Natural Hazards and Hazard Management
in the Greater Caribbean
and Latin America
Rafi Ahmad (Editor)

Publication No. 3, pp. 112 to 123, 1997
Unit for Disaster Studies
The University of the West Indies
Mona, Kingston, Jamaica
ISBN 976-41-0115-1

15 THE POTENTIAL OF BIO-ENGINEERING IN SLOPE STABILIZATION: A CASE STUDY FROM JAMAICA

Rafi Ahmad [1] , J. Clark [2] , J. Hellin [2], Paul A. Manning [3] , and Morag McDonald [4]

[1]Department of Geography and Geology, University of the West Indies, Mona, Kingston 7, Jamaica, e-mail: rahmad@uwimona.edu.jm

[2]Natural Resources Institute, Chatham Maritime, Kent, ME4 4TB, United Kingdom

[3]Mines and Geology Division, Hope Gardens, Kingston 6, Jamaica

[4]Department of Life Sciences, University of the West Indies, Mona, Kingston 7, Jamaica

ABSTRACT

Landslides are very common on Jamaican roads, and the consequences of these slides are costly. We have carried out a rapid assessment of landslide hazard along the Guinea Corn to Corner Shop Road, via Johns Hall in central Jamaica to identify road sections where bio-engineering may be used for an effective road maintenance. This road is subject to recurrent landslide activity and flooding following every significant rainfall event in the Mahoe River watershed.

The existing vegetation types along the road have been described in terms of their function in arresting slope movements and the protective cover they offer against infiltration. In areas where vegetation cover is inadequate or instability observed, recommendations are made as to vegetation type and techniques which may be implemented for slope stabilization. Many of the initiatives currently practiced by local population already make a positive contribution to road-side stabilization.

This research programme has been initiated in Jamaica jointly by Natural Resources Institute (UK) and Departments of Geography and Geology, and Life Sciences, University of the West Indies, Mona.

INTRODUCTION

The cost of repairing landslide damage to roads throughout Jamaica is considerable (Ahmad, 1995). The rainfall associated with September 12, 1988 hurricane Gilbert triggered 478 landslides along 108 km of accessible roadway in the parishes of St. Andrew, St. Catherine, and St. Mary (Manning *et al.*, 1992). Maharaj (1993) mapped 481 landslides, mostly debris flows, along 46.6 km of road network in Upper St. Andrew. Landslides triggered by the M 5.4 earthquake of January 13, 1993 along the road network in St. Andrew have been described by Ahmad (1996). In July 1994, we mapped some 82 landslides along the Guinea Corn Shop to Corner Shop Road in Central Jamaica (Fig. 1). Most of these roads exist on steep terrain in residual soils and highly jointly and deeply weathered bedrock. The failed slopes are susceptible to renewed movements during future storm events. Although the slope instability at any particular site is controlled by a number of factors, the primary cause of shallow failures appears to be the loss of cohesion in slope materials. This results from the

