Slope Assessment Systems: A Review and Evaluation of Current Techniques Used for Cut Slopes in the Mountainous Terrain of West Malaysia

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ABSTRACT

In Malaysia, slope assessment systems (SAS) are widely used in assessing the instability of slopes or the probability of occurrence and likely severity of landslides. These SAS can be derived based on either one particular approach or combination of several approaches of landslide assessment~~s~~ and prediction. This paper overviews five slope assessment systems (SAS) developed in Malaysia for predicting landslide for large-scale assessments. They are the Slope Maintenance System (SMS), Slope Priority Ranking System (SPRS), Slope Information Management System (SIMS), the Slope Management and Risk Tracking System (SMART), and the Landslide Hazard and Risk Assessment (LHRA). An attempt is made to evaluate the accuracy of these SAS in predicting landslides based on slope inventory data from 139 cut slopes in granitic formations, and 47 cut slopes in meta-sediment formations, which are the two most common rock/soil formations found in West Malaysia. Based on this study, it was found that none of the existing SAS is satisfactory for predicting landslides of cut slopes in granitic formations, for various reasons such as the use of a hazard score developed from another country, an insufficient data base, an oversimplified approach, and the use of data base derived from different rock/soil formations. However for the case of cut slopes in meta-sediment, the Slope Management and Risk Tracking System (SMART) was found to be satisfactory with a 90% prediction accuracy. The current database of SMART is largely based on meta-sediment formations from the Kundusang area of Sabah, East Malaysia.

KEYWORDS: Landslides, cut slopes, tropical soils, slope assessment systems, granitic formation, meta-sediment formation.

INTRODUCTION

Landslides have caused large numbers of casualties and huge economic losses in hilly and mountainous areas of the world. In tropical countries the annual rainfall, which can reach as high as 4500 mm, and high temperatures around the year cause intense weathering and formation of thick soil and weathered rock profile (Abdullah, 1996). With these set of climate and geological conditions, combined with other causative factors, landslides are one of the most destructive natural disasters in the tropical region. Malaysia is one of the countries located in the tropical region. During the period from 1993 to 2004 a number of major landslides were reported in Malaysia, involving fill and cut of natural slopes, which also resulted in loss of live. The summary of these landslides is shown in Table 1.

Table 1: Series of major landslide occurrences in Malaysia for the past decade and consequence in terms of loss of live

Date	Location	Type and Nature of Slope Failure	No. of Deaths	Notes
November 1993	Karak Highway, Malaysia	Shallow rotational slide. Failure of cut slope at the side of the highway occurred at dawn - buried a motorcycle with rider and its pillion	2	Cut slope in granitic formation
December 1993	Ulu Klang, Selangor, West Malaysia	Shallow rotational slide. Prolonged and heavy rain triggered retrogressive failure of cut slope behind the Highland Tower apartment building - toppled Block A	48	Cut slope in granitic formation
June 1995	Karak Highway - Genting Highland slip road, Selangor – Pahang border, West Malaysia	Debris flow. Failure of upstream natural dam during heavy rain triggered a ‘snowball effect’ debris avalanche	22	Natural slope in meta-Sediment formation
January 1996	Gunung Tempurung, Kampar, Perak, West Malaysia	Deep-seated rotational slide. Failure of cut slope (in spite of having been strengthened by anchor and guniting) at the side of North-South Highway	1	Cut slope in granitic formation
August 1996	Orang Asli settlement, Post Dipang, Kampar, Perak, West Malaysia	Debris flow from erosion and logging activities along upstream of Sungai Dipang occurred during heavy rain	44	Natural slope in granitic formation
January 1999	Squatters settlement, Sandakan, Sabah, East Malaysia	Shallow rotational slide. Heavy rain triggered landslide - buried a number of houses/huts	13	Natural slope in meta-sediment formation
January 2000	Vegetable farm, Cameron Highlands, Pahang, West Malaysia	Debris flow from upstream landslide and erosion washed away workers squatters	6	Vegetable farm on sloping land in meta-sediment formation
January 2001	Simunjan, Sarawak, East	Shallow rotational slide. Landslide occurred on vegetable farm - buried	16	Vegetable farm on sloping land in

