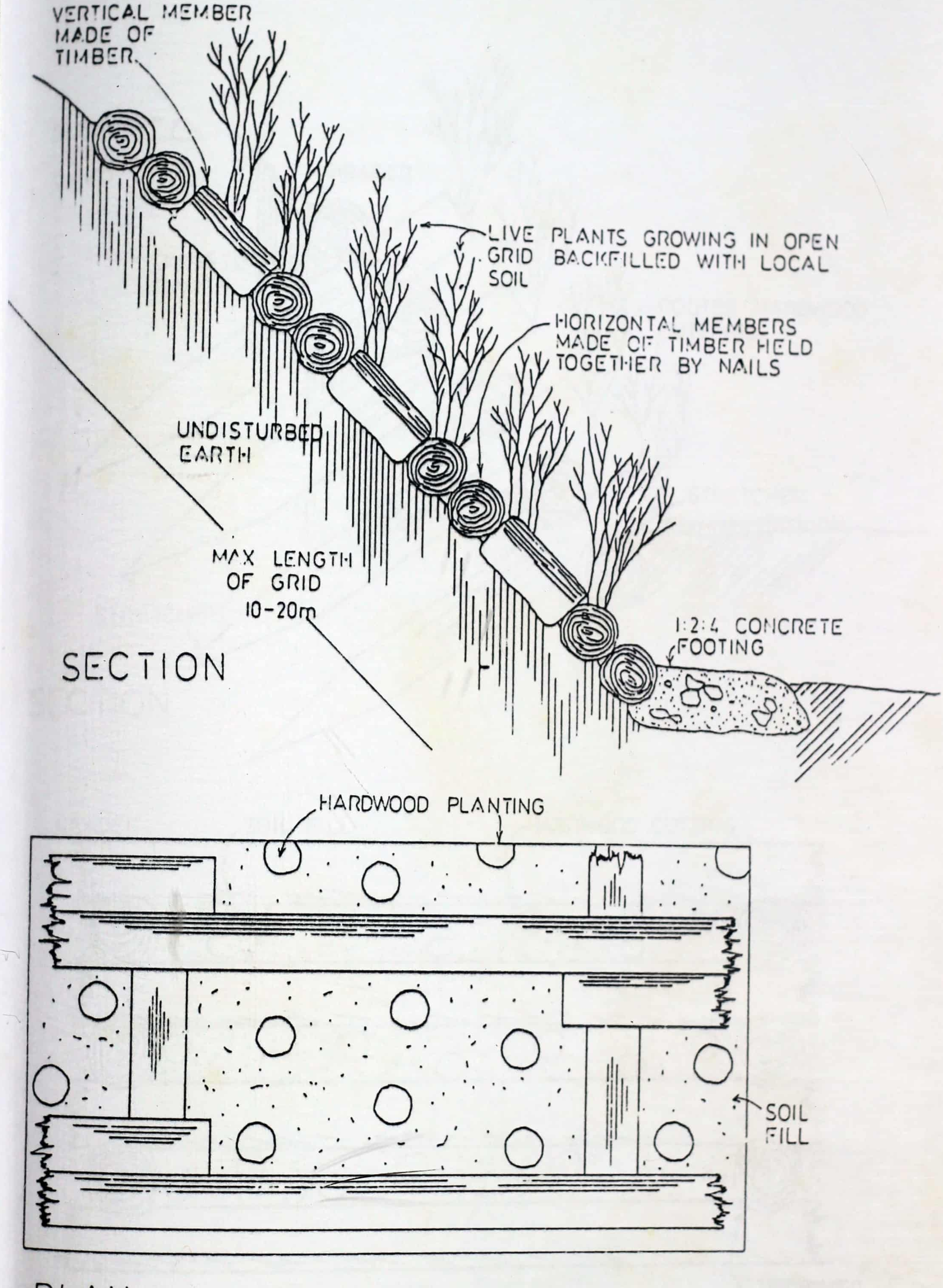


PLAN

