2.6 Current Status of Countermeasure Works

2.6.1 Present Condition of Countermeasure Against Slope Failure

In Malaysia, many type of countermeasure against slope disaster have been done, such as earthwork, vegetation, water drainage, slope work, anchoring, retaining wall catch work, pilling work, protection work, and route relocation.

1) Earthwork

An earthwork is most reliable countermeasure for slope failure to remove unstable mass, or to adjust slope balance by fill or to replace good materials (Figure 2.6.1, 2.6.2, 2.6.3 2.6.4).

2) Water drainage

Water drainage is constructed in good condition as large water channel because of large amount surface water caused by tropical shower (Figure 2.6.6). Horizontal drain hole is not usual countermeasure for ground water and it is only constructed in special case. It seems that the drainage well and drainage tunnel is no achievement in this country.

3) Protection work

The protection work of cutting slope is usually used vegetation (Figure 2.6.5), pitching work, and shotcrete (Figure 2.6.10) or combined with soil nail (Figure 2.6.7,2.6.8,2.6.9), so crib work for protection of cutting slope is constructed as the very rare case (Figure 2.6.11).

4) Catch work

The catch work is constructed as catch gabion the foot of cutting rock slope at mountainous area and it catches falling rock (Figure 2.6.14), and also rock fall catch net and rock fall catch fence are constructed at high rock slope (Figure 2.6.15).

5) Retaining wall

Retaining wall consist many type of form, but in this country, gabion wall (Figure 2.6.12,2.6.13) and crib wall are constructed frequently (Figure 2.6.18). Diaphragm wall made of cast in place reinforced concrete pile and ground anchor is constructed at fill place of road (Figure 2.6.16, 2.6.17). Ground anchor is only used at the slope of main road where the traffic is heavy like north south highway (Figure 2.6.19).

6) Pilling work

The pilling work is constructed in the special place as reinforced concrete pile (Figure 2.6.20), and steel pipe pile and H steel pile is almost no construction.

Rock shed and sabo (check) dam is constructed at only few locations, and gabion wall is often constructed in the place where more effective countermeasure is necessary.

JICA Study Team observed through the site inspection that these countermeasures are designed and constructed in good condition generally, however, these are some comments on their construction method and design as follows

1) The earthwork of countermeasure against landslide is carried out by wrong method, foe example toe cut of landslide or fill of head of landslide in sometimes.

2) Gabion wall is the temporary works, so it should not be used the permanent structures against earth pressure, but it has high permeability, so it is useful to use the counterweight of toe of collapse or counterweight embankment of toe against landslide.

3) Reinforced concrete pile is used for countermeasure against landslide, but against landslide, reinforced concrete pile is not effective to protect landslide because the prevention work of landslide is need the strength of shearing strength of slip surface of landslide.

4) Soil nail is used very much slopes in Malaysia, but it has only function of reinforcement of soil, so in the case of necessity of forth to prevent slope failure, you should use the ground anchor with crib.

Figure 2.6.1 Earthwork (Counterweight Embankment)

Figure 2.6.2 Earthwork (Soil Cutting)

Figure 2.6.3 Earthwork (Displacement)

Figure 2.6.4 Earthwork (Rock Matting)