Date	Location	Type and Nature of Slope Failure	No. of Deaths	Notes
	Malaysia	a number of houses at the toe of slope		meta-sediment formation
December 2001	Gunung Pulai, Johor, West Malaysia	Debris flow. Heavy rain triggered debris flow resulting in a number of small landslides along upstream of Sungai Pulai - washed away settlements along the river bank	5	Natural slope in granitic formation
November 2002	Hillview, Ulu Kelang, Selangor	Debris flow. Sliding/flowing of debris soil during heavy rain - toppled a bungalow at the toe of the hill	8	Dumping area of an abandoned project in granitic formation
September 2003	Gunung Raya Road, Langkawi, West Malaysia	Deep-seated rotational slides. Landslide triggered by heavy and prolonged rain - buried a heavy earthworks machine and its operator while clearing the debris.	1	Cut slope in granitic formation
November 2004	Taman Harmonis, Gombak, Selangor, West Malaysia	Debris flow. Sliding/flowing of debris soil from uphill bungalow project - toppled the back-portion of neighbouring down slope bungalow after week long continuous rain.	1	Dumping area of an ongoing project in meta-sediment formation
December 2004	Bercham, Ipoh, Perak, West Malaysia	Rock fall - buried the back portion of an illegal factory at the foot of the limestone hill.	2	Natural limestone cliff in karst formation
May 2006	Ulu Klang, Selangor, West Malaysia	Landslide due to collapse of retaining wall and retrogressive slope failures. Buried 3 blocks of long houses	4	Cut slope in granitic formation. The area is known to be highly susceptible to erosion.

The most common type of landslide~~s~~ in Malaysia is the shallow slide where the slide surface is usually less than 4 m deep and occurs during or immediately after intense rainfall (Ali Jawaid, 2000). These slides commonly occur in the residual soils mantles of grade V and grade VI according to the commonly used classification systems of Little (1969). Other types of landslides found are deep-seated slides, debris flow and geologically controlled failures such as wedge failures and rock fall. A slide is defined as the downward displacement or soil (or rock) sliding along one or more failure surfaces, rotational for the case of few units; translational for the case of many units (Varnes, 1978). Flows consist of the movement of slurry of soil and loose rocks down slope in a manner analogous to a viscous fluid. Falls are incidence of masses of rocks detaching from a steep slope and descending by free fall, rolling or bouncing. Figure 1 depicts some common landslide types found in Malaysia.

(a) (b)

(c) (d)

Figure 1: Some common types of landsides in Malaysia (a) Shallow slide, (b) Debris flow, (c) Deep seated slide (d) Rock fall.

Landslide assessment for the purpose of estimating the probability of occurrence and likely severity of landslides can be carry out by various methods, namely the statistical method, landslide inventory method, heuristic approach and deterministic approach (Varnes, 1984; Soeters & van Westen, 1996; Van Westen *et al*., 1997 and Hussein *et al*., 2004). Ali (2000), Rosenbaum *et al.* (1997) and Tangestani 2003) describe an attempt to use fuzzy set theory analysis, while Kubota (1996) and Yi *et al.* (2000) use fractal dimension, a mathematical theory that describes the quality of complex shapes of images in nature, in evaluating landslide hazards.

In Malaysia, at least eight slope assessment systems (SAS) that have been developed over the last ten years. Five of these SAS, all meant for large-scale assessment, namely the Slope Maintenance System (SMS), Slope Priority Ranking System (SPRS), Slope Information Management System (SIMS), Slope Management and Risk Tracking System (SMART) and Landslide Hazard and Risk Assessment (LHRA) are described in this paper. The first four SAS i.e. SMS, SPRS, SIMS and SMART were developed by the Public Works Department (PWD) of Malaysia (PWD, 1996; Hussein *et al*., 1999; JICA & PWD, 2002 and PWD, 2004). The fifth SAS i.e. LHRA was developed by Fiener (1999). Large-scale assessment refers to the use of maps of scales between 1:5,000 and 1:15,000. Despite the enormous effort made to develop the SAS, no attempt has been made to date to validate the accuracy of any of these SAS in predicting the likelihood of landslides (slope failures). The accuracy or reliability in predicting future landslides determines the efficacy of any SAS. Incorrect prediction exposes lives to danger and cause economic losses if a slope or an area with a high hazard level is incorrectly classified/predicted to be of a low hazard level. On other hand, if a slope or an area with a low hazard level is incorrectly predicted as of high hazard level, it has financial implications as money will be unnecessarily spent to ‘stabilized’ a stable (not failed) slope. This paper describes a study made to validate the existing SAS based on slope inventory data from 139 cut slopes in granitic formations and 47 cut slopes underlain by meta-sediment formations which are the two major rock/soil formations found in Malaysia (Komoo & Mogana, 1988).