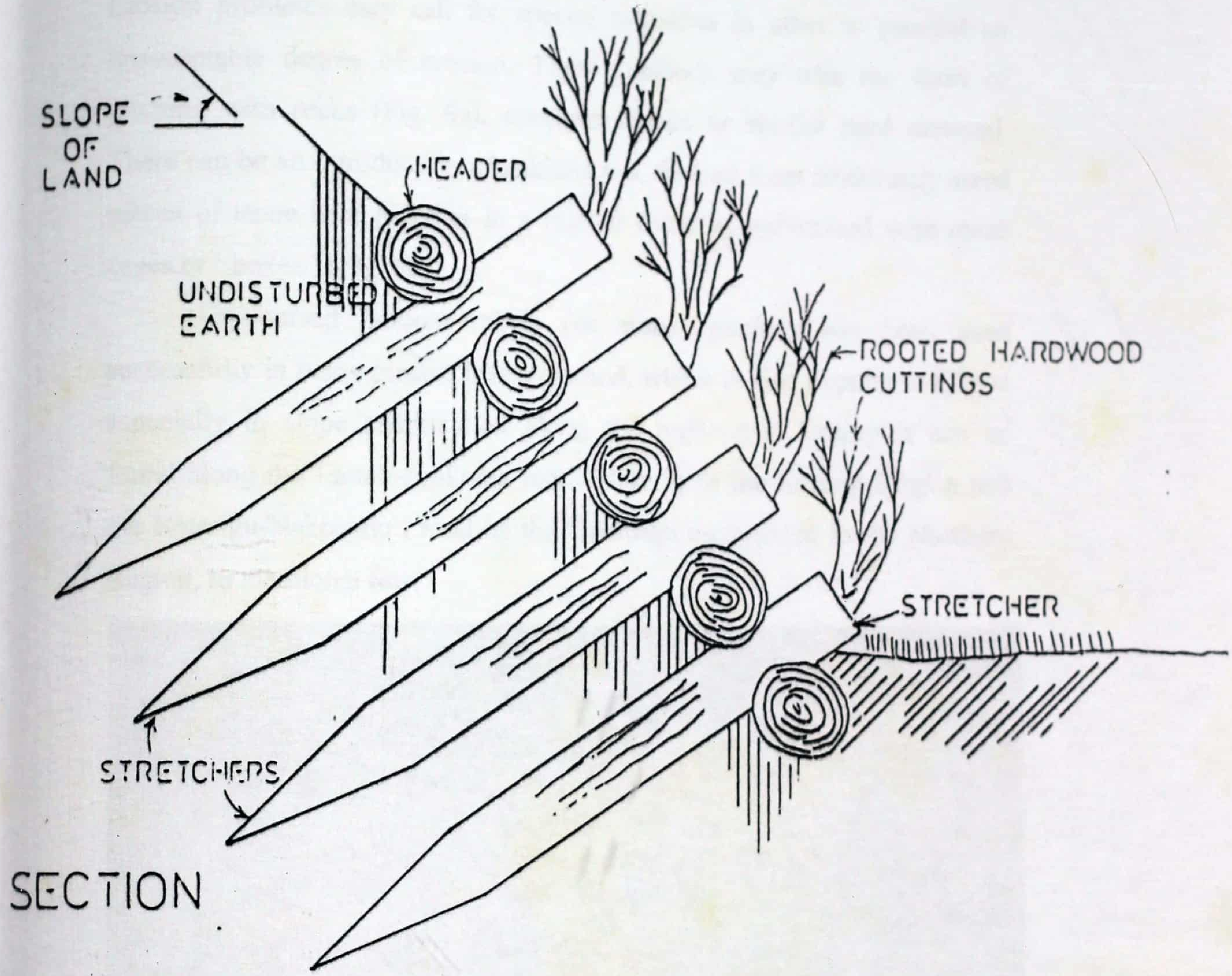
SLOPE GRID

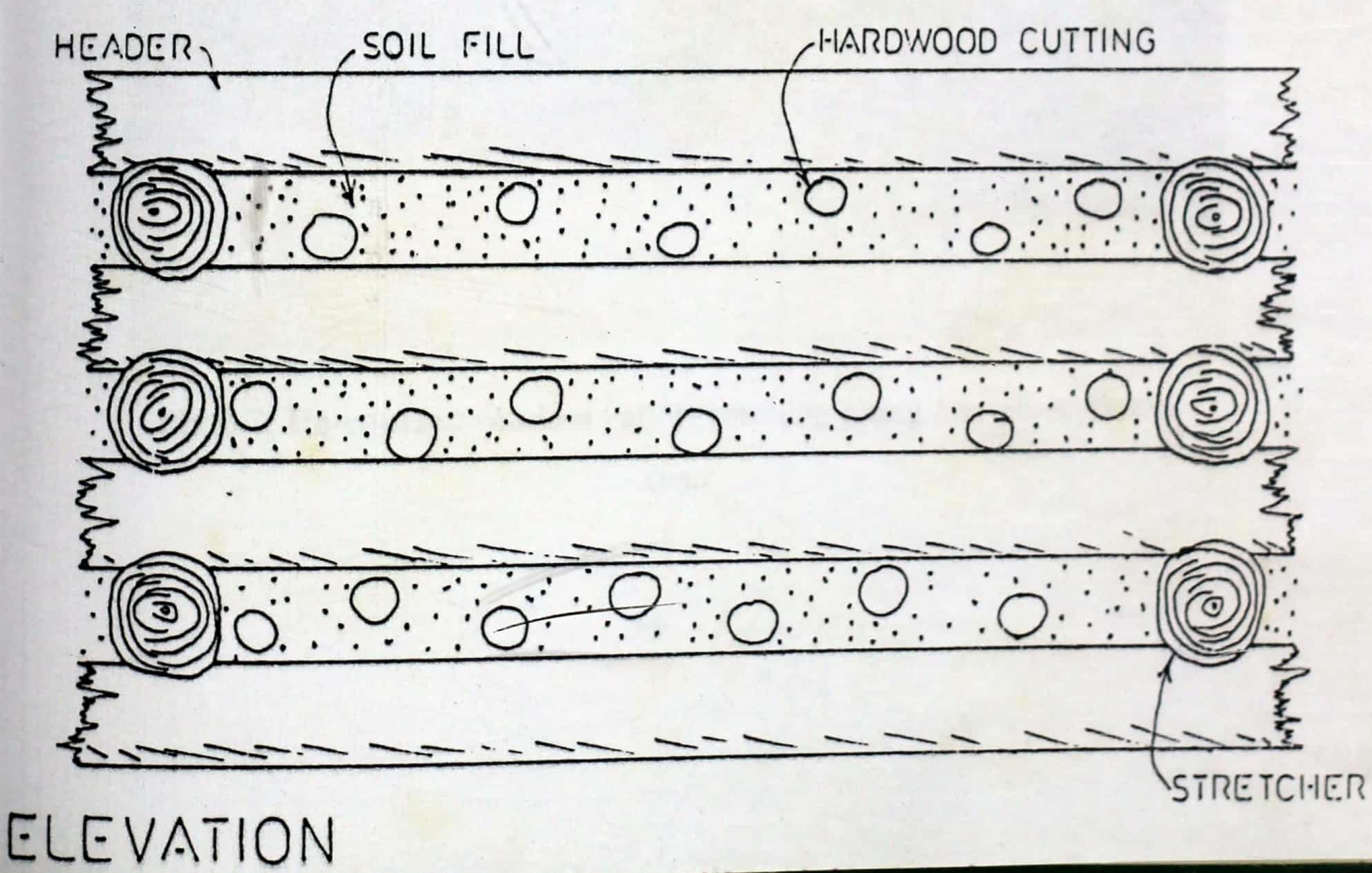
(FIG. 4)



LIVE CRIB WALL

(FIG. 5)