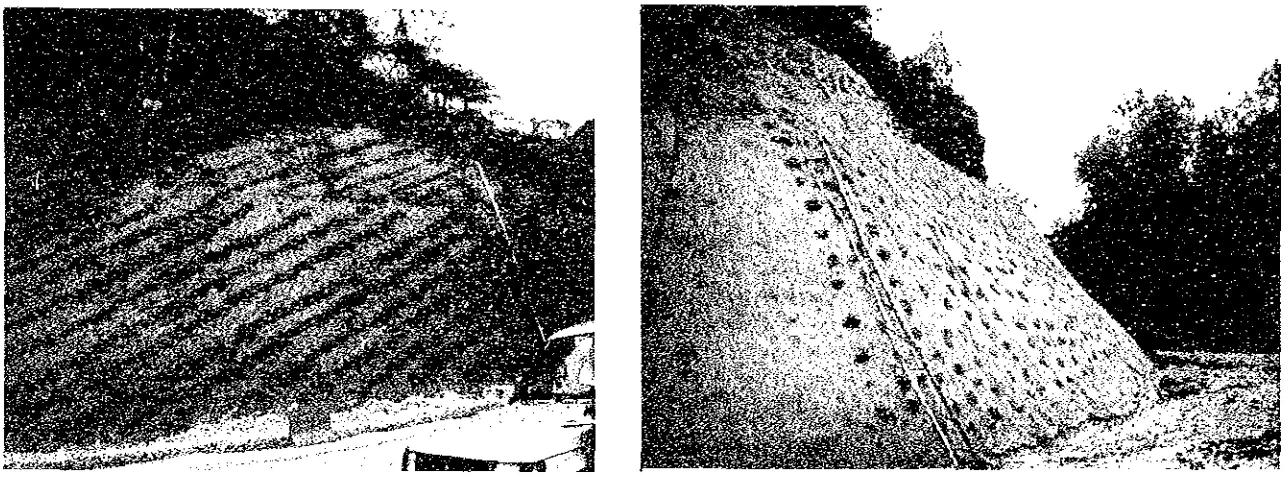


Figure 2.6.5 Vegetation

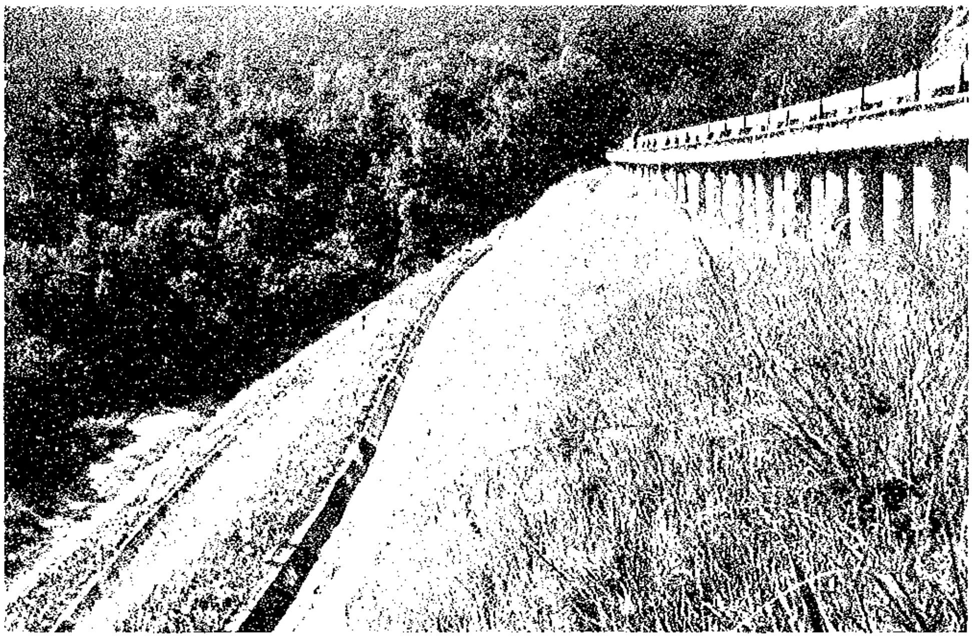


Figure 2.6.6 Water Drainage

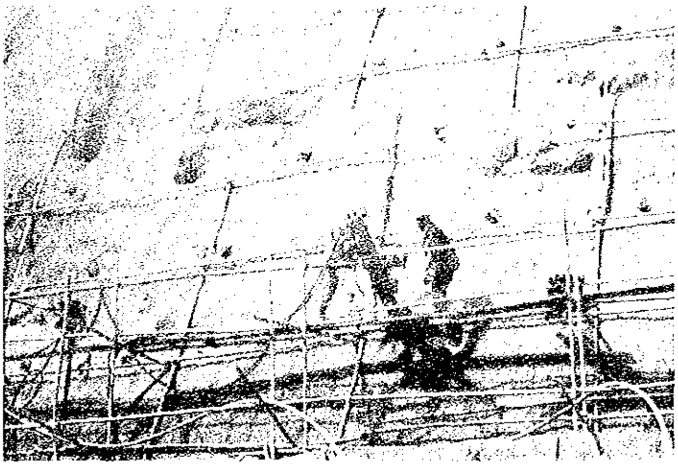


Figure 2.6.7 Soil Nail

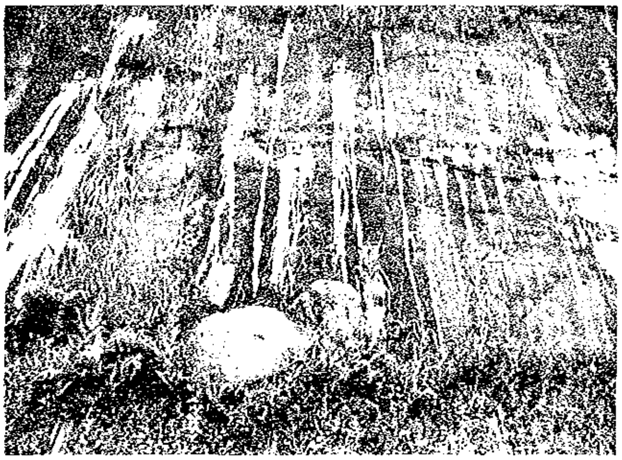


Figure 2.6.8 Soil Nail and Shotcrete

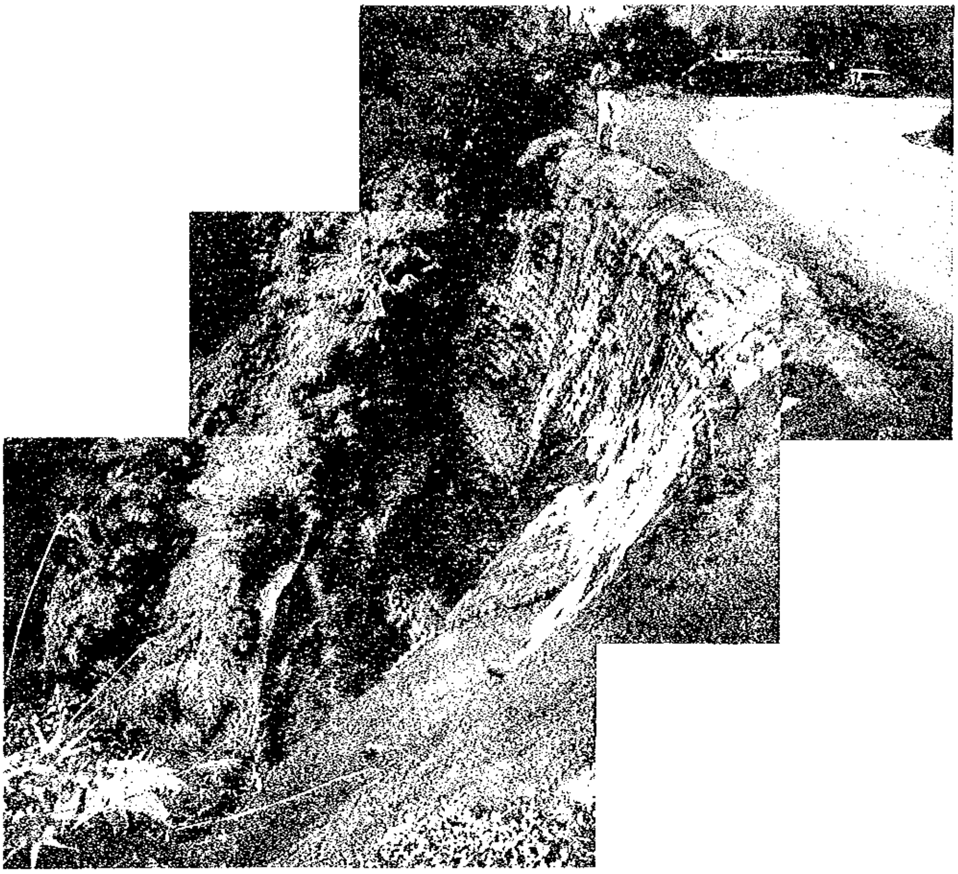


Figure 2.6.9 Soil Nail and Reinforced Shotcrete

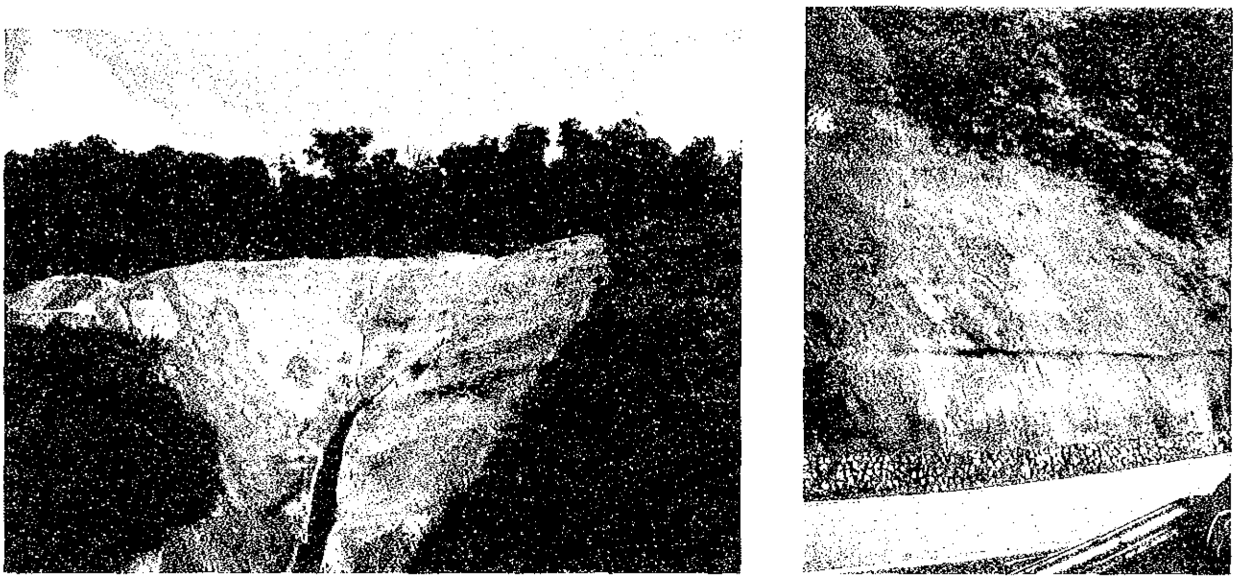


Figure 2.6.10 Shotcrete

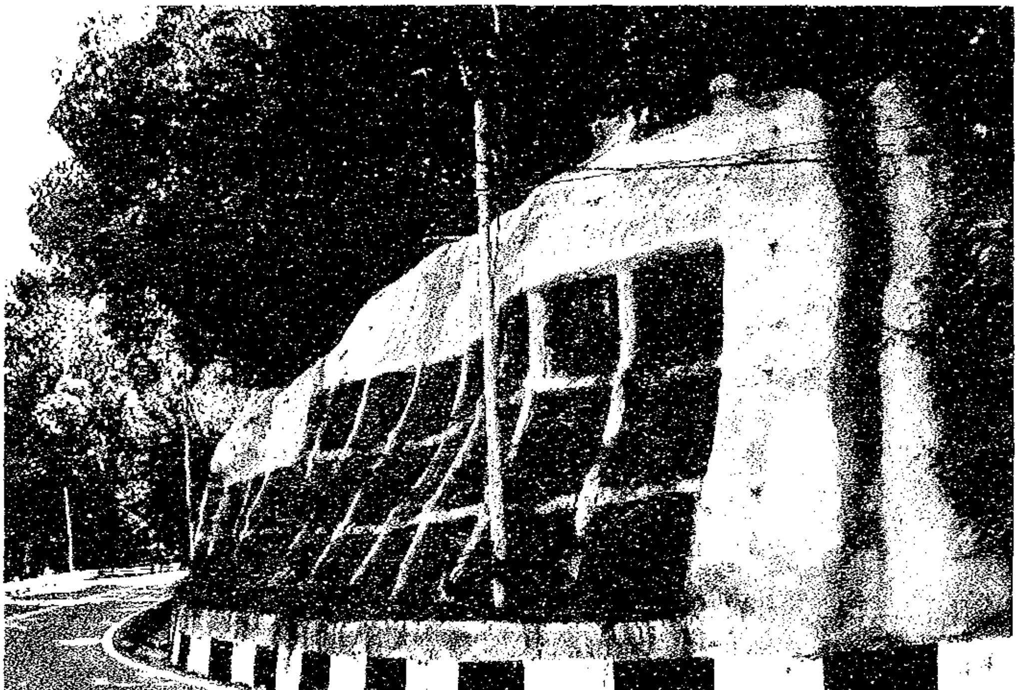


Figure 2.6.11 Shotcrete Crib