Granite is the major rock that underlies virtually every major mountain range in Malaysia with summits exceeding 2,000m. About 30% (5,000km) of major trunk roads which involve many cut slopes, traverse through or are located on hilly and mountainous areas in ~~of~~ Malaysia. Some 75% of the roads that traverse~~d~~ the hilly and mountainous areas cut through and/or are underlain by granitic formation. The remaining 25% of the roads cut through or are underlain by the meta-sediment formations (mudstone, sandstone and siltstone). These mountainous roads have experienced numerous numbers of landslides occurrences, usually during the wet (rainy) season from October to January, causing disruption to traffic, injury to and loss of life. A study carried out in the year 2000 along six selected hilly and mountainous roads showed that out of 444 landslides of various types (shallow slides, deep seated slides, debris flow and rock fall), 420 occurred in cut and natural slopes (Othman & Lloyd, 2001). The other 24 slides occurred on embankment (fill) slopes.

SLOPE ASSESSMENT SYSTEMS

The Slope Maintenance System (SMS) was the first slope assessment system to be developed by the Public Works Department (PWD) of Malaysia, as part of the East-West Highway long-term preventive measures (PWD, 1996). A statistical method using discriminant analyses based on slope type (embankment/fill and cut/natural slope) is used to determine the hazard values (Jamaluddin *et al*., 1999; Lloyd *et al*., 2001). The parameters captured for each slope include the age of the cut slope, batter height, bench width, ratio of crest length to edge length, number of culverts, relationship between slope and topography, distance to ridge/gully, etc. From the discriminant analysis, significant slope parameters that contributed to the landslides along the highway were determined. The weightings for each parameter were then calculated using factor-overlay analysis, similar to the method proposed by Anbalagan (1995). The maximum parameter~~s~~ weighting of 2 is assigned to the relatively most hazardous sub-parameter of each parameter. The weighting for other sub-parameters of each parameter is then calculated using equation (1) below.

Weighting = Landslides frequency for sub-parameters x Max. Parameters Eq. 1
Total number of landslides weighting

For example out of 100 known landslides, 5 in number~~s~~ are in the 8 to 11 years old range slopes, so the weighting for this range of age is 0.1 (i.e. 5 divided by 100 and multiply by 2). Using this method, the weightings for other slope parameters are established. Table 2 shows an example of hazard weighting for cut slopes in granitic formation as used in the SMS. The hazard weighting was developed based on 74 cut slopes (of which 31 were failed slopes) in the main range granite formation along the East-West Highway of West (Peninsular) Malaysia.

Table 2: Hazard weighting for cut slopes of main range granite used in the SMS (PWD, 1996).

Parameter	Sub-parameter	Weighting
Age in years	< 8	0.1
	8-11	0.1
	12	2.0
Culverts	Culvert	0.13
	No Culverts	2.0
Erosion	Gully; Very severe	2.0
	Gully; Moderate to severe	1.6
	Gully; Minor	1.27
	Rill; Very severe	0.87
	Rill; Moderate to severe	0.73
	Rill; Minor	0.6
	Sheet; Very severe	0 (no occurrences)
	Sheet; Moderate to severe	0 (no occurrences)
	Sheet; Minor	0 (no occurrences)
	No Erosion	0.53
Percentage of feature uncovered	0-19%	0.46
	20-39%	0.67
	40-59%	1.07
	60-79%	1.47
	80-100%	2.0
Feature aspect in degrees (°)	0-59°	0.2
	60-119°	0.1
	120-179°	0.87
	180-239°	2.0
	240-299°	0.4
	300-360°	1.33
Rock condition profile	Claystone	0 (no occurrences)
	Conglomerate	0 (no occurrences)
	Granite	2.0
	Limestone	1.8
	Phyllite	1.33
	Sandstone	0.27

Table 3 below shows example of hazard weighting for cut slopes in meta-sediments use in the SMS. The hazard weighting was developed based on 141 cut slopes, 54 of it were failed slopes, in meta-sediment formations along the East-West Highway of West Malaysia.