4.2.4 INERT CONSTRUCTION

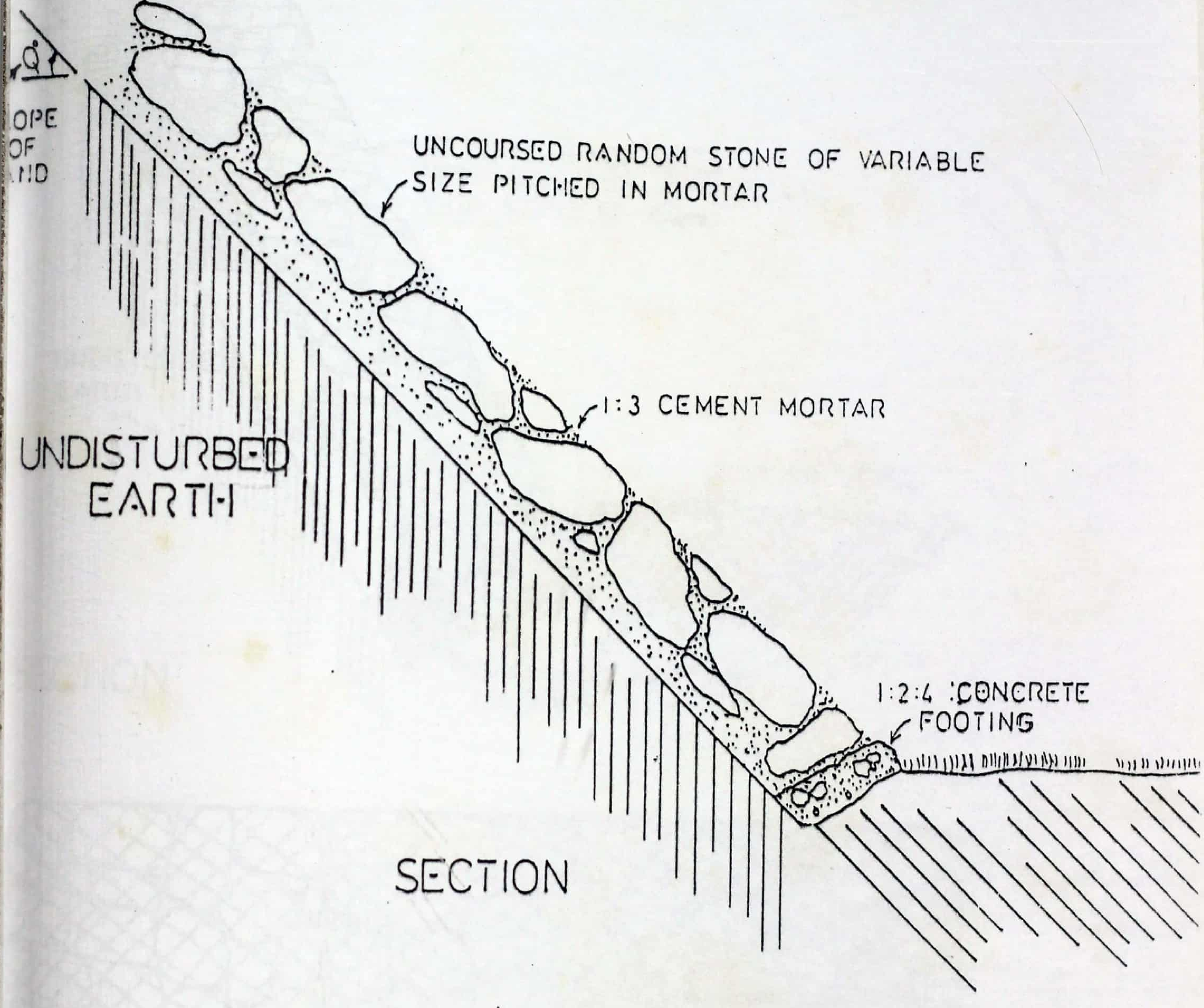
Erosion problems may call for special measures in other to prevent an unacceptable degree of erosion. These methods may take the form of pitching with rocks (Fig. 6a), concrete blocks or similar hard material. There can be an introduction of gabions too, formed from moderately sized pieces of stone held together in a regular mass by galvanized wire mesh cages or ‘ boxes ’ (Fig. 6b).

Un-coursed random rabble (or stone) pitching has been used successfully in many places. It is a method, which is also popular in Ghana especially in slope stabilization along the high-ways. Examples can be found along the Larteh-Ayikoma road (Plate 7) in the Eastern Region and the Nalerigu-Nakpanduri road on the Gambaga escarpment in the Northern Region, to mention a few.