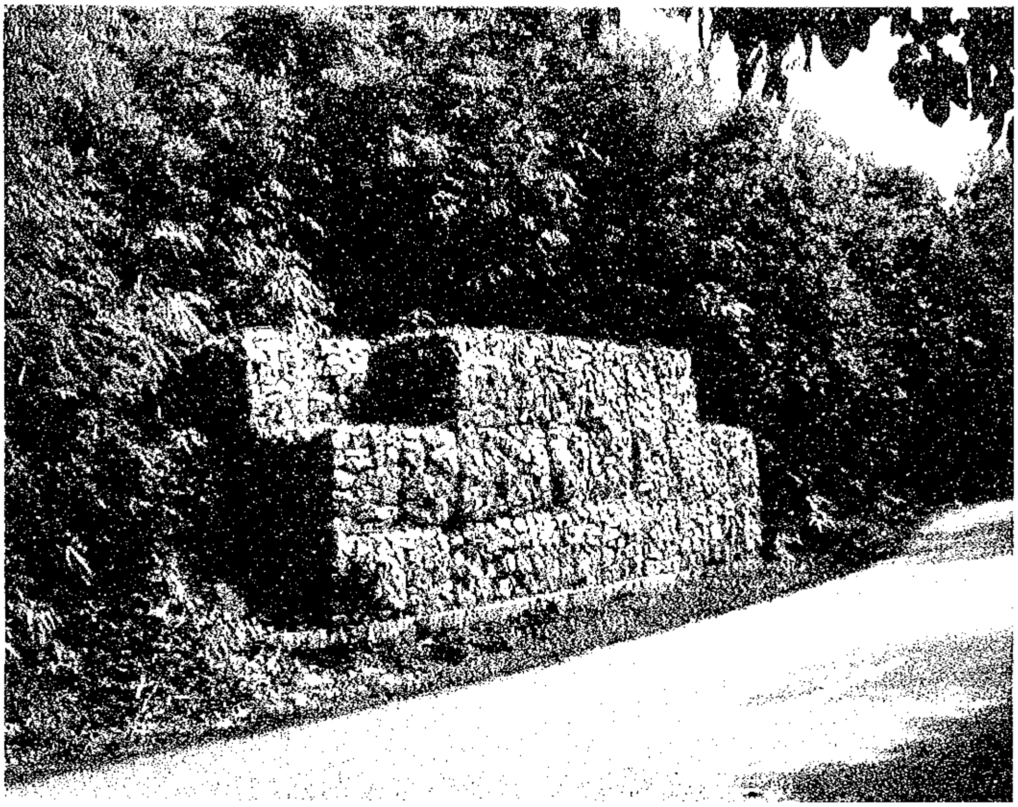


Figure 2.6.12 Gabion Wall

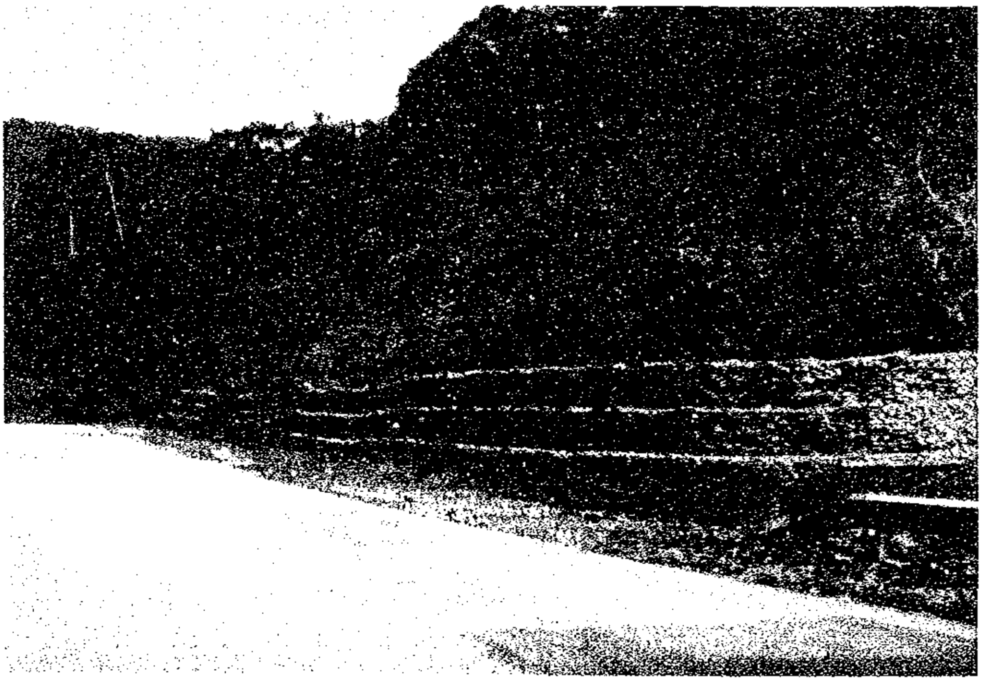


Figure 2.6 13 Gabion Wall

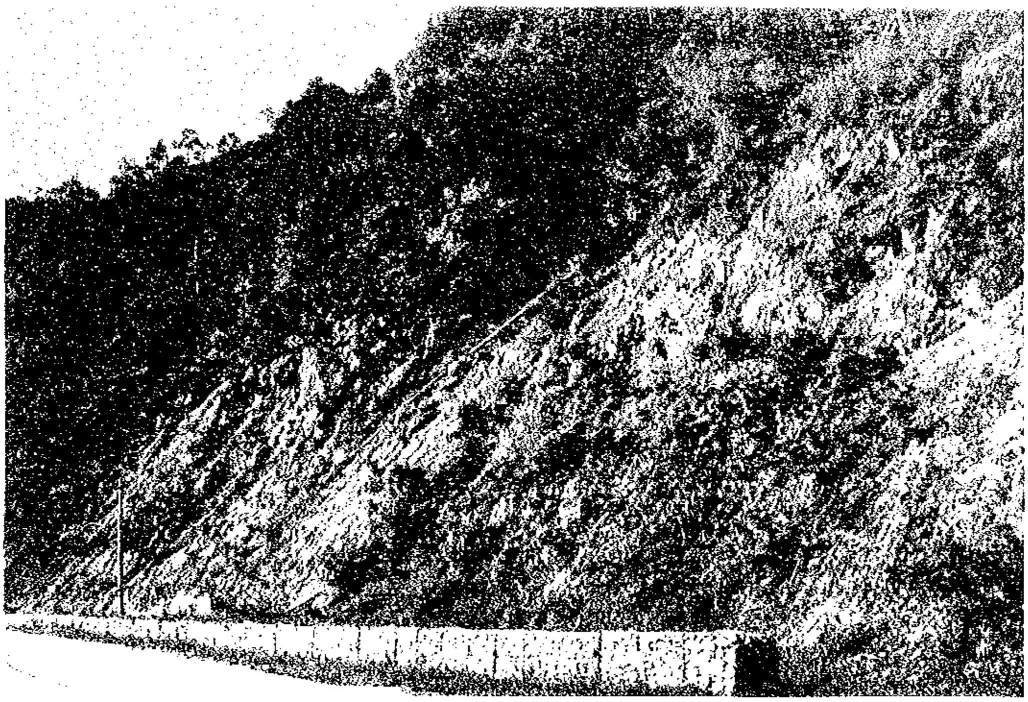


Figure 2.6.14 Catch Gabion

Figure 2.6.15 Rock Fall Catch Net

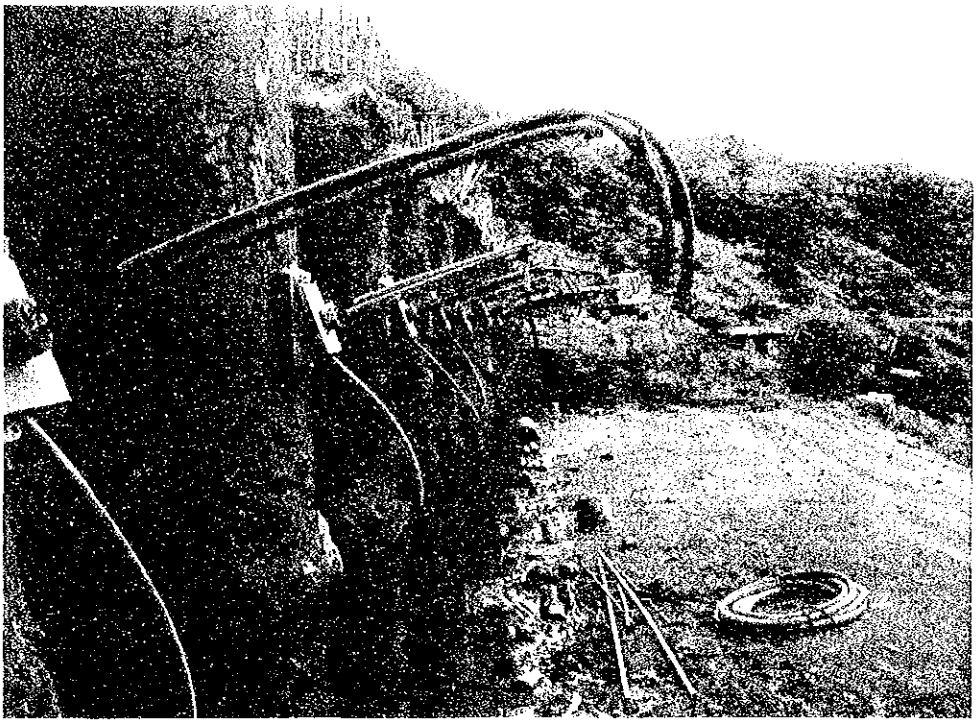


Figure 2.6.16 Reinforced Concrete pile with Ground Anchor

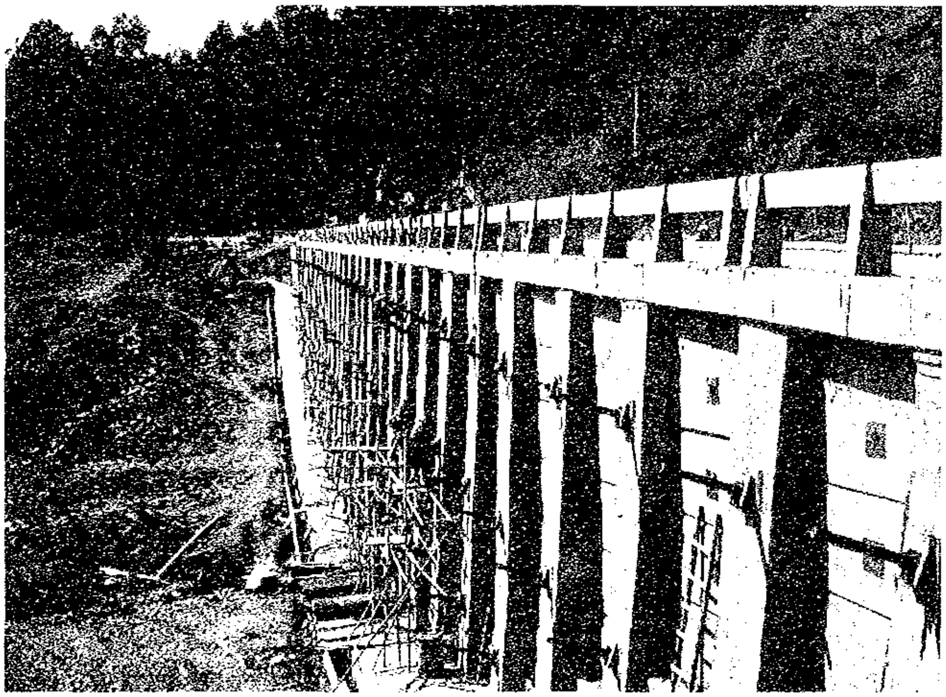


Figure 2.6.17 Reinforced Concrete Crib with Ground Anchor

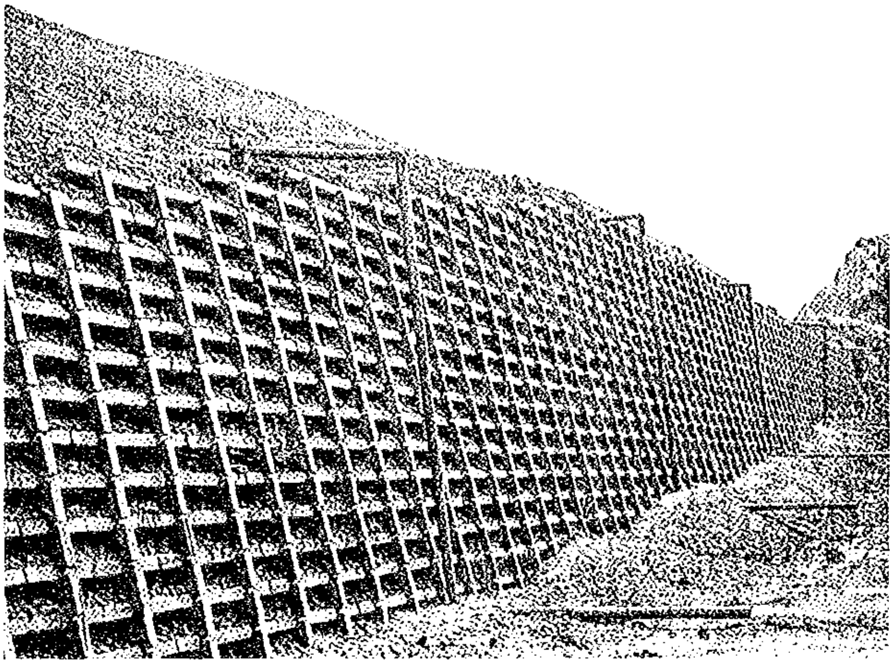