Table 3: Hazard weighting for cut slopes of meta-sediment use in the SMS (PWD, 1996).

Parameter	Sub-parameter	Weighting
Number of water courses within features	0	1.38
	1	1.88
	2	2.0
Rock condition profile	Granite	2.0
	Limestone	1.73
	Phyllite	1.27
	Sandstone	0.85
Erosion	Gully; Very severe	2
	Gully; Moderate to severe	1.65
	Gully; Minor	1.46
	Rill; Very severe	1.19
	Rill; Moderate to severe	1.19
	Rill; Minor	1.04
	Sheet; Very severe	0
	Sheet; Moderate to severe	0
	Sheet; Minor	0.96
	No Erosion	0.96
Distance to ridge or gully in meters	0 m	0.46
	1-99 m	0.81
	100-199 m	1.27
	> 200 m	2.0
Feature aspect in degrees (°)	0-59°	0.91
	60-119°	2.0
	120-179°	0.61
	180-239°	0.38
	240-299°	1.81
	300-360°	1.42
Slope angle in degrees (°)	20-29°	0.12
	30-39°	0.38
	40-49°	1.5
	50-59°	1.84
	60-69°	1.92
	70-79°	0
	80-90°	2.0

The Hazard Score in percentage is computed by summing up the hazard weighting of all the parameters for each assessed slope and divided by the total maximum hazard weighting. The Hazard Score is then converted into a hazard rating or hazard level as shown in Table 4.

Table 4: Hazard level and range of hazard rating in percentage use in the SMS (PWD, 1996).

Hazard Score	Hazard Rating / Level
80.1% -100%	Very High
60.1% - 80%	High
40.1% – 60%	Medium
20.1% – 40%	Low
0% – 20%	Very Low

In 1999, the PWD developed the Slope Priority Ranking System (SPRS) as a tool for quick assessment of all slopes in Malaysia to enable repair work to be prioritized and carried out. The SPRS helped in identifying budget requirements for slope repairs. The hazard score used in the SPRS was established using a very simple approach with associated ratings of 0, 1, and 2, according to the definitions of each parameter given by Hussein *et al.* (1999). The hazard attributes for a cut slope include slope angle, height of slope, slope cover, surface drain, natural water path, seepage, ponding, erosion, slope failure, surroundings upslope (human activity), soil type, weathering grade and discontinuities. Table 5 below shows the hazard score used for cut slopes in the SPRS.

Table 5: Hazard score used for cut slopes used in SPRS (Hussein *et al.*, 1999).

Cut Slopes Hazard Attributes	Score		
	0	1	2
i. Slope angle	<45^0	45^0 - 63^0	>63^0
ii. Height of slope	<12m	12m–24m	>24m
iii. Slope cover	>20%	<20%	-
iv. Surface drains	Good	Blocked	Repair required
v. Natural water path	No	-	Yes
vi. Seepage	No	-	Yes
vii. Ponding	No	Yes	-
viii. Erosion	Slight	Moderate	Critical
ix. Slope failure	No	-	Yes
x. Surroundings upslope	No	-	Yes
xi. Soil type	Gravel/sand	Silt	Clay
xii. Weathering grade	I	II, III	IV- VI
xiii. Discontinuities	No	-	Yes

The Hazard Score in percentage for each assessed slope is computed by summing the slope attributes hazard score of the slope and divided by the total maximum hazard score. The hazard score is then converted into a hazard rating as shown in Table 6.