Plate 7: Un-coursed random rubble pitching along Larteh-Ayikoma road

UNCOURSED RANDOM STONE PITCHING

(FIG. 6a)



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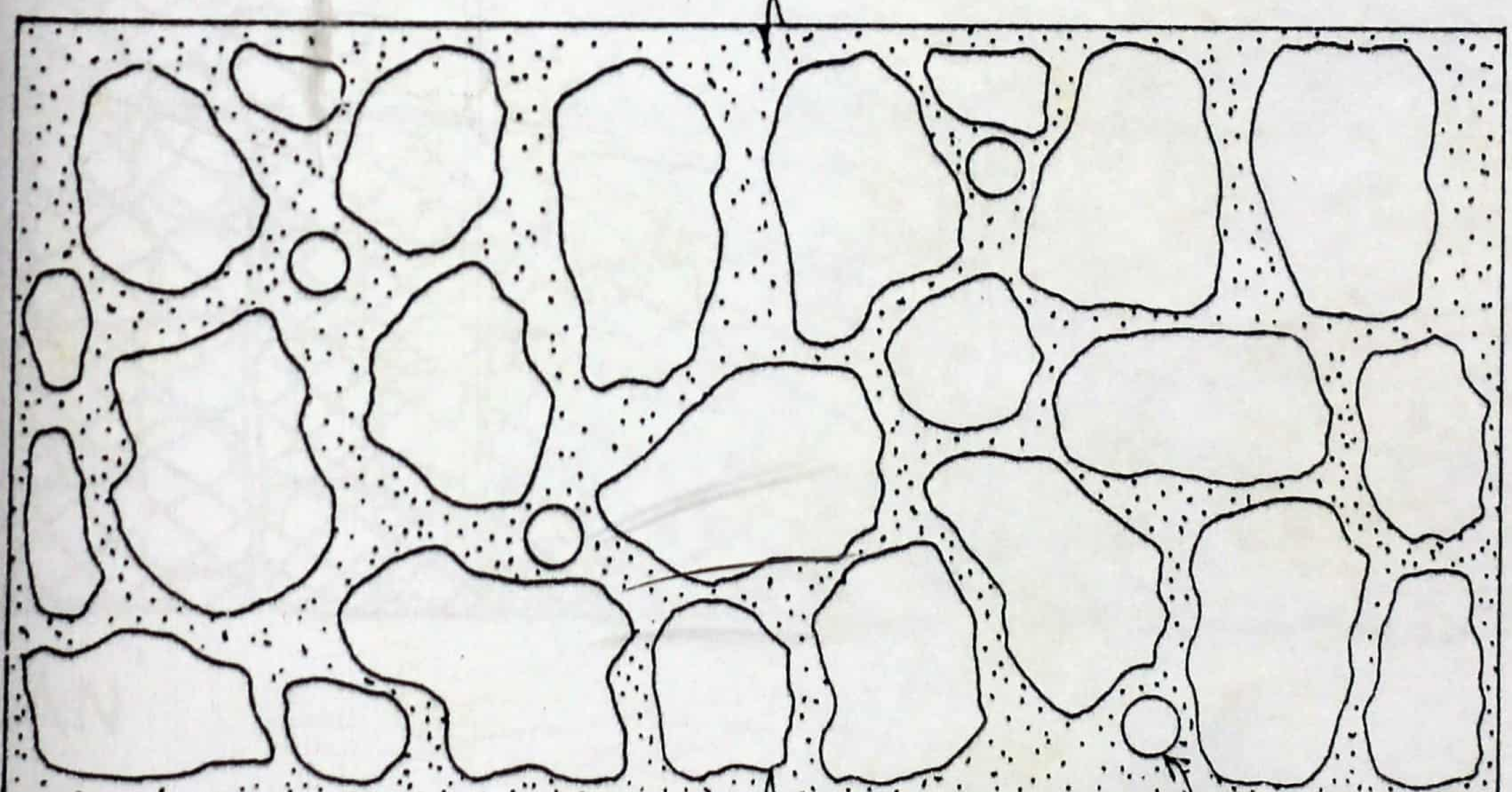
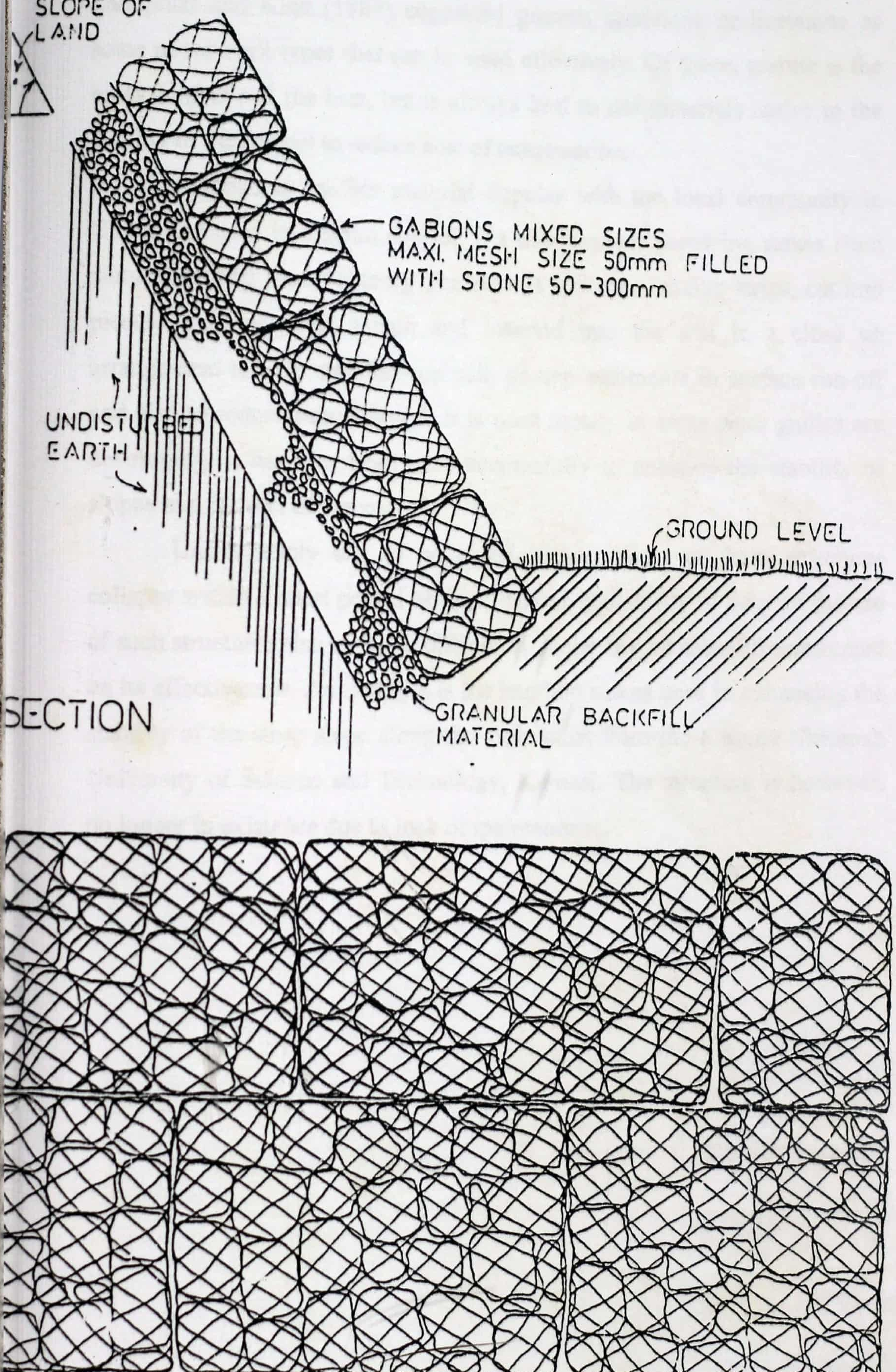