Figure 2.6.18 Crib Wall

Figure 2.6.19 Ground Anchor

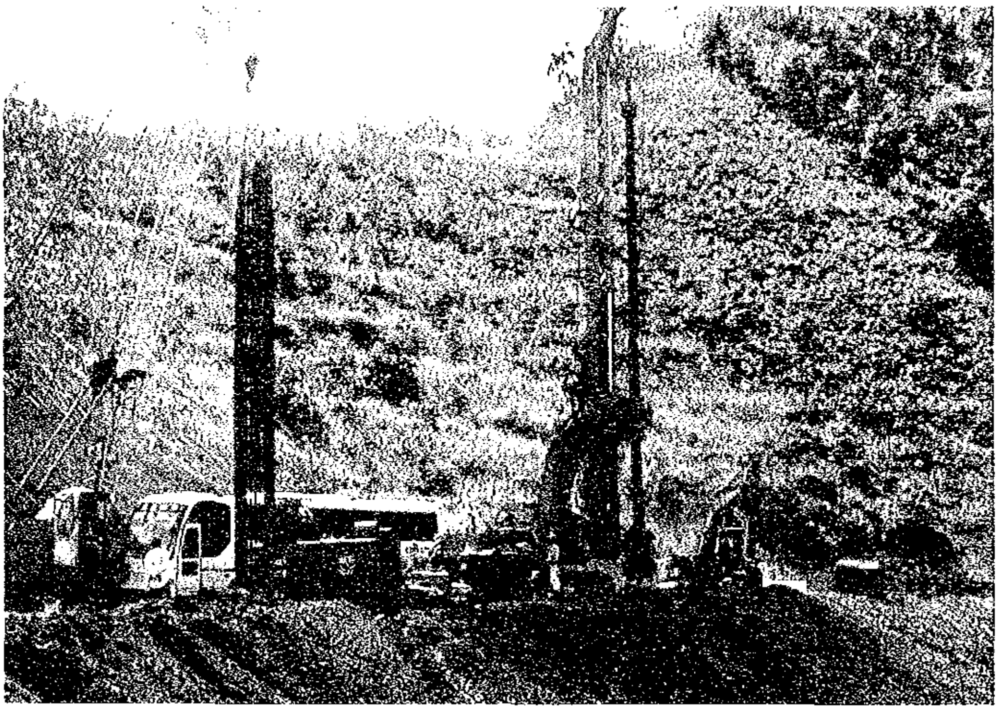


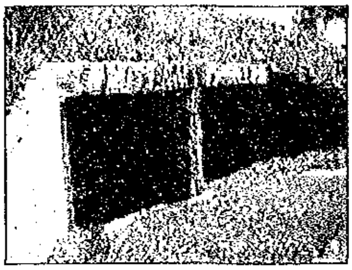
Figure 2.6.20 Cast-in-Place Reinforced Concrete Pile

2.6.2 Present Condition of River Crossing Drainage in Malaysia

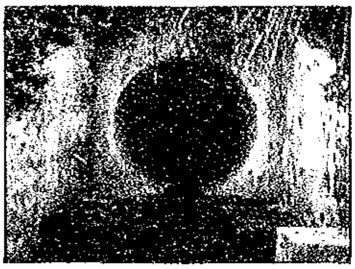
Under the present circumstances, there is no design standard for river crossing drainage in Malaysia. That is, a capacity and/or structure of the drainage facilities have been decided as occasion may demand by the designer.