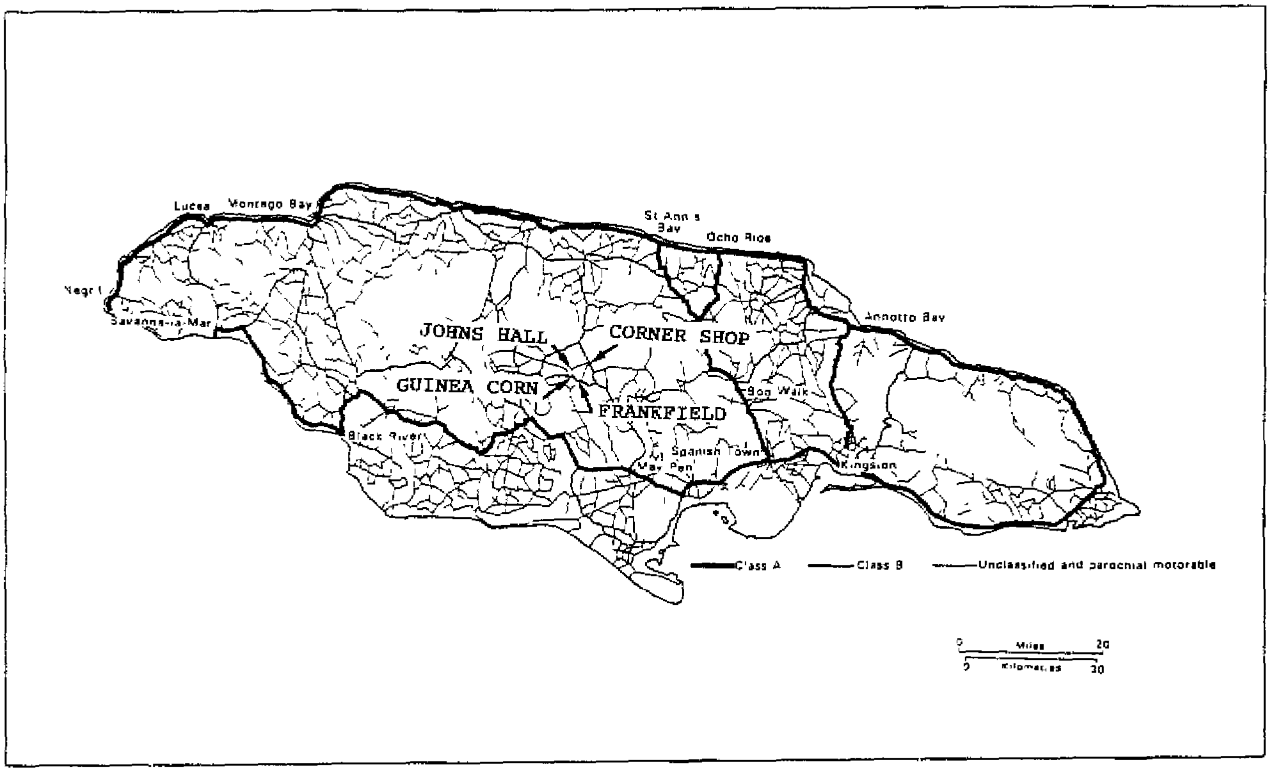

Fig. 1. Jamaica, showing the road network (modified from C.G. Clarke, Jamaica in Maps. Hodder & Stoughton. London) The location of Guinea Corn to Corner Shop Road is highlighted.

direct infiltration of rain water into the slopes following prolonged and/or intense rainfall. It follows, therefore, that one of the key aspects in improving slope stabilization is to protect the slopes against excessive infiltration. Vegetative stabilization is one of the several techniques used for controlling unstable slopes (Greenway, 1987; Schuster, 1995). Our experience in the Caribbean and elsewhere (Clark and Hellin, 1996) suggests that when employed along with other conventional methods, bio-engineering may offer simple, robust and cost-effective solutions to arrest shallow landslides and prevent soil erosion along roads. However, the effective use of vegetation in slope stabilization must be based on an understanding of local geology, landslide processes, the plant species available, their bio-engineering characteristics in terms of hydrological and mechanical influences, and their establishment requirements.

The aim of this paper is to highlight the potential engineering functions of vegetation in improving slope stabilization on the Guinea Corn to Corner Shop Road, via Johns Hall in the Mahoe River watershed, Clarendon, Jamaica (Fig. 2). The first section of the paper includes a description of human geography, geology and geomorphology of the area. This is followed by an assessment of landslide hazard. In the last section, existing vegetation types along the road are described in terms of their bio-engineering functions and recommendations are made on the most suitable techniques to use.

Improvement of the Guinea Corn to Corner Shop Road is being undertaken by the Jamaican government's Ministry of Construction as part of the Inter-American Development Bank funded Rural Road Rehabilitation and Improvement Project. This section of the road has been selected as a case study for the Natural Resources Institute/Overseas Development Administration funded bio-engineering project in the Caribbean (Clark and Hellin, 1996).

HUMAN GEOGRAPHY, GEOLOGY, GEOMORPHOLOGY AND SOILS

The study area is a part of the Mahoe River Watershed, located in the northwestern section of the Parish of Clarendon in central Jamaica (Figs 1 and 2). Major rural settlements in the area are Guinea Corn (population<500), Johns Hall (<500), Fairburn (population data not available), and Corner Shop (<500). Most of the population is engaged in agriculture. In the area surveyed, nearly all the farm holdings appear to be