GABIONS

(FIG 6b)



(ADAPTED FROM LITTLEWOOD. M. (1993) LANDSCAPE DETAILING pp76)

The method is effective on soils with low productive potential and also on slopes with high moisture content (Hargett *et al.*, 1982; Preece, 1991). Landphair and Klatt (1988) suggested granite, sandstone or limestone as some of the rock types that can be used effectively. Of these, granite is the most durable and the best, but is always best to use materials native to the locality of the project to reduce cost of construction.

Bamboo is another material popular with the local community in Ghana and used in erosion control. It's use involves preparing stakes from mature bamboo shoots (Stem). The stem is split into smaller strips, cut into pieces of about 40cm length and inserted into the soil in a close up arrangement to help stabilize top soil, or trap sediments in surface run-off and also to reduce runoff speed. It is used mostly in areas were gullies are developing. It has also been used successfully to enhance the stability of slopes in a number of places.

Unfortunately due to poor maintenance most of these structures collapse within a short period of time. The unavailability of data on the use of such structures also makes it difficult to make any meaningful assessment on its effectiveness. An example is the bamboo stakes used in enhancing the stability of the steep slope along the main exist from the Kwame Nkrumah University of Science and Technology, Kumasi. The structure is however, no longer in existence due to luck of maintenance.

CHAPTER 5

5.0. ANALYSIS OF LANDSCAPE TECHNIQUES FOR EROSION CONTROL AND SLOPE STABILIZATION

Most of the techniques discussed may be foreign but effectively may be adapted to the Ghanaian environment. Slope fascines for instance may be used successfully only in areas where no other vegetation is to be established. This is because of the nature of the design. It may thus not be used in farming areas where every bit of land is needed.

Effective use of live woody materials in slope stabilization will require the use of plants which are easy to root, have good strength and are adapted to harsh environmental conditions. It will also be necessary to have a reliable supply of such materials to meet demand based on long term resource management policies (National Academy of Sciences, 1979).

The following are some of the plants suggested; *Millettia thonningii, Spondias mombin, Leucaena leucocephala, Azadirachta indica,* and Acasia.

Most of the methods discussed allow for low maintenance. However their effectiveness will depend on how well the design is monitored to ensure that dead plants are replaced; weak points identified, and the necessary changes made to prevent deterioration.

Where inert materials are used, the material should be such as to withstand deteriorating conditions of the environment. For instance woody materials in slope stabilization will require treatment against rot inducing organisms. This will however increase cost considerably as compared with the use of rabble, which will require little or no treatment at all. Another fact is the already scarce supply of timber products on the market.

The use of timber or woody materials in slope stabilization may thus have to be compared carefully with other methods. Use of timber off-casts from the timber industry may be a way to solve this problem (Odei, 1999).

5.1. SUMMARY:

The problem of erosion and unstable slopes has been created largely through human activity. However their effect on the environment can be minimized by use of techniques, which will provide long-term solutions and at the same time create harmony in the environment.

These techniques may range from the use of cheap live materials to inert more expensive materials of high quality. Landscape practice can help in ensuring the adoption of the right design and the choice of durable and cost-effective materials to meet acceptable construction standards.

5.2. RECOMMENDATIONS:

No single method can be recommended for use. However a combination of methods can be used, the choice of which will determine its effectiveness. This may be based on such factors as: the nature of the site, accessibility, machinery available, reliability of the design scheme (including type of technique chosen) and the consequences of failure. Others are cost implications, maintenance requirements and the designer or client's own preferences.

A combination of some of these methods of erosion control and slope stabilization can be used as means to enhance our environment and to protect it. This can be by the selection of spots of strategic panoramic beauty. These spots can then be preserved, protected (by a legislative instrument) and developed into invaluable monuments of landscape value that can be factored into our budding tourist industry. In this regard the contribution of the landscape architect cannot be over emphasized.

Another important factor, which should be given serious consideration, is the control of physical development on sloping areas, more especially as it may pose a direct risk to human life and property. Physical development in such places should only be by strict supervision of the District / Metropolitan Assemblies in consultation with the Town and Country Planning Department and such Research Institutions as the Building and

Road Research Institute, Environmental Protection Agency (E. P. A.) and the Ghana Institute of Engineers.

The Environmental Protection Agency has the legislative power to oversee all developments that may have some effect on the environment (Environmental Protection Agency Act, 1994 Act 490). This, the E. P. A. does through the Environmental Assessment Regulation (L. I. 1652, 1999). In this regard it is recommended that in assessing developments in sloping areas and areas exposed to erosion, the E. P. A. should ensure that a professional landscape architect is made part of the team. This will ensure that areas considered to be of landscape interest, as elaborated earlier, are preserved and protected from uncontrolled exploitation.

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