To grasp the present condition of the facilities, field inspection for the river crossing drainage was carried out at approximately 20 points in East-West Highway.

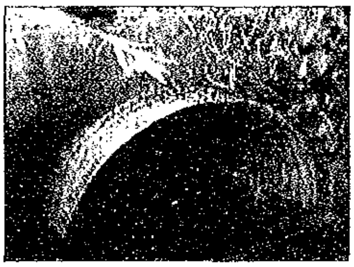
Adopted types at East-West Highway are three (3) types of facilities which are box culvert, circular culvert (hume pipe) and circular culvert (corrugated steel pipe) as shown in the following photos.



Box culvert



Circular culvert (hume pipe)



Circular culvert (corrugated steel pipe)

Figure 2.6.21 Three Type of Culvert at East-West Highway

A general drainage system of mountainous road and existing drainage facilities in East-West Highway are shown in Figure 2.6.22. At East-West Highway, many improvement works have been carried out since it had been constructed about 20 years ago. It could be commented that most of the facilities are allowable and good condition beyond our expectations in point of a drainage capacity of the culvert and a structure of the inlet and outlet at present.

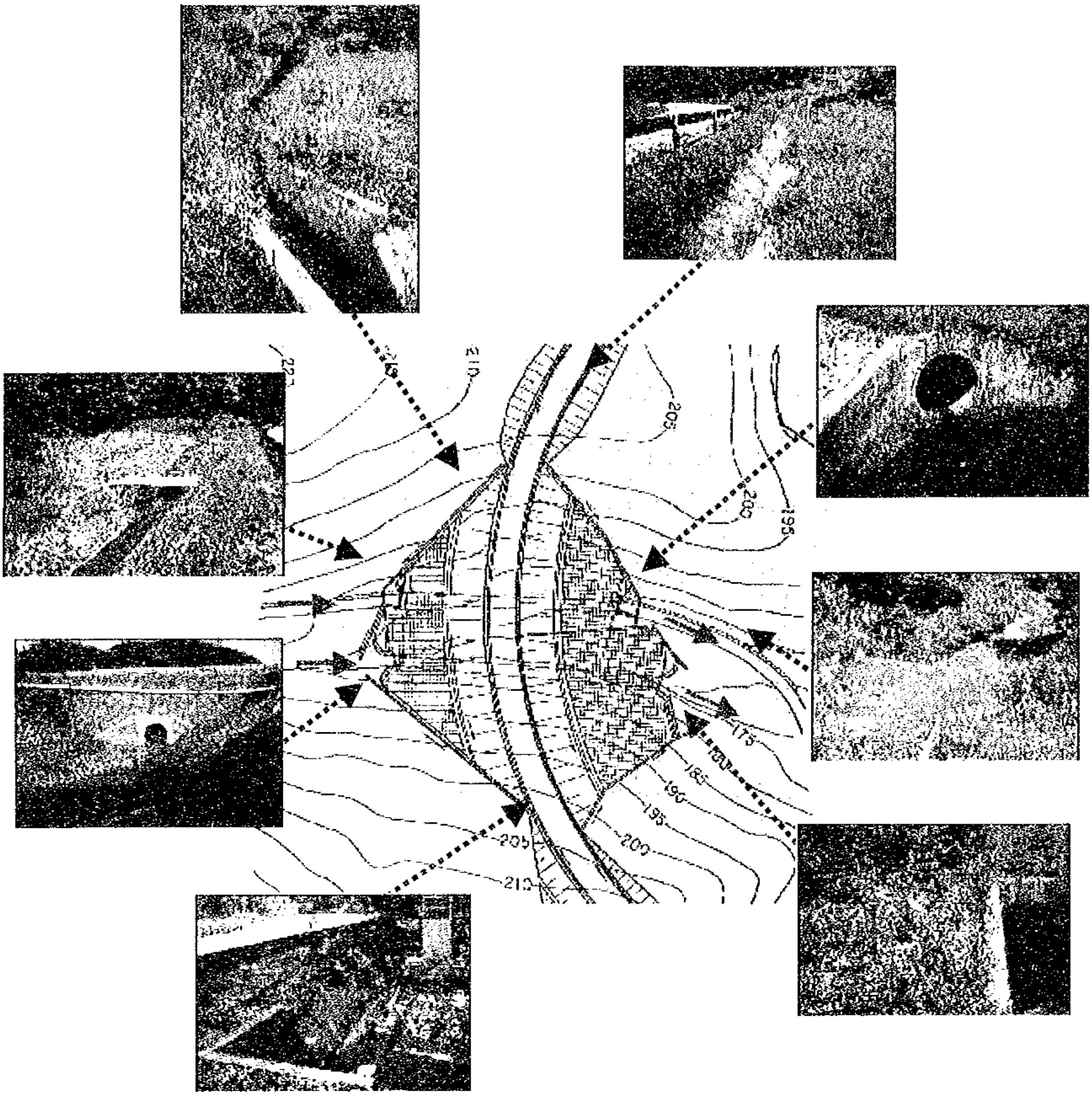


Figure 2.6.22 Drainage System of Mountainous Road and Existing Drainage Facilities in East-West Highway

However, the following problems have been remained yet.

- Due to a shortage of the drainage capacity, pools might be formed at the inlet after rainfall.

Figure 2.6.23 Condition of Inlet at Chainage 38.4 km

- Due to a lack of proper prevention works, there might be scoured caused by erosion at the outlet.

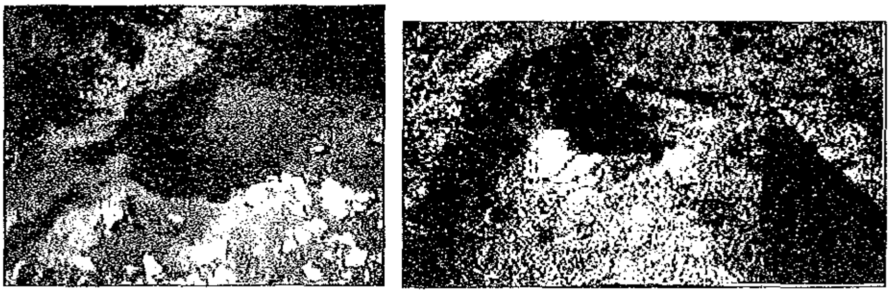


Figure 2.6.24 Erosion at the Outlet of Culvert (chainage 106.6km)

Deposit of sediments and/or drift plant might disturb an adequate water flow at the inlet and inner part

Figure 2.6.25 Sedimentation of Big Tree at chainage 28.4 km

Because the problems mentioned above might have much influence on a foundation of the embankment, prompt improvement and constant maintenance are required.

2.7 Classification and Mechanism of Slope Failure

2.7.1 Outline of Geological Setting

As described in *2.3.4 Geology*, Malaysia comprises a broad range of rock types including igneous rock (plutonic rock to volcanic rock), metamorphic rock, sedimentary rock and sand/silt of coastal plains. But the distribution of rock is different in Peninsula Malaysia and East Malaysia.

In Peninsula Malaysia, granitic rocks, metamorphic rocks are mainly distributed. These rocks were formed in the geological age ranging from Pre-Cambrian to Cretaceous (3,880 million year to 65 million year) accompanied by a small amount of young sedimentary rocks and volcanic rocks (Neogene Tertiary in geological age). This geological setting and history suggest that this Peninsula had been exposed to tropical weathering for long time. So, most parts of mountainous terrain are underlain by the residual soils of bedrock.