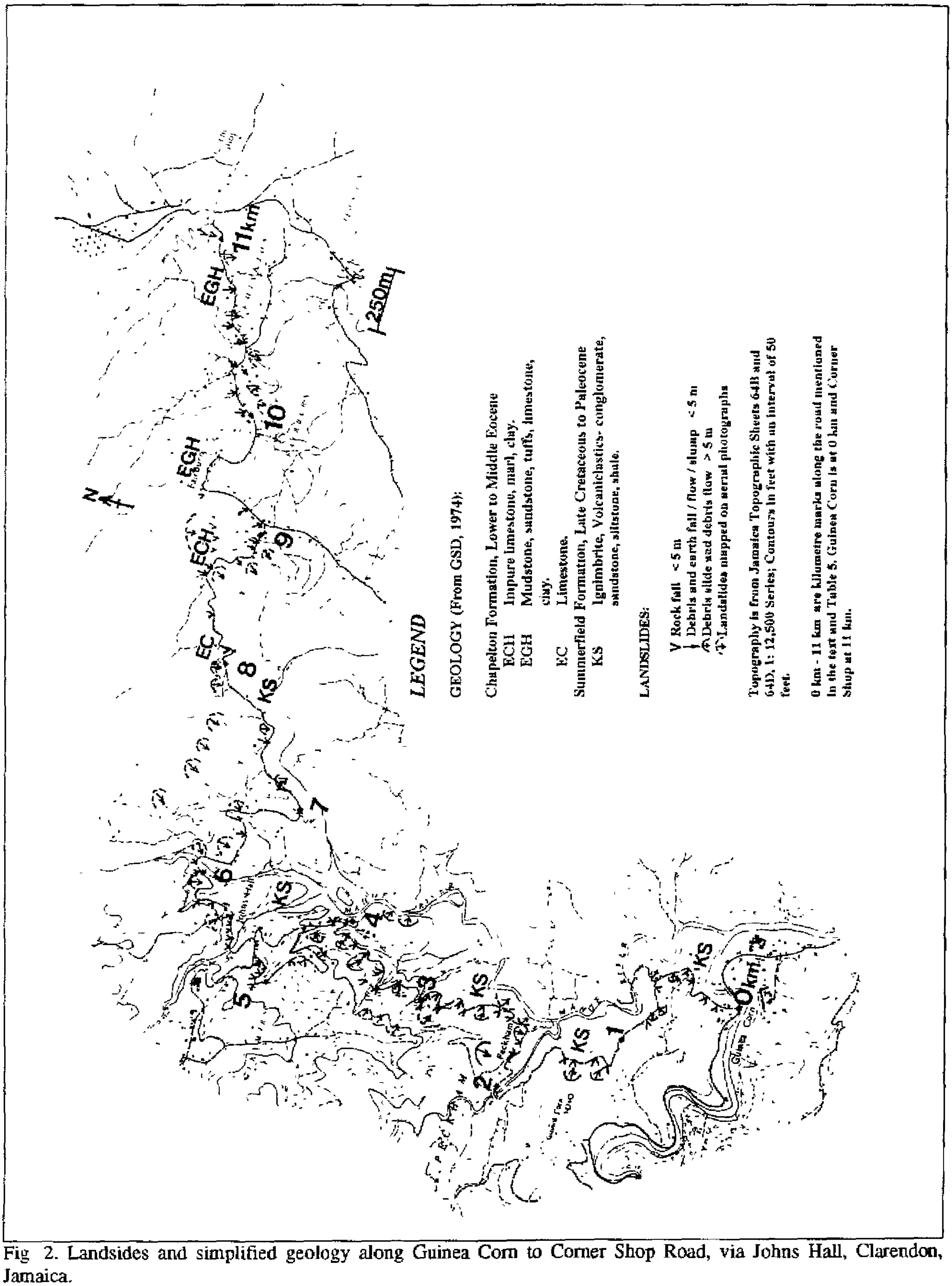

Fig 2. Landsides and simplified geology along Guinea Corn to Corner Shop Road, via Johns Hall, Clarendon, Jamaica.

FORMATIONS	Area in ha	Percent of the total area
Summerfield Formation	284.26	62
Chapelton Formation	146.5	32
White Limestone Group	26.84	6
Total	457.5	100

Table 1 Area of bedrock exposed along the Guinea Corn to Corner Shop Road.

less than 2 hectares. The Guinea Corn to Corn Shop Road via Johns Hall is the only metalled road connecting these rural communities with Frankfield which is the nearest township. The houses and farms are all located within a distance of about 1km from the road which serves as the hub for all the social and economic activities.

The average annual rainfall is between 127 to 177.8 cm which is seasonal and occurs mainly in May-June and September-October (Finch and Jones, 1959). Tropical storms and hurricanes may bring rainfall in excess of 30 cm over a 24 hour period. The rainfall is, in general, of short duration and high intensity, however, the rainfall associated with stationary weather systems and tropical systems is intense and prolonged (Earle, 1991). The average summer and winter temperatures are 28° C and 25.5° C respectively.

GEOLOGY

Geologically, the Mahoe River Watershed is a part of the Central Inlier which exposes a sequences of Cretaceous volcaniclastic sediments, andesites, mafic rocks, and limestones (GSD, 1974).

The oldest rocks in the study area are a 540 m thick sequence of alternating ignimbrites and volcaniclastic sediments - conglomerates, sandstones, siltstones, and shales which are referred to as the Summerfield Formation (Late Cretaceous to Paleocene). These rocks are massive to thinly bedded and are moderately to deeply weathered. Structural discontinuities mapped include faults and joints. The major faults trend NW and NE and are steep structures. Joints are intensely developed defining N, NE, E, NW trends with dips ranging between 30° - 82°.

The Summerfield Formation is exposed for a distance of 8 km in the steep road cuts along the Guinea Corn - Corner Shop road (Fig. 2). It covers an area of about 284.26 ha or some 62% of the total area mapped (Table 1). The road cuts exhibit highly fractured rock exposures which are in some areas overlain by highly weathered bedrock and lithosols reaching a maximum thickness of about 1.0 m.

The Summerfield Formation is overlain by a sequence of (i) limestone, (ii) mudstones, sandstones, tuffs, limestone, and red clays, and (iii) impure limestones, marl, and red clays referred to as the Chapleton Formation (Lower to Middle Eocene) of the Yellow Limestone Group. These rocks are exposed for a distance of 3 km between kilometre marks 8 and 11 along the road section (Fig. 2). The limestone exposures in the Chapelton Formation are in red clays and fine clastic sediments with large limestone blocks and boulders which do not appear to be *in situ* outcrops. Based on aerial photo-interpretation, two major fault trends, NNW and NW, have been mapped in the Chapelton Formation. The rocks of this formation occupy an area of about 146.4 ha or some 32 percent of the total area mapped (Table 1).

