

# **GROUND FAILURES IN SOUTHEAST ASIAN COUNTRIES**

by

**Z.C. Moh, W.S. Guo and C.T. Huang**

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GROUND FAILURES IN SOUTHEAST ASIAN COUNTRIES

Z.C. MOH, W.S. GUO and C.T. HUANG  
Moh and Associates Group  
Malaysia, Singapore, Taiwan

**ABSTRACT** Ground failures occur in many different modes. Landslide is the most common type of ground failure which may occur due to natural processes or man-made activities or their combinations. With the exception of some large deltaic plains, a large proportion of land area in Southeast Asia is hilly and mountainous. Warm, wet climatic conditions, and sometimes augmented by seismic activities are often responsible for landslide occurrence in the region. Due to the large variation in the properties of residual deposits and the complex geological conditions, many highways in mountainous terrain in Southeast Asian countries were constructed without applying geotechnically satisfactory design procedures but by judgement and precedents. Many slopes have failed and many others are unstable. These resulted in large maintenance commitment, inconvenience, traffic disruption and even safety. This paper describes a qualitative assessment approach for categorizing slopes for hazard mitigation adopted for two highways crossing mountainous terrains in Malaysia. The approach is extended and a quantitative rating system is established for the Central Cross-Island highway in Taiwan.

INTRODUCTION

Ground failures occur in many different modes and result in damage to constructed facilities such as structures and transportation routes, and safety hazard to mankind. The most commonly occurring ground failures are slope failures (or landslides), ground subsidence, and excessive settlement or loss of ground. The occurrence of a ground failure and the extent of failure are controlled by the inherent characteristics of the ground and

and the external factor which motivates or triggers the failure. The geology, nature of soil and rock formation, geomorphology (landform and topography) and slope condition (height, gradient, vegetation, etc) are the basic inherent characteristics. Ground movements or failures are usually brought up by certain external factors. The most notably ones are change in the stress condition acting on the ground, and change in the hydrometeorological environment. The former includes loading due to filling, unloading due to cutting or excavation, and dynamic loading due to seismic activity. The latter involves change in the porewater pressure in the soilrock-formation, movement of surficial and underground water. These external causes can be the result of either natural processes or very frequently due to man-made activities. This paper deals with only the first type of ground failure, i.e. slope failure or landslide.

#### LANDSLIDE PROBLEMS IN SOUTHEAST ASIA

The Southeast Asian archipelago has been described as being physiographically and geologically the most complex area in the world. It covers a total land area of about 3.2 million sq km and a population of over 300 million. With the exceptions of some large deltaic plains, the majority of the terrain of the land areas of Southeast Asian countries is hilly or mountainous. The mainly warm, wet climatic conditions have resulted in varying depths of weathering of a wide variety of igneous, metamorphic and sedimentary rocks. The region experiences high seasonal rainfalls, sometimes in excess of 4,500 mm annually with intensities that can exceed 150 mm per hour. In addition, a large part of the Southeast Asian region is in the Pacific earthquake belt which runs through Indonesia, Philippines and Taiwan. Several countries including Indonesia, Philippines, Taiwan and Hong Kong are also under the influence of typhoons. Landslides in these countries are often associated with these two natural hazards.

BRAND (1984, 1985) made a comprehensive review of the State-of-the-Art of landslide situation and their control in the Southeast Asian region. During the past one and one-half years, since the publication of Brand's paper, there are not much newly published literature on the subject relating to this region. Majority of the unpublished reports deal with remedial measures or improvement of specific slide failure. These work

are usually well designed based on geotechnical principles and employing advanced techniques such as the use of horizontal drain systems, rock anchors, bolts, etc. In so far as the State-of-the-art of landslides is concerned, the overall assessment made by BRAND in 1985 as shown in Table 1 is still more or less valid.

Table 1 Significance of Landslides in Southeast Asian Countries

Country	Area (sq. km)	Population (millions)	Significance of Landslides	Volume of Relevant Literature	Assessed State-of-the-art of Landslide Prevention & Control
Singapore	580	3	Low	Moderate	Moderate
Thailand	513 517	48	Moderate	Low	Low
Sri Lanka	65 610	15	Moderate	Low	Low
Malaysia	330 669	15	Moderate	Moderate	Moderate
Philippines	299 765	52	High	Very Low	Very Low
Taiwan	35 980	18	High	Moderate	Moderate
Indonesia	1 919 263	157	Very High	Low	Low
Hong Kong	1 050	6	Very High	Very High	Very High

In this paper, three case records of landslide mitigation for mountainous highways are described.

#### LANDSLIDE MITIGATION STUDY FOR MALAYSIAN HIGHWAYS

Malaysia is a country which is physically divided into two distinct parts. West Malaysia, commonly referred to as the Peninsula Malaysia, has a land area of about 130,000 sq km and a population of about three-fourth of the entire country. The low lying coastal areas on the east and west of the peninsula are separated by a central spine of hills generally less than 500 m high but rising in thin ribbons as high as 2,000 m. The geology is complex (Fig. 1). Two granitic intrusions into the sedimentary rocks essentially form the high relief. The rocks are generally very deeply weathered with considerable thicknesses of residual

soils covering the terrain. The climate in the country is hot and wet with an average annual precipitation of about 3,100 mm on the east coast and 2,500 mm on the west coast. Rainfall intensities can reach more than 100 mm per hour.