On the other hand, East Malaysia is mainly composed of sedimentary rocks of Tertiary based on small outcrops of Palaeozoic Formations.

Fault and sheared zones are not so frequent like in Indonesia or Philippines, but some extent of faults are developed in accordance with the geological development of Peninsula Malaysia and East Malaysia.

2.7.2 Classification of Road Slope Failure

Under geological setting as mentioned above, heavy rainfall over 3,000 mm/year makes slopes unstable and almost all types of slope failures are developed in hilly region. These slope failures are also found along federal roads in Malaysia, which generates considerable slope hazard and block traffic function.

JICA Study TEAM classified failure types along federal roads following six groups by analysing the mechanism of slope failure.

(1) Collapse (CL), (2) Rock Fall (RF), (3) Rock Mass Failure (RM)
(4) Land Slide (LS), (5) Debris Flow (DF), (6) Embankment Failure (EB)

These six types of slope failure are roughly defined below and in the Table 2.7.1.

(1) Collapse (CL)

Failure of loose and porous soils and rocks of slope that occurs when the loose materials are filled by water in a heavy rainfall infiltration or swayed by earthquake. This failure type is marked sudden and rapid movement without prior indication.
Mechanism of collapse is breakdown of loose and porous part of slope itself. Generally, size of failure is less than 1,000m^3 because only the loosened part of slope surface collapsed down.

(2) Rock Fall (RF)

Free fall or rolling down of a rock or few rocks individually from a steep slope or cliff. This failure type is also marked by sudden and rapid failure that is prone to occur in a heavy rainfall. But this type of failure happens sometime no relation with weather conditions. Generally, the size of failure is small that is less than $5m^3$.

As mentioned above Collapse and Rock Fall occur in similar topography/geological conditions.

(3) Rock Mass Failure (RM)

Mass failure in a rock slope such as planar slide, wedge slide, and toppling that mechanism is closely related with distribution of geological discontinuity. Deformation of rock mass often implies signal of final failure. Generally, size is more than 100 m^3.

(4) Landslide (LS)

Mass movement of highly weathered rocks, debris, soils slide that has slip surface. It is characterised by its deformed slope landscape. Size of it is big generally more than 5,000 m^3 and often ranges several hundreds thousand.

Generally, rock mass failure is also defined to "landslide". But, classification for the slope management of federal road in Malaysia they are divided into two categories because of difference of mechanism and method of treatment for them.

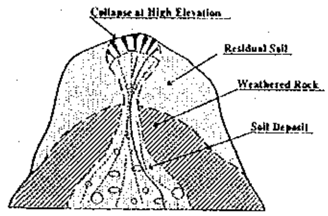
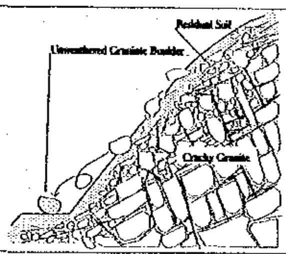
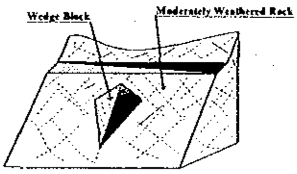
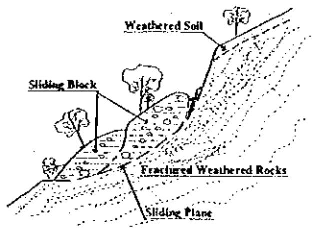
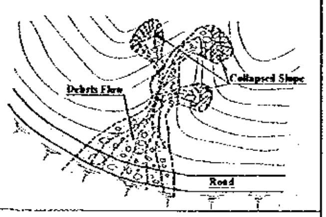
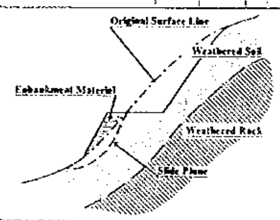
(5) Debris Flow (DF)

Source area is upstream of road slope. Rapid flow of boulder, gravel, sand, silt clay mixed with big amount of water that is generated mainly generated by slope collapse and heavy rainfall. It flows down riverbed of over 20-degree gradient and stops to deposit under 10-degree gradient riverbed.

(6) Embankment Failure (EB)

All type of slope failure such as slump or collapse of slope, settlement of road surfaces by various causes, scouring of toe part and so on.

Table 2.7.1 Characteristics of Six Slope Failure Types

FAILURE TYPE (Inspection Sheet to be applied)	**Characteristics**	**SCHEMATIC ILLUSTRATION**
1. Collapse (CL)	- Collapsing materials are residual soils and highly weathered or jointed rocks. - Prone to occur on steep slopes. - Mostly triggered by rainfall infiltrating - Similar to slump failure in some cases. - Size is generally less than1,000 m^3	
2. Rock Fall (RF)	- Free fall or rolling down hard rocks and boulders in the slope. - Occur on steep slope and cliff. - Falls occur due to gravity and are controlled by the distribution of joints. - Size is generally less than 5 m^3.	
3. Rock Mass Failure (RM)	- Materials are hard jointed rocks. - Failure modes include wedge slide, plane slide and toppling. - Size is generally more than 2-3 m^3.	
4. Landslide (LS)	- Materials are clayey soils and highly weathered rocks. - Marked by topographic features that is gentle and deformed -Chiefly influenced by increased pore-water pressure by infiltration of heavy rainfall. -Size is generally more than 5,000 m^3.	
5. Debris Flow (DB)	- Rapid flow of boulder, gravel, sand, silt and clay mixed with big amount of water. - Occurs in a contributory areas that contains collapsible slopes	
6. Embank-ment Failure (EB)	All type of slope failure in embankment - Slump or collapse of slope, - settlement of road surface - Scouring of toe part	

2.7.3 Mechanism of Slope Failure

Many factors influence the development of slope failures as listed in Table 2.7.2.

These factors influence either to increased shear stress or to reduced shear strength for each failure type.

Table 2.7.2 Factors of Slope Instability

Type		Typical factors
Increase of shear force	1. Removal of lateral support	- Stream, rainfall water, sea wave, or glacial erosion - Weathering, wetting drying, and frost action - Slope gradient increased by slope failures, uplift of land, volcanic activity - Artificial soil work: Quarries, pits, cutting, etc.
	2. Overloading	- Weight of rainfall infiltration, snow, new talus deposit, failure mass - Embankment structures
	3. Transitory stresses	- Earthquake - Vibration
	4. Lateral pressure	- Pore pressure in cracks, fissures, etc. - Freezing of water - Swelling by hydration of clay and clay minerals
Reduction of shear strength	1. Reduction of strength	- Weak and sensitive materials such as volcanic tuff and sedimentary clays - Easily weathered or jointed materials such as mudstone, shale, and granitic rocks - Loosely consolidated materials such as failure mass, talus - Easily liquefied materials such as sand or silt deposits
	2. Physico-chemical reaction	- Cation exchange - Hydration of clay - Drying of clays
	3 Vegetation	- Removal of tree, reducing normal loads and apparent cohesion of tree roots

(1) Collapse (CL)

Soils susceptible to large decreases in bulk volume when they become saturated are prone to collapse. Residual soils forms collapsible grain structure as a result of leaching of soluble and colloidal material. Soils in this structure contains little amount of clay minerals and having little or no cohesion, which prone to collapse.