The youngest rocks in the area are white and hard, recrystallized limestones belonging to the White Limestone Group (Middle Eocene). These rocks form a prominent ridge and are exposed along the end of the road section at Corner Shop around kilometre mark 11. A NNW trending fault has juxtaposed the rocks of the White Limestone Group and the Chapelton Formation. These limestones are highly fractured and occupy an area of about 26.84 ha or some 6 percent of the total area mapped along the road section (Table 1).

Map symbol	Soil	Depth	Dominant slope angle	Drainage through soil	Moisture supplying capacity	Layering, if any, limiting root Penetration	Erosion hazard	Natural fertility
DGL	Donnington Gravelly Loam	Shallow to medium	2° – 10°, locally > 30°	Extremely rapid to rapid	Fair	Shattered bedrock at 30 – 92 cm	High	Medium, acidic.
WCL	Wirefence Clay Loam	Deep	5° – 30°	Moderate	Fair	–	High	–
WC	Waitabit Clay	Deep	5° – 30°	Rapid	Moderate	–	High	–
CHC	Carron Hall Clay	Moderate	10° – 20°	Moderate, but slow in sub-soil	High	Bedrock at 45 – 122 cm	Moderate to Slight	High to very high, alkalinity increasing with depth

Table 2. Some important characteristics of the soils along the Guinea Corn to Corner Shop Road.

SOILS

The bedrock in the study area is deeply weathered with the depth of the weathered zone extending up to about 30 m, sometimes more. This may be observed in all the lithologies except limestone. The soils developed on the weathered bedrock reflect the nature of the parent material from which they are derived. These lithosols are generally 1.0 to 1.5 m deep. The present study has adopted the detailed soil classification of Finch and Jones (1959).

The main soil types recognized are.

(i) Donnington Gravely Loam developed over the weathered volcaniclastic sediments of the Summerfield Formation,

(ii) Wirefence clay developed over the deeply weathered, fine-grained volcaniclastic rocks of the Summerfield Formation and fine-grained clastics and clays of Chapelton Formation

(iii) Waitabit clay developed over the deeply weathered clays and fine-grained clastics of the Chapelton Formation and other fine-grained volcaniclastic sediments, and

(iv) Carron Hall Clay developed over the hard, fragmented, rubbly limestone of the White Limestone Group.

Some of the important characteristics of these soils in relation to bio-engineering are given in Table 2.

SLOPE ANALYSIS

Landforms in the study area are profoundly influenced by the nature of the bedrock, faults and joints. Most of the drainage is fault controlled and hillslopes intensively dissected. Surface drainage is absent in the areas underlained by limestones. The Guinea Corn - Corner Shop Road is located along the south-facing slopes of the Mahoe River Valley.

We have used 1:12,500 scales topographic sheets 64 B and 64 D to carry out a slope analysis of the area. The results are summarized in Table 3. The predominant slopes are in the range of 10° to 30°, 65% of the area, whereas slopes less than 10° occupy 31% of the area, and slopes above 30° constitute some 4% of the total area mapped.

BEDROCK-SLOPE COMBINATION

An analysis of various bedrock-slope combination (Table 4) suggests that along the road most of the slopes above 20° (28.5%) are confined to the Summerfield Formation. Some 58.34 percent of all the slopes in the area between 5° - 30 ° also occur in this formation which has the highest outcrop area. The majority of the slopes in the Chapelton Formation are between 5° - 20° . Since the lithosols surrogate bedrocks, the above distribution also holds true for the various soil-slope combinations. These soil/bedrock-slope combination distributions have significance in controlling the occurrence of landslides in the area.

LANDSLIDE INVENTORY

The preparation of landslide inventory map along the road section involved two steps:

(i) Mapping of landslides and geology on panchromatic aerial photographs, scale 1: 15,000, prior to the field work. These data were transferred to the 1: 12,5000 topographic maps, and

(ii) Fieldwork which involved the verification of data in (i), mapping of additional landslides, classification,

Slope Categories	Area in ha	Percent of the total area
VI > 40°	6.1	1
V 30° – 40°	13.42	3
IV 20° – 30°	147.32	32
III 10° – 20°	151.28	33
II 5° – 10°	117.12	26
I < 5°	21.96	5
Total	457.2	100

Table 3. Slope categories mapped along the Guinea Corn to Corner Shop Road.

and identification of inherent conditions that promote landslides in the area.

The information in steps (i) and (ii) was synthesized to produce the final inventory map (Fig. 2).

Landslide types

The various landslide types mapped are shown on Figure 2.