In the mountainous regions of West Malaysia, landslides in natural slopes are fairly common. A large number of slides take the form of shallow slides. Surface erosion has been one of the major causes of slides of steep slopes. Due to the large variations in the residual materials from the geological and weathering points of view, it is generally difficult to apply satisfactory slope design procedures, engineering judgement and precedent experience have been heavily relied upon for the determination of cut slope angles for road construction. Two of the major highways in West Malaysia, the East-West Highway and the Kuala Lumpur - Karak Toll Highway have suffered numerous slide failures. They represent a continuing heavy commitment for maintenance and substantial economic losses and inconveniences due to disruption of traffic. Although no major casualties be recorded, threat to the safety of road users has always been a major concern to the authorities. Since 1983, the authors' firm has been responsible for the study and design of slope improvement works to mitigate landslide hazards on these two highways (MOH AND ASSOCIATES, 1983A, 1983A - 1984, 1985, 1987) in conjunction with the Malaysian Thai Development Sdn Bhd.

### East-West Highway

The 116 km long East-West Highway linking Kampong Jeli in the east (Kelantan state) and Grik town in the West (Perak state) is the only road connection in northern Peninsula Malaysia (Fig. 1). The highway has greatly facilitated the previously long journey between the Kota Bharu on the east and Penang on the west coasts by shortening distance considerably from 1,037 km to 363 km. The highway passes through territories near the Malaysia border to Thailand and was a remote jungle classified as security area by the Government. Construction commenced in 1969 even before designs were made. Detailed survey and geological/geotechnical investigations were severely limited by security problems.

The alignment of the Highway rises from approximately El 100 m to El 1,050 m at the highest point on the main mountain range at about mid-way

of the route. About 25% of the whole length of highway traverses through mountainous terrain amidst dense forests. Because of security reason, the option of constructing long viaducts over deep valleys or tunnels through mountains were categorically ruled out. Construction of this Highway were essentially limited to earthworks. A total of 27.5 million cu m of earth were moved. At the high points, earthwork averaged 1.5 - 2.5 million cu m per mile, resembling a series of high embankments connecting the mountain saddles. (HENGCHAOVANICH, 1984). In the course of construction which took a period of about 12 years, a number of slope failures have occurred. After opening the Highway in 1982, severe erosions were observed to take place at a number of high-fill embankment slopes. In the monsoon season of 1983/84, a large number of failures took place on both embankments and cut slopes. These failures have caused severe disruptions to traffic and endanger the safety of highway users. Besides those slopes which were redesigned and reconstructed, over 500 fill and cut slopes were required to be examined.

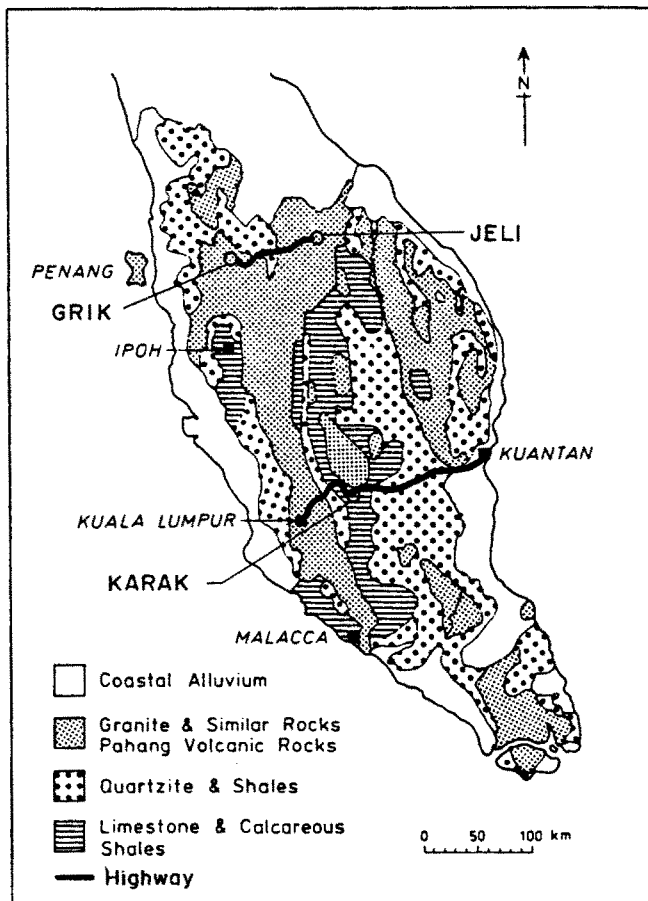


Fig. 1 Geology of West Malaysia

		Potential of Slope Failure				
		Failure due to occur or have occurred	Failure most likely to occur	Failure likely to occur	Failure may occur	Failure not likely to occur
Risk to Road Usage	Highest	Ia	Ib	II	III	IV
	High					
	Medium					
	Low					

Fig. 2 Qualitative Categorization of Slopes

## Kuala Lumpur - Karak Highway

The Kuala Lumpur - Karak Toll Highway is a part of the overall Federal Route II which is the major east-west link in the Central part of Peninsula Malaysia passing through the capital of the country (Fig. 1). The Highway traverses through varied terrains ranging from flat land to rolling, rugged and mountainous. The construction of the 49 km stretch of the Highway in mountainous and hilly region was characterized by deep cuts with height exceeding 60 m and fills reaching 24 m high. Construction of the Highway was started in 1975 and the final stretch was opened to traffic in the latter part of 1979.

About seven years after the opening of the Highway many of the high cut slopes started to have erosional and stability problems which became progressively more serious. Frequent slides of slopes along this busy highway during rainy days imposed serious inconveniences as well as safety problems. A total of 166 slopes including both cut slopes and fills were identified as problem slopes which could be potentially unstable.

### Slope Categorization

To cope with the vast number of slopes, some of which may be potentially unstable and some have already failed, a qualitative categorization system was adopted (MOH and WOO, 1986). Categorization of the slopes is based on the potential of failure of the slope (or instability) and the risk to road usage if failure occurs. The degrees of potential of slope failure are categorized as follows :

- A) Failure is imminent or has already occurred
- B) Failure is most likely to occur
- C) Failure is likely to occur
- D) Failure may occur
- E) Failure is not likely to occur

The degrees of risk to the usage of the highway are classified as follows :

- a) Highest - complete or substantial loss/blockage of access
- b) High - partial loss/blockage of access

- c) Medium - minor blockage of access or damage to appurtenant road structure up to the limit of the carriageway
- d) Low - effect, if any, would be inconsequential

Based on these two factors, the slopes can be classified into the following five categories as shown in Fig. 2.