Malaysian federal roads are often encountered residual soils of granitic rocks, schistose rocks, and sedimentary rocks. Rock forming minerals in these rocks are often changed chemically to soluble clay minerals under tropical climate, which leach out from the soil to form collapsible structure. (Figure 2.7.1)

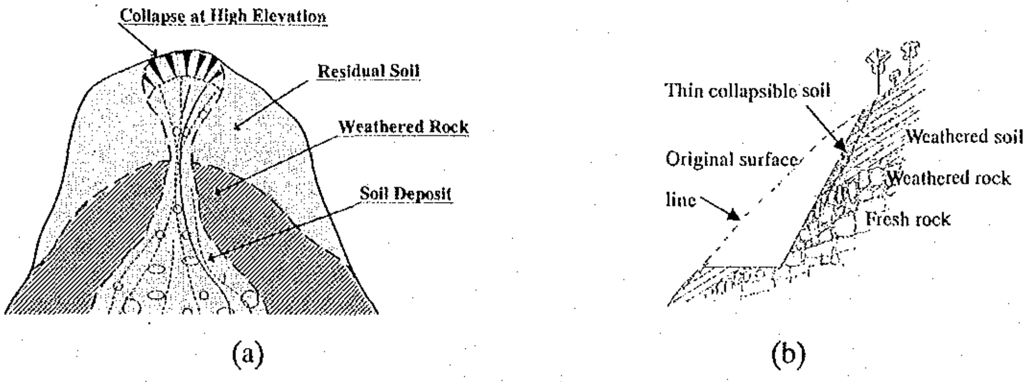


Figure 2.7.1 Collapse of Residual Soil

In addition to this microstructure of soils, relict structures in the slope (relict fault/sheared zone, joint, foliation, and bedding) makes it loose and permeable. Heavy rainfall can easily saturate openings of soils and slope to cause slope collapse. (Figure 2.7.1)

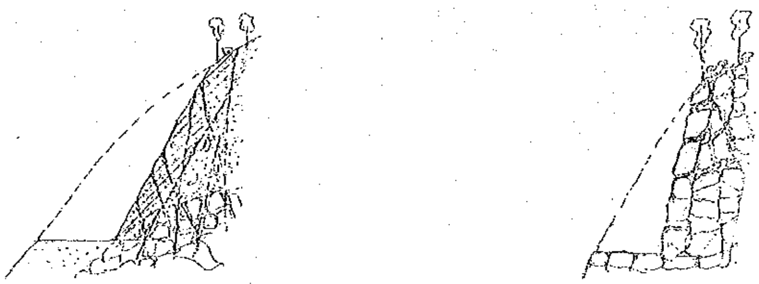


Figure 2.7.2 Collapse in Loose Jointed Structure

The mode of failure seems like slump. But it is considered that most failures is collapse. The following items are important in evaluating the probability of collapsing.

(a) Soils are collapsible or not
(b) Existence of relict structure and firmness of slope

(2) Rock Fall (RF)

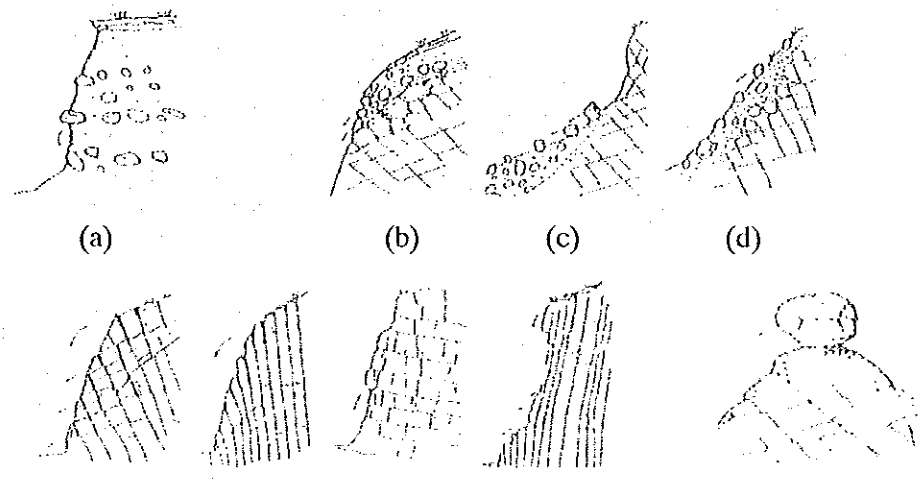
Rock fall is a free or rolling down of detached rocks from a steep slope or over hanging cliff. Rock fall of slope happen mainly under the following conditions.

(a) Over hanged or steep hard rock slope (over 50 degree) where many discontinuity developed. (Figure 2.7.3 (a), (b), (e) to (h))

(b) Deformed slope planar, daylight wedge or toppling, where unstable rocks are produced. (Figure 2.7.3 (e) to (h))

(c) Rather gentle slope (under 45 degree) where fresh and hard boulders are exposed. (Figure 2.7.3 (c), (d))

Many high cut slopes over 30m had been made in federal roads of Malaysia under that natural slope gradient range of 30 to 40 degrees. Gradient of cut slopes is generally 45º but in hard rock area slope angle are often constructed over 60 degrees. In these unstable rocks had fell down or been removed in the construction stage. But action of nature like gravity, weathering under the tropical climate, flowing out of material along discontinuity generates new unstable rock.



(a) (b) (c) (d)

(e) (f) (g) (h) (i)

Figure 2.7.3 Image of Rock Fall

In the deformed slope by slide or toppling, rock masses near the surface are always unstable. Under these conditions, frequent rock fall may happen in the rainy season.

One more type of rock fall is rolling down of fresh core boulders that get rid of weathering and remain in the residual soils. This type of rock fall occurs mainly in the granitic rock area. (Figure 2.7.4)

Rock fall in the residual soils in granitic rock areas. In these areas, heavy rain easily erode soft residual soil and make core boulders unstable. This type of rock fall is found typically in mountainous areas along Penang Road.

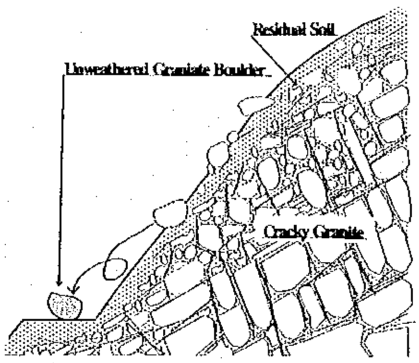


Figure 2.7.4 Rock Fall in the Residual Soils

(3) Rock Mass Failure (RM)

Planar rockslide, wedge rockslide, and toppling are large-scale rock slope failure, which are classified as Rock Mass Failure because the main instability factor of these rock failures is geological structure.

Planar rock slide and wedge rockslide occurs in the same kind of mechanism that is dip side slide on the one or intersecting discontinuity plane of rock. High and steep cutting exposes many 'daylight' planes and rock masses become unstable. On the other hand, toppling is the forward rotation out of the slope mass of rock about a point or axis below the centre of gravity of the displaced mass. In the schistose rock flexural toppling may occur. This is the phenomenon of rock slope in which continuous columns break flexure as they bend forward.(Figure 2.7.5 to 2.7.7)

Federal roads in Malaysia, rock mass failures are mainly found in the East-West Highway that has many high cut rock slopes.

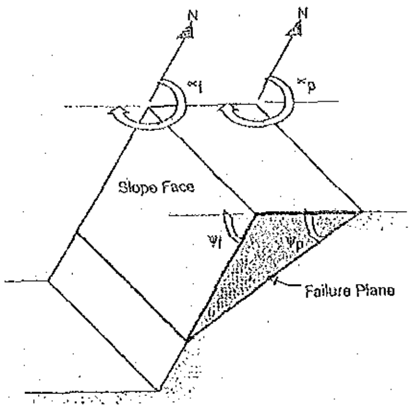


Figure 2.7.5 Image of Planar Slide

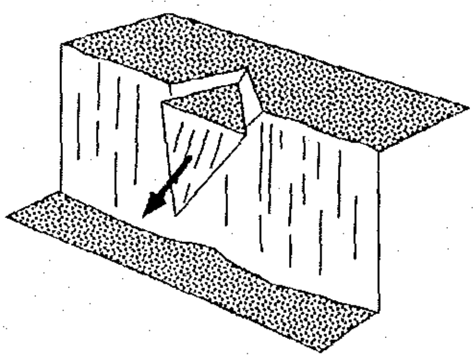


Figure 2.7.6 Conceptual Diagram of Wedge Block

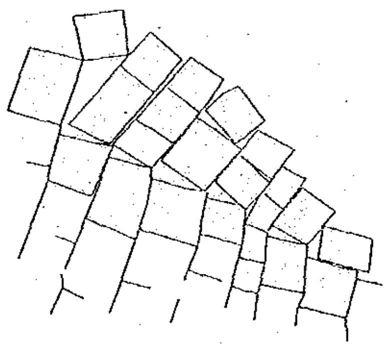


Figure 2.7.7 Schematic Diagram of Toppling

(4) Landslide (LS)

Generally, rock mass failure mentioned in the former section is also defined to "landslide". But in this study for road disaster management, landslide is defined as "a big mass movement of highly weathered rocks, debris or soils slide down a slope". Schematic block diagram is shown in the Figure 2.7.8 after Varnes (1978). Landslide is big slope failure having slip surface that had been generated in the process of geomorphic history.