Rock Falls are confined to all those areas where highly fractured bedrock is exposed along the road cuts with >20° slopes, especially between Guinea Corn and Johns Hall (0 km mark, Fig. 2). Although this type of failure is <5 m in the longest dimension, it is capable of blocking the road and causing a serious injury to the road users. The triggering mechanisms for rock falls in the area are medium to heavy rainfall and/or seismic vibrations (Earle, 1991). This mode of failure is most common in the highly fractured rocks of the Summerfield Formation exposed between kilometre marks 0 and 8 along the road. The longest dimension of

	FORMATIONS								
	Summerfield Fm. (I)			Chapelton Fm. (II)			White Limestone Fm. (III)		
Slope categories	Area in ha	% of area in (I)	% of total area	Area in ha	% of area in (II)	% of total area	Area in ha	% of area in (III)	% of total area
VI >40°	2.44	1	0.5	None	–	–	3.66	14	0.8
V 30° – 40°	10.98	4	2.4	2.44	2	0.53	None	None	–
IV 20° – 30°	117.12	41	25.6	16.78	11	3.67	13.42	50	2.93
III 10° – 20°	96.38	34	21	48.8	33	10.67	6.10	23	1.33
II 5° – 10°	53.68	19	11.74	61	42	13.34	2.44	9	0.53
I < 5°	3.66	1	0.8	17.08	12	3.73	1.22	4	0.26
Total	284 26	100	62.04	146.1	100	31.94	26.84	100	5.85

Table 4. Slope / bedrock combinations along Guinea Corn to Corner Shop Road.

Segment length km.	Types and numbers of failures: Falls < 5m = A Slides etc. < 5m = B Slides > 5m = C Note: Landslides mapped on aerial photos are excluded	Total number of failures	Predominant slope angle	Lithology/soils	Severity Index = Number of failures/ total length of road, km.
Guinea Corn 0–1	A = 6 C = 3	9	20° to 30°	Summerfield Fm./Donningtion Gravelly Clay Loam	0.81
1 – 2 Peckham	A = 4 C = 2	6	> 20°	"	0.54
2 – 3	A = 10 C = 3	13	> 20°	"	1.18
3 – 4	A = 7 B =1 C = 2	10	> 20°	"	0.9
4 – 5 Johns Hall	A = 3 B = 1 C = 1	5	> 20°	"	0.45
5 – 6	A = 10 B = 3	13	10° to 30°	"	1.18
6 – 7	A = 2 B = 1	3	5° to 20°	"	0.27
7 – 8	B = 1 C = 4	5	> 20°	"	0.45
8 – 9	A = 1 B = 2	7	10° – 20°	Chapleton Fm./Clay Loam and clay	0.63
9 – 10	A = 1 B = 2	3	< 10°	"	0.27
10 – 11 Corner Shop	B = 8	8	10° to 20°	"	0.72
Total Road Length = 11 km		82			

Table 5. Relative landslide hazard along Guinea Corn to Corner Shop Road expressed as severity index.

the rock fall deposits is generally <5 m. Most of the slopes steeper than 30° occur around the 1km, 2 km, and 7 km marks (Fig. 2). The incidence of rock falls has been further increased by the modification of slopes for the placement of the road.

Rockfalls have also been observed in the fractured limestones of the Chapelton Formation between km marks 8 and 9; near Fairburn; and in the limestones of White Limestone Group in the Corner Shop area.

The rock falls are controlled by the discontinuities that daylight into the slopes. Lithological characteristics also influence rock falls.

Debris and Earth Fall and Flows are confined to the lithosols and underlying weathered bedrock in all the lithologies exposed along the road section. They are usually <5 m in the longest dimension and are generally triggered by the rainfall. This mode of failure is generally associated with slopes <20°. Some of these failure also occur along lithological contacts.

In the Summerfield Formation, there are several examples of debris and earth flows and falls. The road cuts in the deeply weathered and fractured bedrock often fail by debris flows.

In Chapelton Formation shallow debris slides have occurred along the road in the rubbly limestones inter-layered with clays. These slides appear to be related to a build up of a perched water table between the clay layers and the rubbly limestone. The base of the slope is often marked by springs.

The debris flows and slides are very common in the clastic sequences of the Chapelton Formation exposed between Fairburn and Corner Shop. Most of these slides are formed in the lithosols (Carron Hall Clay and Waitabit clay) that overlie the clastics.

The common practice of bushing the road shoulders as a part of Christmas Work often leads to the de-stabilization of slopes.

Large Debris Slides and Flows have been mapped on the slopes adjacent to the Guinea Corn - Corner Shop Road (Fig. 2). These are restricted to the lithologies in the Summerfield Formation and occur on slopes >20°. The smaller slides described in the previous two sections generally occur in the toe regions of these old slides. In other words, the smaller slides are a consequence of the reactivation of the old slides which has taken place following successive storm events.

Landslides mapped on the aerial photographs

The interpretation of aerial photographs suggests the presence of several landslides, especially in the first-order streams, in the upper sections of the slopes (Fig. 2).

FACTORS AFFECTING SLOPE STABILITY

The basic factors of lithology, structure, and geomorphology provide conditions that favour landsliding in the area.

Most of the landslides are confined to the Summerfield Formation where a combination of lithology, presence of discontinuities due to bedding and joints, and slopes >20° have all contributed to slope instability conditions.

In the Chapelton Formation, the slope instability is due to the highly fractured nature of the limestone and the nature of soils and bedrock. The landslides are confined to the highly weathered bedrock and lithosols.