Category Ia - Instability of slope is highest and risk to road usage is imminent. Slope requires immediate rectification.

Category Ib - Blockage or loss of the road access is impinging. Slopes require immediate attention.

Category II - Danger to road is adherent. Slope requires moderate improvement work.

Category III - Danger to road is implicit. Slope requires monitoring.

Category IV - No danger or road blockage. Slope improvement work, if any, would be minimal.

Assessments of degree of potential of failure of the slopes are made on the basis of information collected from desk study, field reconnaissance, geomorphology and geological appraisal, and hydrological appraisal. All available information including topographic map, aerial photographs, geological maps, rainfall records, design and construction plans of the slopes, past records of failure and rectification work form essential parts of desk study. Field reconnaissance examines and records physical features of the slopes, (including height, gradient, surface conditions and signs of failure), surface geology (including rock outcrops, discontinuities, beddings, weathering state, grain size, lithological characteristics, signs and extent of seepage), conditions of water courses, and other physical conditions which may affect the stability of slopes.

After carrying out geological, topographical and hydrological appraisals, qualitative assessment and rating of the degrees of failure potential of the slopes are then made. Degree of risk of a slope failure

to the road usage depends primarily on the location and geometry of the slope in relation to the roadway, and traffic volume.

On the basis of this categorization system, a total of 590 slopes including 300 fill slopes and 290 cut slopes, along the East-West Highway were examined and classified. Nineteen slopes were found to belong to Category Ia, 70 in Ib, 140 in II, 102 in III, and 259 in IV. For the KL - Karak Highway, among the 166 slopes examined, twenty slopes are in Category I, 46 are in Category II and the remaining 100 in Category III.

Detailed geotechnical investigations were carried out for all Category I slopes. Improvement or rectification works were then performed in accordance with geotechnical design principles.

#### SLOPE MAINTENANCE CONTROL SYSTEM FOR TAIWAN HIGHWAY

The Central Cross-Island Highway (Highway No. Tai-8) is the main road system connecting the less developed eastern part with the more populated western part of Taiwan. The highway also serves as the main traffic artery to two important multi-purpose water reservoirs. In addition, there are many scenic locations along the highway which attracts a great number of tourists from both local and abroad. The highway plays a very important role in the economic development of the eastern region of the island.

Ever since its completion and open to traffic in 1960, the 189 km long Central East-West Cross Island highway has suffered numerous disruptions to traffic and enormous economic losses due to slope failures and landslides. Road safety to human life is another important effect of great concern. In 1986, Moh and Associates was commissioned by the Taiwan Highway Bureau to establish a Slope Maintenance System for this important highway.

The study covers three sections with a total length of about 59 km which is about one-third of the total length of the Central Cross-Island Highway. The terrains in all three sections are of typical Taiwan mountainous terrain with very steep sideslopes, complicated geological structure, meandering river course, deep valleys and steep river beds.

However, the geomorphology and geological conditions in the three sections are quite different. Figure 3 shows the general geology of Taiwan and the location of the Highway.

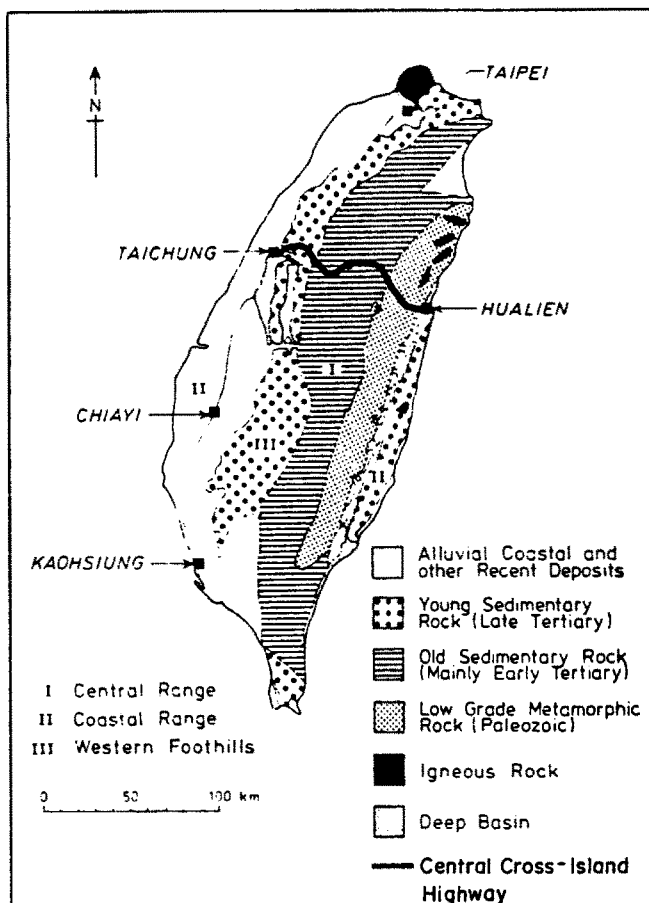


Fig. 3 Geology of Taiwan

### Site and Geological Conditions

The Kukan-Techi Section covers the area from Station 41k + 250 to 62k + 140 of Highway Tai 8 and 0k + 000 to 16k + 640 of Highway Tai 8A. It is situated on the western flank of the Central Mountain Range with elevation ranging from 1,000 m to 1,500 m above the mean sea level. The terrain has an average gradient of about 30 to 40 degrees. Due to construction and widening of the highways, most of the side cut slopes are very steep, in the order of about 70 degree or more. The outcrops along the section are mainly Tertiary sub-metamorphic rocks with metamorphism increasing in an eastward direction. The geological structure in the area is very complex with many colluvial deposits. Rock type varies from hard shale, interbedded shale-sandstone, and sandstone. Small fracture and fault

zones are often visible on the cutslope faces. Figure 4 shows the complex geology along a short section of the Highway.