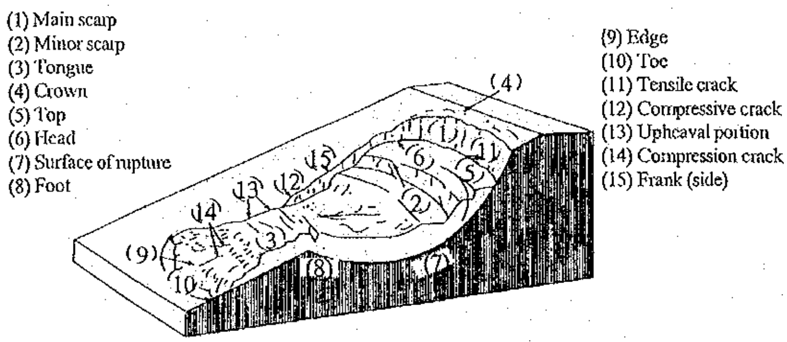


Figure 2.7.8 Schematic diagram of landslide(after Varnes,1978)

Slopes in landslide area show characteristic topography resulting by movement and deformation as listed below. (More detailed description is in the "Guide II Slope Inspection" Chapter 3.)

(a)Disturbance of contour line, (b) Set of slope- gentle slope-steep slope,
(c)Pond, swamp or marsh on a linear line, (c) Vanishing or detouring of small valley,
(d)Upheaval or swelling of slope, (e) Unusual meandering of river
(f) Evidence of movement or deformation

Stability of landslide material on a slip surface is defined in following Safety Factor (FS).

$$Fs = \frac{(\Sigma N - \Sigma U) \times \tan\phi + C \times \Sigma L}{\Sigma T}$$

Fs: Safety Factor
N(kN/m) : Normal force attributable to gravity of slice,
N=W · cos θ
T(kN/m) : Tangential force attributable to gravity of slice,
N=W · sin θ
θ (°) : Angle of the base of slice to the horizontal .
U(kN/m) : Pore water pressure acting on the base of slice
L (m) : Length of sliding surface acting on the slice
C(kN/m^2) : Cohesion of sliding surface
ϕ (°) : Internal friction angle of sliding surface

In this stability concept, following matters are considered as acceleration factors that lead a road slope unstable.

(a) Cutting of toe part of landslide slope (reduction of normal force, N; Figure 2.7.9)

(b) Banking of head part of landslide slope (increase of tangential force, T; Figure 2.7.10)

(c) Rising of water level (increase of water pore pressure; U)

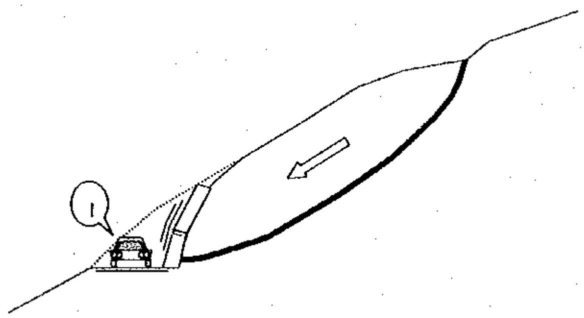


Figure 2.7.9 Cutting Toe part of Landslide

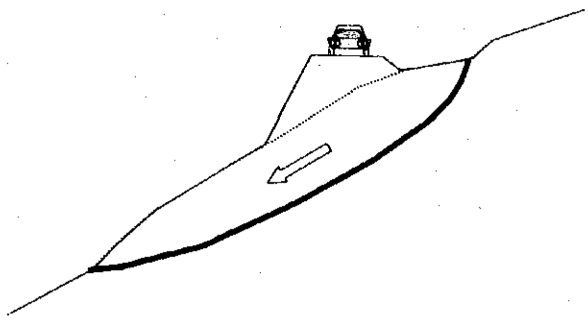


Figure 2.7.10 Embankment on Head Part of Landslide

As the landslide slope is gentle, roads in the mountainous region often pass through landslide slopes. Cutting of toe or loading of upper part of landslide makes unstable conditions for the slope.

(5) Debris Flow (DF)

Debris flow is a phenomenon in which soils and boulders involved in the water flow down along valley. Followings are general condition to generate debris flow.

(1) Slope collapse by heavy rainfall in the steep valley
(2) Collapsing of natural dam that formed by debris temporary
(3) Flow down of clayey landslide
(4) Flow down of riverbed material by big amount of flood

Figure 2.7.11 shows a schematic plan of debris flow. Debris flow is preceded by collapse or slide in the slopes of contributory area in that river gradient steep. And collapse soils are brought down mixed with water.

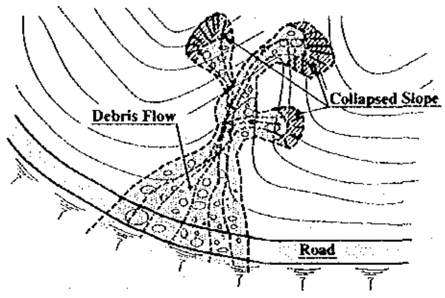


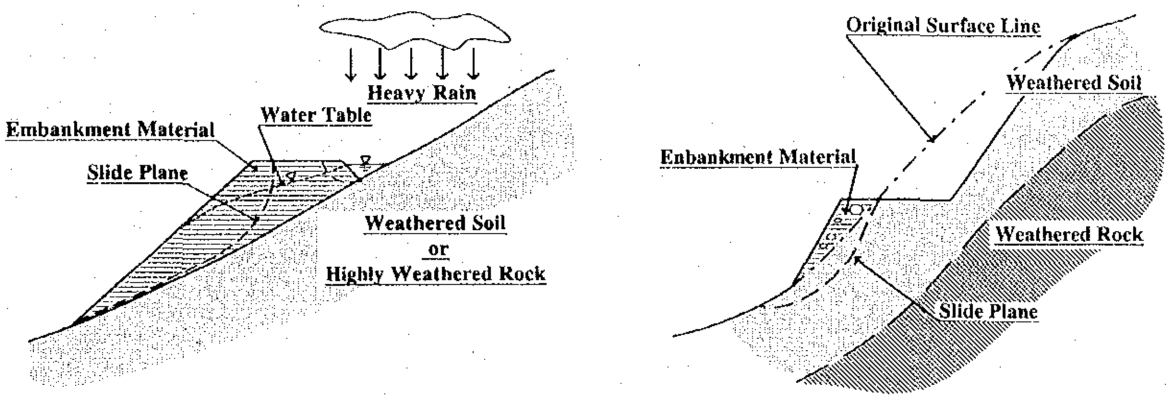
Figure 2.7.11 Schematic Plan of Debris Flow

In Japanese experience, debris flow occurs in the river bed gradient over 15 degree and stop to deposit in the riverbed gradient between 3 to 10 degree.
Debris flow is not so common in federal roads in Malaysia that slope condition is stable covered by natural forest. But, some debris flow was found in the Penampang-Tambnan-Keningau Road. In the future, debris flow may increase according to development of hilly region.

(6) Slope Failure of Embankment (EB)

There are two types of embankment in the federal road in mountainous area;

(a) River crossing embankment
(b) Embankment on the down slope



(a) River Crossing Embankment (b) Embankment on the Down Slope

Figure 2.7.12 Type of Embankment

(a) River Crossing Embankment

In case of the river-crossing embankment, dam up by heavy rainfall generates critical conditions for the embankment that is cased often by short of cross section of the culvert. When the entrance of culvert can not guard the toe of slope, the river scours the slope. And when the length of culvert is short, the river also scours the slope. These conditions of culvert make slope unstable and lead to final slope failure.

(b) Embankment on the Down Slope

Embankment on the down slope is difficult to make slope standard gradient, 1:1.6 to 1:2.0 that is because natural slope in mountainous terrain is steeper than standard gradient of embankment slope in Malaysia. Embankment without treatment for this problem has cause to be unstable.

Source:

- Landslide-investigation and management, 1996; A.Keith and Robert L Schaster, Transportation Research Board ,USA
- Prediction and countermeasure of soil disaster, 1996; Geotechnical Society of Japan
- Proceeding for National Slope Seminar, 2001; JKR,Malaysia