The landslide initiating conditions in the area are related to rainfall and anthropogenic activities. Earle (1991) has estimated that in the Rio Minho watershed the antecedent rainfall of 300 mm initiates a widespread landslide activity, while the average hourly rainfall intensity required is about 100-440 mm/hr. The most significant human activities are road building and inappropriate agricultural practices. The over-steepening of natural slopes for placing roads is the primary cause of slope failures in the Summerfield Formation. It has been observed that the unchannelled surface flow along the inner shoulders of the road causes erosion at the base of the cut slope thus initiating landslides. The practice of bushing the toes of landslides along roadsides also contributes to the reactivation of the previous slope failures.

ANALYSIS OF LANDSLIDE HAZARD AND RECOMMENDATIONS

Landslide Hazard

The landslide inventory map (Fig. 2) shows the landslides mapped along the road section. A comparison of this data with the bedrock slope analysis, and soils brings out the basic conditions that favour landsliding in the area. A summary of these conditions is presented in Table 5.

Relative landslide hazard

The relative landslide hazard along the different sections of the Guinea Corn to Corner Shop Road has been determined by using a ratio number of slope failure/km divided by the total length of the road. This ratio is termed here as the Severity Index and is considered most appropriate for bio-engineering purposes. A value of zero would indicate that there were no slope failures in that segment. Table 5 gives the severity index (S.I.) for different road segments in relation to lithology, slope angle, and slope failure types. The highest values of 1.18 are recorded for segments 2-3km, and 5-6 km. This area is underlain by highly fractured bedrocks of Summerfied Formation where slopes are generally in excess of 20°. The lowest value of 0.27 is recorded from (i) the segment 9-10 km which is associated with small soil slips in clays where slopes are <10°, and (ii) the segment 6-7 km which is underlain by Summerfield Formation where the slopes range between 5° to 20°. An examination of the different S.I. values suggests not only the relative hazard but also the slope conditions. These parameters may be used to suggest remedial measures for slope stabilization using vegetation.

SLOPE STABILIZATION

In the pre-design phase, collection of physical data such as bedrock geology structure and geomorphologic processes acting upon the area has been made. In this section, an analysis of the vegetation is made to supplement this information. The objectives were two-fold; firstly to describe existing vegetation types and land-use practices along the road in terms of their function in catching material that is moving downslope; the protective cover that it offers to the slope against rain-splash, run-off and undercutting at the toe or in gullies and rills on a slope; and support offered to the slope from the base. Secondly, in areas where vegetation cover is incomplete, or instability is observed, recommendations are made as to vegetation types and techniques which could be implemented to increase slope stability. To this end, an assessment is made of characteristics of existing vegetation with regards to its ability to coppice, display rapid regrowth, nodulate, its adaptability to variation in sites and to poor site conditions, robustness, ability to propagate vegetatively and whether it will direct seed. Where these criteria are not met by existing vegetation, other species are recommended which would grow well in the observed conditions.

BIO-ENGINEERING

Bio-engineering is most simply defined as the use of grasses, shrubs and trees to protect the land - it utilises the beneficial mechanical and hydrological effects of a plant community to fulfill an engineering function.

Beneficial hydrological effects include:

Vegetation intercepts rainfall causing absorptive and evaporative losses, thus reducing the amount of rainfall available for infiltration. Interception also reduces the kinetic energy of rainfall and thus erosivity. Litter and vegetative structures confer greater roughness on the flow of air and water, reducing its velocity and hence capacity for erosion. The presence of root structures extracting water from the soil profile increases soil suction and lowers pore-water pressure, both of which increase soil strength.

Beneficial mechanical effects include:

Roots binding soil particles making them more resistant to erosion and increasing shear strength. Deep roots can also anchor into firm strata, bonding the soil mantle to stable subsoil or bedrock, and support the up-slope soil mantle through buttressing and arching. Stems and leaves cover the ground surface, protecting it from traffic and erosive overland flows.

Reasons for adopting a bio-engineering approach:

- cost effectiveness,
- environmental compatibility (including agro-social compatibility),
- utilisation of indigenous materials and local skills, and
- labour intensive.

VEGETATION DESCRIPTION OF THE GUINEA CORN - CORNER SHOP ROAD

There is no original, intact forest along this stretch of road, although there are several mature trees present, and in some of the gullies, reasonably good forest cover has developed. The large, mature trees (10m) are principally *Samanea saman* (guango), *Bursera simaruba* (red birch), *Spathodea campanulata* (African tulip tree), *Delonix regia* (poinciana) and large *Cecropia peltata* (trumpet tree) a variety of fruit trees, including *Mangifera indica* (mango), *Artocarpus altilis* (breadfruit), *Artocarpus heterophyllus* (jackfruit), *Blighia sapida* (ackee), *Melicoccus bijugatus*, (guinep), *Syzygium jambos* (rose apple), *Chrysophyllum cainito* (star apple) and *Manilkara zapota* (naseberry).

Several cut slopes have been colonised by a variety of weed species which provide good soil cover and a range of rooting depths. These include ferns, principally

Polypodium spp and *Nephrolepis* spp, and a number of herbs including *Mikania micrantha, Potomorphe* spp, *Cassia* spp, *Bryophyllum pinnatum* (leaf-of-life) and members of the geni Piperaceae and Melastomataceae.