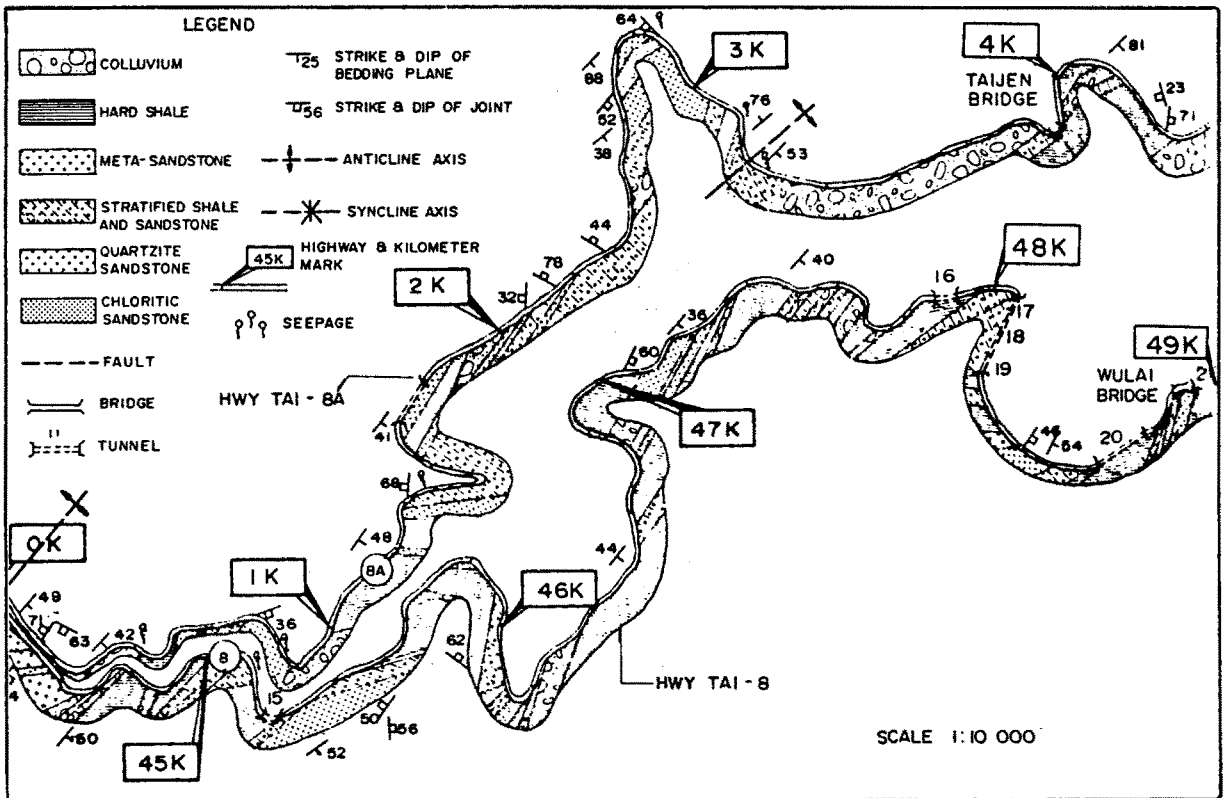


Fig. 4 Geology along a section of the Cross - Island Highway

The Yunhai Slide Zone is located near the ridge of the Central Mountain Range. The top of the old slide Zone is at El 2,300 m with the toe at about El 2,100 m, with a general gradient of about 40 degrees. The area has been developed as fruit orchards but with relatively poor soil conservation. The highway section in this Zone is mainly constructed on colluvial deposit of slate origin. The slate has well developed joints and are easily softened by rain water. Continuous movement of the cut slopes has been observed during every rainy season which has caused serious settlement of the road foundation.

The third section covers the area from Tayuling to Tzuen (Highway Tai 8 Sta. 112k + 400 to 133k + 000), and situates on the eastern flank of

the Central Mountain Range. The highway runs from El 2,600 m to 2,000 m with side slopes between 30 and 40 degrees. The major rock formations along the route are Tertiary sub-metamorphic and Pre-Tertiary metamorphic rocks with increasing metamorphism in a west to east direction. Colluvial deposits, phyllites, meta-sandstones, interbedded sandstones and phyllites, chloritic schists, and meta-calcites are found at different locations.

### Types of Hazard and Past Records

Due to restriction of the topography, complex geological condition, and more importantly, economic constraint, the Central East-West Cross-Island Highway was constructed without proper engineering design. A major part of the roadway was constructed by direct excavation or cut into the steep natural slopes.

Landslide or slope failure may be classified or categorized in accordance with the pattern of movement, speed of movement, morphology of the sliding area materials involved in the slides or causes responsible for the slides. The Taiwan Highway Bureau adopts the system proposed by the U.S. Highway Research Board (1958) classifying land movements into 5 main categories on the basis of slide movement pattern. They are falls, topplings, slides, flows and complex. These failures can occur in either rock, or soil deposit or its combinations. In the three sections of the Cross-Island Highway being studied, rock falls, movement of old slide zones and debris flow are the most commonly occurred ground movement. Figure 5 shows schematic illustrations of these three modes of ground failure. Rockfall involves the movement or falling of individual pieces of rock, boulder or block of soils. Usually these pieces exist in a metastable condition, they may fall without any pre-warning. Rockfalls are usually triggered by heavy rain storm or seismic activity. In many areas of the highway, the road was constructed on old slides which had attained temporary stability. Construction of the roadway has disturbed the ground formation and increased water infiltration which could lead to a reduction of stability. In area where good soil conservation has been carried out, the old slides formation are relatively stable. However, any further construction activity such as widening of the roadway, and destruction of the vegetation could lead to new failure.