Continuous cover is provided on some cut slopes or previous landslides by *Wedelia trilobata* (marigold), *Callisia fragrans* and *Lantana camara* (wild sage), and garden escapees or ornamentals such as *Guillania purpurata* (red ginger) and *Sansevieria metallica*. Larger shrubs providing cover include *Caesalpinia decapetala* (wait-a-bit), *Bauhinia divaricata* (bull hoof), and, very commonly in gregarious clumps, *Moghania strobilifera* (wild hops).

The overall land-use along the roadside is that of small farms and home gardens. Such systems incorporate a number of different means of the use of vegetation for land stabilisation. Cropping systems commonly include citrus trees, cocoa, yams, coconuts, sugar-cane, bananas and coffee in a variety of combinations. Timber trees are scarce on farmed land, but there are a few isolated *Pinus caribea, Hibiscus elatus, Cedrela odorata* and *Eucalyptus robusta.*

Very common is the use of living fence-posts, principally of *Gliricidia sepium* (quickstick), but also *Erythrina corallodendrum* (sword) both of which coppice well and can provided a permanent feature. Hedging is provided by *Hibiscus rosa-sinensis* (shoe-black) and barriers created by *Bambusa vulgaris* (bamboo) and *Vetiveria zizanioides* (vetiver grass).

Good slope stabilisation was observed with the use of small plots of *Saccharin officinarum* (sugar-cane) at the road-edge, which is cut green and provides permanent cover and rooting.

RECOMMENDATIONS

Several areas were observed which demonstrated instability, and where a bio-engineering approach may be appropriate. Many areas of instability were observed, including leaning trees, or bending upwards from the base on cut slopes or scars, exposure of tree roots and exposure of unweathered rock faces.

Overall, slopes in need of attention are short, and therefore maintenance of cover is considered to be the most important function of protection, combined where necessary with stabilization of the slope toe where cutting has taken place to widen the road. To this end, no intervention is recommended where natural vegetation already exists, or on low banks which will naturally stabilize in time, unless landscaping for aesthetic purposes is deemed to be required.

Given the nature of this road-side community, and the intensive agriculture practiced, many of the recommendations are designed to improve land management in the vicinity of the road, and to introduce a number of farm-forestry options. This will, as well as reducing erosion, ensure a positive contribution to local development, and entail active participation by the community. Hopefully, this will encourage continued maintenance of the road-side, rather than just piece-work over the short term of the road improvement programme.

Many of the initiatives currently practiced by the local people already make a positive contribution to roadside stabilization as shown in the preceding set of plates, and most of the recommendations simply augment existing practices. A common feature is pastureland adjacent to the roadside - in such areas, dense hedges are considered an option, where, in addition to controlling erosion, control of livestock which are potentially damaging to the road and its verges would be advantageous. *Caesalpinia decapetela* is a legume found ubiquitously, and its prickly armament and proven ability to form dense thickets would render it an excellent measure for stock control. Alternatively, potential fodder trees which also make good hedges, such as *Gliricidia sepium, Leucaena leucocephala* or *Calliandra calothyrsus* would be an option. Farmed fields bordering the road probably offer the most potential for vegetative control, given the opportunities to recruit community involvement, and the frequency with which fields are worked and hence potentially prone to erosion.

Vetiver grass is commonly used at trail edges and field borders, but oftentimes, such areas are in need of additional planting to form thicker, more effective barriers. *Pennisetum purpureum* (Napier grass) is another tufted perennial, potentially very deep-rooting which would be an effective species planted as a border.

Steep areas which are actively cleared and cultivated would benefit from the integration of permanent tree crops into the farmed field, either by growing timber trees such as *Cedrela odorata* or *Hibiscus elatus* to increase the value of the farmed area, as well as stabilising the soil. Erosion control in the fields could be enhanced by the use of live barriers planted along the contour. A range of species could be used for this purpose - tree species which can yield fodder, fuelwood, fix nitrogen and whose use has already been demonstrated in the area are *Leucaena leucocephala, Calliandra calothyrsus* and *Gliricidia sepium.* Alternatively, food crops such as dasheen can provide effective barriers, or, if erosion control is the sole objective, vetiver grass has been demonstrated as a very effective erosion control in farmed land, with very low management requirements, unlike the trees which need active, continuing management. Well established hedges of *Hibiscus rosa-sinensis* are observed in several areas. However, often these hedges need thickening, or weakened stretches strengthened. Also, in places where insufficient cover had been maintained below the hedge, scouring has occurred in one place, leading to collapse of the hedge after a heavy rain event in May, 1994. In areas where active management is unlikely to occur remote from dwellings, hedging species producing less biomass such as vetiver or napier grasses should be used in preference. Cover must be maintained below the hedge to prevent scouring. On less steep slopes species such as *Wedelia*, *Lantana* or *Callusia* will provide cover while not conferring much structural support, on steeper slopes more firmly rooted shrubs such as *Moghania* would be appropriate, or, low statured, rhizomatous or stoloniferous grasses such as *Zoysia tenuifolia* or *Cynodon dactylon* could be introduced.