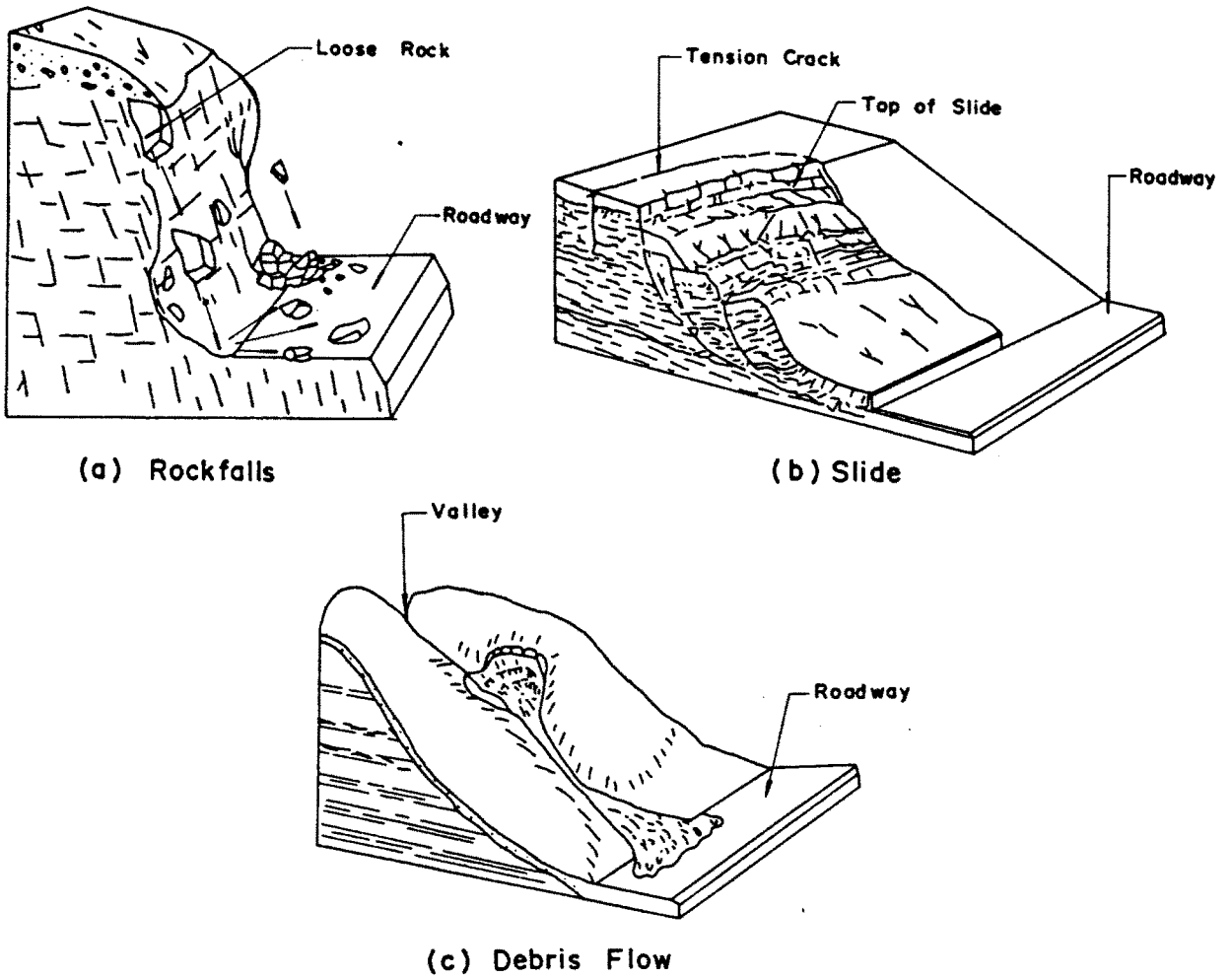


Fig. 5 Schematic Illustration of three most Commonly Occurred Types of landslide Along the Central Cross-Island Highway in Taiwan

Debris flow refers to movement of unconsolidated materials including rock fragments, cohesionless sand, cohesive soils and their combinations. As illustrated in Fig. 5 (c), debris flow usually does not have distinct sliding surfaces and are more surficial. The speed of movement is fairly rapid. They are commonly found in steep valleys after heavy rains. A thorough investigation was carried out in the three study areas to identify potential instability of the side slopes along the highway. Included in the investigation were landform, topography, geological condition, vegetation, existing slope protection measures, past hazard records, and etc. A total of 388 locations were studied. Among them, rockfall (including some soil falls) has been identified as the most common type of potential hazard (Table 2).

Table 2 Statistics of Potentially Unstable Slopes,  
Cross Island Highway, Taiwan

SECTION HAZARD TYPE	Kukan - Techu Section		Yunhai Old Slide	Tayuling - Tzuen Section	Total
	Hwy Tai - 8 41 k + 250 62 k + 240	Hwy Tai - 8A 8 k + 000 16 k + 640	Hwy Tai - 8 95 k + 500 96 k + 000	Hwy Tai - 8 112 k + 400 133 k + 000	
Rockfalls	137	133	0	55	325
Old slides	0	0	1	17	18
Debris flow	22	17	0	6	45
Total	159	150	1	78	388

### Assessment and Rating of Potentially Unstable Slopes

Figure 6 (a) shows the flow diagram of processes involved in the slope assessment work. The assessment and rating of the 388 potentially unstable slopes were carried out following the flow diagram shown in Fig. 6 (b). Besides identifying the type of potential slope failure, two major factors are considered. They are potential of failure and hazard to road usage. Semi-quantitative ratings are introduced into the assessment in order to arrive at a final rating. The following sections describe briefly the methodology adopted for the recommended rating system.