Lack of cover below hedges or other supporting vegetation, or a lack of management of larger trees and shrubs was observed to cause a number of problems along the road. In particular, *Bambusa vulgaris* (bamboo) which had not been cut-back regularly, and displaying shallow rooting was seen to be undercut in several areas - where it has been cut, the problem was less marked. The most common reason to cut the bamboo is to provide yam sticks. The use of live yam sticks using a wide range of species (e.g. *Spathodea campanulata*) is being actively promoted in this area by the Forestry and Soil Conservation Department of the Ministry of Agriculture. The use of live yam sticks reduces pressure on the surrounding forest and prolongs the life of an individual yam stick (bamboo generally only lasts for one year). This system should be encouraged in this community as a positive environmental development, but if the use of bamboo is diminished, and potentially left unmanaged, undercutting at the road edge may become a more widespread problem.

Similarly, trees growing at the road-edge also require active management if they are not to cause problems Pollarded *Spathodea campanulata* is observed where cover below the trees has not been maintained, and the slope will remain active until the *Spathodea* roots are exposed, conferring potential instability, or damage to the trees. Short slopes such as these could be seeded with grasses such as *Zoysia* or *Cynodon* to establish protective cover.

Considerable effort has been made by the Ministry of Construction in the installation of drainage structures, which obviously require a high degree of protection to ensure their longevity. The use of the vetiver grass should be expanded to form a dense barrier immediately above the culvert. The area above this, and below the dwellings should be protected by a cover of *Wedelia* or seeded with *Zoysia* or *Cynodon*. Several drains have been installed along the road in natural drainage features. However, small gullies have developed above some of them with actively eroding sides. Light-weight fascines of *Gliricidia sepium* carefully keyed into the gully sides will develop shoots and roots and arrest further gullying or instability.

CONCLUSIONS

The bio-engineering recommendations are designed to augment existing practices and include: an increase in the density of *V. zizanioides* planting; the establishment of fascines using species that are already used in live fences; the use of grasses such as *Cynodon dactylon* to prevent scouring of a slope; and the use of a greater range of shrub / tree species that would also contribute to local peoples livelihoods through the provision of fodder and fuelwood (Clark and Hellin, 1996).

Many of the initiatives currently practiced by local people already make a positive contribution to roadside stabilization.

The Ministry of Construction has made a considerable effort in the installation of drainage structures, which obviously require a high degree of protection to ensure their longevity.

Bio-engineering structures can be more cost effective than inert structures because:

- they can often check shallow sub-surface slides and soil erosion and prevent them developing further,
- if well-established and managed they will increase in strength over time while an inert structure will become weaker,
- they utilize locally available materials such as vegetation and rock,
- they are environmentally compatible,
- they are labour-intensive and therefore offer employment opportunities to local communities,
- and any of the species used can benefit local communities in terms of the provision of fuelwood, fodder, fruit and material for handicrafts.

ACKNOWLEDGMENTS

Rafi Ahmad is responsible for writing the first part of the paper dealing with geology and landslides, while Morag McDonald has contributed the bio-engineering section.

REFERENCES

Ahmad, R. 1995 Landslides in Jamaica: extent, significance and geological zonation. In D. Barker and D.F.M. McGregor (editors), Environment and Development in the Caribbean Geographical Perspectives. The Press. University of the West Indies, Barbados, pp 147 - 169.

Ahmad, R 1996. The Jamaica Earthquake of January 13, 1993: geology and geotechnical aspects. Journal Geological Society of Jamaica, vol. 30, pp. 15 - 31.

Clark. J. and Hellin, J 1996. Bio-engineering for Effective Road Maintenance in the Caribbean. Chatham, UK: Natural Resources Institute. 121 p.

Earle, A. 1991. Landslides in the Rio Minho watershed in central Jamaica. Unpublished M.Phil. thesis, University of the West Indies, Mona campus.

Finch, T. and Jones. T. 1959. Soil and Land-use Survey Report No. 7. Parish of Clarendon, Jamaica. Imperial College of Tropical Agriculture, Trinidad, W.I.

Geological Survey Division(GSD) 1974 Geological Sheet No. 12. Spaldings, scale 1 : 50,000, with marginal notes. Mines and Geology Division, Govt. of Jamaica, Hope Gardens, Kingston, Jamaica.

Greenway, D.R. 1987. Vegetation and Slope Stability. In M.G. Anderson and K.S. Richards (editors). Slope Stability. J. Wiley. New York. pp. 187 - 230.

Maharaj. R.J 1993. Landslide processes and landslide susceptibility analysis from an upland watershed: a case study from St. Andrew. Jamaica, West Indies. Engineering Geology, vol. 34, pp. 34 - 53.

Manning. Paul A.S., McCain, Trevor and Ahmad, Rafi 1992. Landslides triggered by 1988 hurricane Gilbert along roads in the Above Rocks area, Jamaica. In Rafi Ahmad (editor), Natural Hazards in the Caribbean, Special Issue No. 12, Journal Geological Society of Jamaica, pp. 34 - 53.

Schuster, R.L. 1995. Recent advances in slope stabilization. Keynote paper, Session G.3 Stabilization and Remedial Works. Proceedings Sixth International Symposium on Landslides, Christchurch, New Zealand, vol. 3, A.A Balkema, Rotterdam, pp. 1715 - 1745.