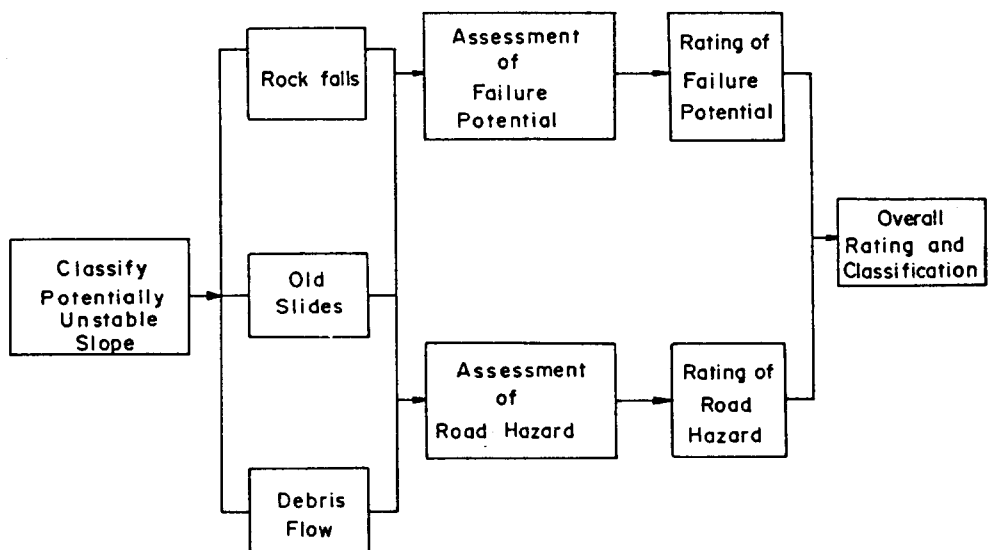
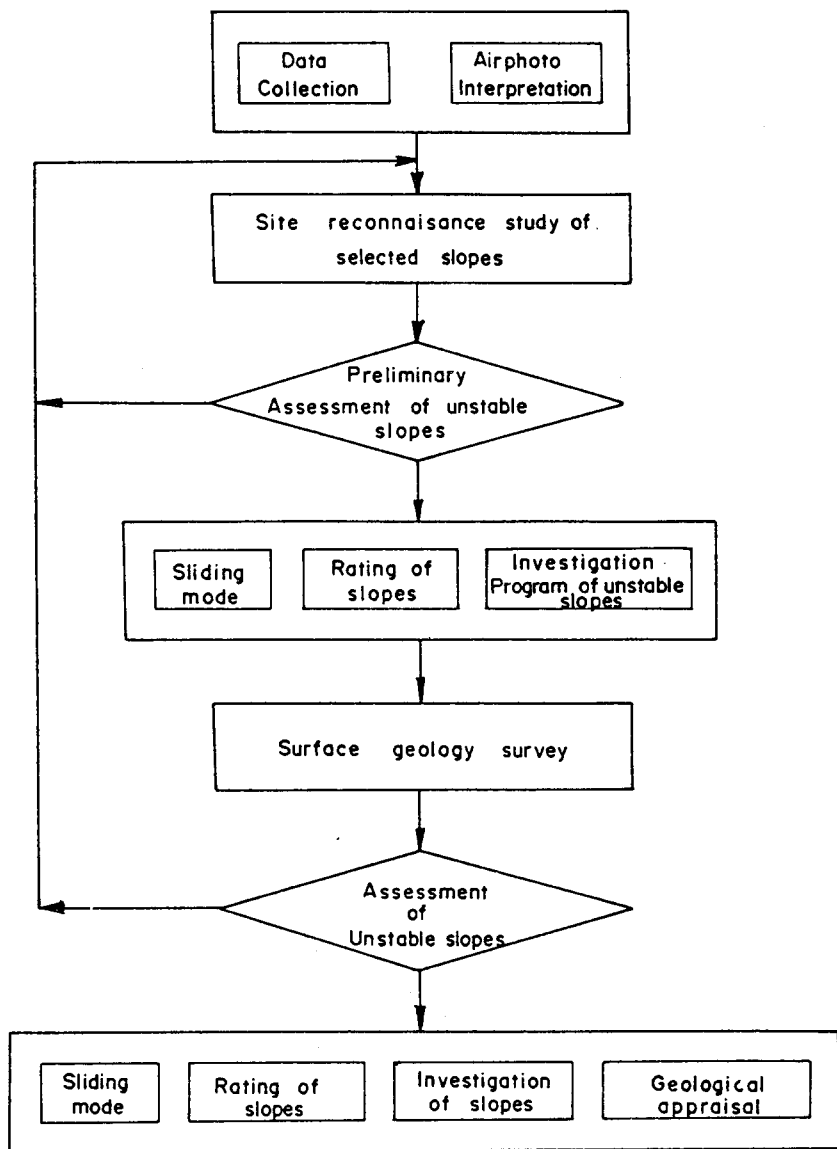


Fig. 6 Flow Diagram for landslide Assessment

## Assessment of Landslide Failure Potential

As pointed out in previous sections, occurrence of landslides depends upon both the inherent characteristics of the terrain and the external factors which often are the triggers for failure. The most important inherent characteristics of a terrain are topography and geology. In evaluating protective measures against rockfalls for their national highways, the Japanese Road Federation (1983) classified the two most important physical attributes of terrain topography, e.g. slope height and average slope gradient, into 4 classes each. When the average gradient is larger than 90 degrees, it is considered as overhang. The latter is also divided into 4 classes. When the vertical shadow of an overhang covers more than one-fifth the road, it is classed as "large". When the shadow does not cover the roadway, it is a "small" overhang.

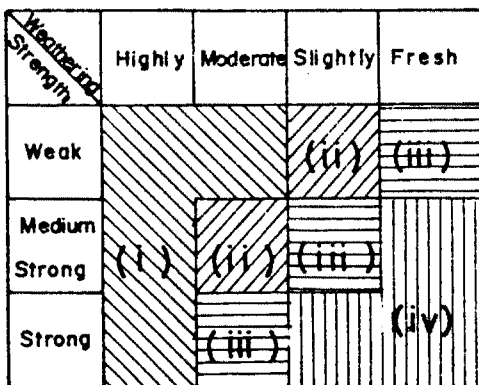
Rock strength, weathering intensity, conditions of joints, and degree of fracturing are the main elements of the geology characteristics which are considered in assessing potential of rockfall. Based on the interrelationship between rock strength and weathering intensity, the rock formation can be divided into 4 classes as shown in Fig. 7. Table 3 shows the classification of joint system and degree of fracturing in rocks. Besides the above inherent characteristics, the degree of stability of overhanging rocks on slope surface and the condition of vegetation are other factors included into consideration.

The most common external factors which will trigger rockfalls are seismic activity and water pressure. According to the seismicity zoning of Taiwan (HSU, 1975), all the three study areas belong to low seismicity. Therefore, seismicity is not considered as a separate factor for assessment.

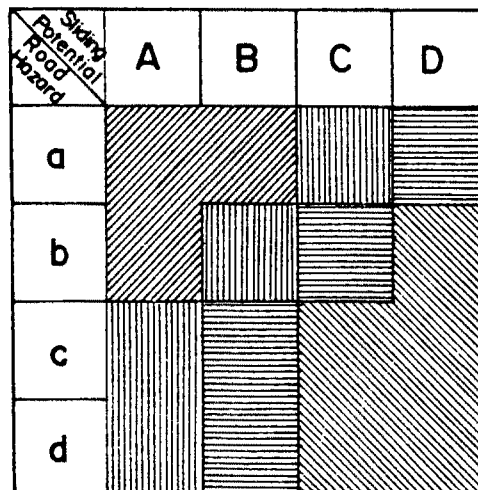
Water pressure can be caused by surface flow due to rainfall and/or underground seepage. According to the rainfall records in the Central Mountain Range, the rainfall factor is divided into 3 classes. When the annual precipitation exceeds 3,000 mm it is classified as "Heavy". For average annual precipitation less than 2,500 mm it is classified as "Light" and those in between as "Medium". Seepage of underground water is qualitatively classified as none, small, medium and large on the basis of observed quantity of seepage water on the slope surface.

Table 3 Classification of Joint System and Degree of Fracturing in Rocks

Class	Joints			Degree Fracturing
	Opening	Set & Distance, d	Continuity	
i	> 5mm or < 5mm with in-fill	> 2 sets d < 2 m	Cover more than 50% of slope surface	High
	< 5 mm	> 2 sets d < 20 cm	Cover more than 50% of slope surface	
ii	< 5 mm	> 2 sets d = 20-60 cm	Cover more than 50% of slope surface	Medium
	Closed	> 2 sets d = < 20 cm	Cover more than 50% of slope surface	
iii	< 5 mm	> 2 sets d = 20-60 cm	Cover more than 50% of slope surface	Low
	Closed	> 2 sets d = 20-60 cm	Cover more than 50% of slope surface	
iv	Others	Others		Intact



Note: Rock Strength and degree of Weathering Classifications after ISRM (1981)



▨: I    ▤: II    ▥: III    ▧: IV

Fig. 7 Rock Strength and Weathering Intensity

Fig. 8 Slope Maintenance Control Assessment Classification

By combining all the above attributes, a chart as shown in Table 4 is developed for assessing the potential of rockfalls. Similarly, charts for assessment of potential of failures due to old slides and debris flow are prepared. For old slides, slope gradient, slope length, vegetation, activity of the old slide, amount of rainfall and seepage water, and degree of land utilization are the main attributes to be considered. In addition to the above factors, length of water course is another attribute to be included in assessing debris flow type of failure.

Table 4 Assessment of Failure Potential in the Form of Rockfall

Topography	Slope Height	< 10m	10m - 30m	30m - 50m	> 50 m	4	Index			
		1	2	3	4					
	Ave Gradient	< 45°	45° - 60°	60° - 80°	> 80°	4				
		0	1	2	3					
	Overhang	None	Little	Medium	Large	5				
		0	1	2	3					
Geology	*Rock Strength and weathering	(iv)	(iii)	(ii)	(i)	3				
		0	1	2	3					
	Joints and Fracture **	iv	iii	ii	i	5				
		0	1	2	3					
Others	Stability of Loose rock on Slope Surface	None	Dangerous rock			Loose rock			10	
			Lit	Med	Many	Lit		Med		Many
		0	1	2	3	3	4	5		
	Vegetation	Dense	Medium		Scarce			2		
1		2		3						
External	Annual Precipitation	Light	Medium		Heavy			1		
		1	2		3					
	Groundwater Seepage	None	Small		Medium		Large	2		
		0	1		2		3			

\* Refer to Fig. 7

\*\* Refer to Table 3

## Assessment of Hazard to Road Usage

Hazards to road usage due to failure of side slopes along the roadway are mainly referring to the degree of blockage of the roadway for traffic movement and safety to road users. There are at least three major factors to be evaluated for assessment of potential hazard to road usage due to failure of unstable slopes. They are extent of effect of slope failure on the road, frequency of failure and traffic volume. The principle of assessment is summarized in Table 5.

Table 5 Assessment of Hazard to Road Usage due to Landslide

Size of Slide Failure	Small < 3 hectares		Medium 3-8 hectares		Large > 8 hectares	4	Weight Index
	1		2		3		
Effectiveness of Protective Measure	V. Good	Good	Fair	Poor	V. Poor	6	
	0	1	2	3	5		
Frequency of Failure	Low		Medium		High	3	
	1		2		3		
Traffic Volume	Light		Medium		Heavy	1	
	1		2		3		

- Notes : (1) Frequency of failure based on failure records from 1977 to 1986  
 High - more than 12 times  
 medium - between 4 to 10 times  
 Low - infrequent
- (2) Traffic volume rating :  
 Light - 800 passenger car unit per day  
 Medium - 800 to 1000 pcu per day  
 Heavy - more than 1000 pcu per day

## Quantitative Assessment of Potentially Unstable Slopes

Quantitative assessment of the potentially unstable slopes is carried out by using the following equation :

$$R = aW + bX + cY + dZ + \dots$$

(1)

where R is the assessed value of a particular slope, W, X, Y, Z ... are the assessment attributes and a, b, c, d ... are respective weight indices. In the process of quantitative assessment, a simple numbering system, from 1 to 2 and upwards (or starting from 0), is used to describe each assessment attribute.

For example, for rockfall type of failure, considering the assessment attribute of slope height, the lower the height the less is the effect on the potential of failure. Therefore, the numbering system for slope height is 1 for slope height lower than 10 m and 4 is assigned to slope height more than 50 m. The next important item being considered is the weight index. Since each assessment attribute has different degree of influence on the potential of failure or hazard on road usage, different weight indices varying from 1 to a maximum of 10, are first assigned according to judgement. By using Eq (1), the total assessed value of a slope can be obtained. By referring to Table 6, the assessed class or rating of the particular slope is determined. Table 7 presents the recommended weight indices for the two major factors in assessment.

Table 6 Slope Maintenance Control Assessment Classification

Failure Potential	Class	A	B	C	D
	Rockfall	$R' \geq 80$	$80 > R' \geq 60$	$60 > R' \geq 40$	$R' < 40$
	Old Slide	$R' \geq 70$	$70 > R' \geq 50$	$50 > R' \geq 30$	$R' < 30$
	Debris Flow	$R' \geq 70$	$70 > R' \geq 50$	$50 > R' \geq 30$	$R' < 30$
Road Hazard	Class	a	b	c	d
		$R'' \geq 45$	$45 > R'' \geq 35$	$35 > R'' \geq 25$	$R'' < 25$
Overall Assessment	Class	I	II	III	IV
		$R > 8$	$8 \geq R \geq 7$	$7 > R > 5$	$R \leq 5$

Notes :  $R'$  - Assessment value for failure potential  
 $R''$  - Assessment value for road hazard  
 $R$  - Overall Assessment. See Table 7

Table 7 Determination of Slope Maintenance Control Assessment Value

Failure	A	B	C	D	1.5	Weight Index
Potential(F)	4	3	2	1		
Road	a	b	c	d	1	
Hazard (H)	4	3	2	1		

Notes :  $R = (F) + (H)$

The physical meanings of each of the class are described in Table 8. Since this process of classification depends greatly upon the value of the weight index assigned to each attribute, and for preliminary assessment, the assignment is rather subjective. The preliminary rating or classification is then compared with and evaluated against the actual field condition. The values of the various weight indices are adjusted. By using a computer program, the process of comparison with actual field condition and adjustment of the weight indices is iterated until reasonable agreements between the field conditions and the classes determined from the proposed system of assessment are reached. The final values of the weight indices are as shown in Table 4. The classification system based on attribute assessments in Table 6 can also be represented by Fig. 7. By using the assessment system, the 388 slopes along the three sections of the Cross-Island Highway under study are classified. Twenty eight slopes are classified as Class I slopes which require immediate attention for more detailed investigation and design of preventive measures. Instrumentation monitoring and pre-warning system are recommended for some of the 47 Class II slopes. It is believed that this assessment system for potential landslide hazard can be extended to the entire mountainous highway system in Taiwan in order to ensure a good road transportation network and to reduce risks to safety.

Table 8 Physical Interpretation of Slope Assessment Rating

Potential of Failure	Road Hazard Due to Slope Failure	Overall Assessment
A. Failure imminent	a. Will cause major disruption	Slope unstable, immediate attention required
B. Failure likely	b. Will cause disruption	Slope unstable, improvement needed
C. Failure possible	c. May cause disruption	Slope appears stable, monitoring suggested
D. Failure not likely	d. Insignificant effect	Stable slope, occasional rockfall may occur

### CONCLUSIONS

A high proportion of the land area of Southeast Asia is hilly or mountainous and because of its position in the tropics, it suffers large precipitation with high intensity. Some of the countries in the region lies in the Pacific active earthquake zone. Heavy rain and seismic activity are the two major triggering factors caused by nature for landslide occurrence. Landslide occur in both natural slopes and man-made slopes. Cut slopes are notably the most hazardous. The large majority of them were never engineering designed but were simply formed on the basis of experience or empirical rules; this is especially true for road cuttings.

In Southeast Asia, due to rapid economic development, more and more highways are being constructed through mountainous and hilly terrain. Landslides or slope failures along these highways have significant consequence on the economy as well as safety. Proper engineering design of slopes become more and more important. However, for a highway extends many kilometers in mountainous terrain, it may be economically unfeasible to design all slopes with proper engineering methods. It will be of great practical value if the slopes can be categorized into different classes by taking into consideration the importance of risk to road usage and the degree of failure potential.

A qualitative slope categorization system has been adopted for the slope improvement work of two major highways in Malaysia. The system was further developed by incorporating quantitative ratings. This system is developed for maintenance control of a mountainous highway in Taiwan. To ensure economic and safe design, similar approach can be adopted for new highways.

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