Table 6: Hazard score and rating used in the SPRS (Hussein *et al*,. 1999)

Cut Slope		Fill Slope	
Hazard Score	Hazard Rating	Hazard Score	Hazard Rating
40% to 100%	Very High	40% to 100%	Very High
30% to 40%	High	30% – 40%	High
19% to 30%	Moderate	20% – 30%	Moderate
8% to 19%	Low	10% – 20%	Low
0% to 8%	Very Low	0% – 10%	Very Low

In 2002, the Public Works Department (PWD) and the Japanese International Cooperation Agency (JICA) jointly developed the Slope Information Management System (SIMS) (JICA & PWD 2002). In this system, the slopes are assessed based on a predefined likelihood of failure type based on the definition used in Japan; i.e. slope failure/rock fall, rock mass failure, landslide, debris flow and embankment failure. The hazard score used was adopted from the Japanese experience. Parameters considered include topography, slope geometry, slope forming material, geological structure, any presence of slope deformation, surface condition and countermeasure effectiveness. Table 7 below shows hazard score used for slope failure/rock fall type of failure. Table 8 shows the hazard rating applied in the SIMS.

Table 7: Hazard score assign for slope failure/rock fall type of failure used in the SIMS (JICA & PWD, 2002).

Condition of Slope (for slope failure/rock fall)			Score
Topography	Alluvium slope	Yes	2
		No	0
	Trace of slope failure	Yes	1
		No	0
	Clear knick point or overhanging	Yes	1
		No	0
	Concave slope or debris slope	Yes	1
		No	0
Geometry; select higher point of A or B	A: Soil slope	H > 30m	30
	H: High of soil	$H \leq 30m, I > 45^0$	24
	I: Slope angle	$15m \leq H < 30m, I \leq 45^0$	20
		H<15m	10
Geometry; select higher point of A or B (continued)	B: Rock slope	H>50m	30
	H: High of rock	$30m \leq H < 50m$	26
		$15m \leq H < 30m$	20
		H<30m	10
Material; select A and B	A: Soil character; Swelling clay contents	Conspicuous	8
		Slightly	4
		None	0
	B: Rock quality; Sheared rock, Weathered rock	Conspicuous	8
		Slightly	4
		Not available	0
Geological Structure	Daylight structure (Planar, wedge)	Yes	8
		No	0
	Soft soil over base rock		6
	Hard rock over weak rock		4
	Others		0
Deformation	Slope Deformation: Erosion (gully, rill, sheet, fretting), rock fall, exfoliation etc.	Visible	10
		Obscure	8
		None	0
	Deformation at adjacent slope (rock fall, slope failure, crack, etc.)	Visible	6
		Obscure	4
		None	0
Surface Condition	Condition of Surface	Unstable	8
		Moderate	6
		Stable	0
	Ground Water	Natural spring	6
		Water seepage	3
		Dry	0
	Cover	Bare	4
		Grass + Structure	3
		Structure	1
	Surface Drainage	Available (good)	0
		Available (need repair)	2
		Not available	1
Countermeasure effectiveness	Effective		-20
	Partially effective		-10
	Not effective or No countermeasure		0
Total Score			

Table 8: Hazard rating applied in the SIMS (JICA & PWD, 2002).

Level of Slope Management	Hazard Score (%)	Hazard Rating
Level I	$R \geq 75$	Very High
Level II	$75 > R \geq 65$	High
Level III	$65 > R \geq 50$	Moderate
Level IV	$R < 50$	Low

The Slope Management and Risk Tracking Systems (SMART) is the latest slope management system to be developed by the Public Works Department (PWD, 2004). This system was ~~is~~ developed based on data from the Tamparuli - Sandakan road in Sabah, East Malaysia, along which there have been numerous slope failures. In developing SMART, data from 918 cut slopes comprising of 741 not failed slopes and 177 failed slopes was used. This road is underlain mainly by sediment and meta-sediment formations of mudstone, sandstone and siltstone, inter-bedding with each other (PWD, 2004).

This system uses slope inventory forms similar to the SMS with some slight modifications. In SMART, the hazard score or instability score (IS) ranges from 0 to 1 and is derived through the integration of results from three assessment methods, that is the statistical method (stepwise discriminant function analysis converted into probability), deterministic method (factor of safety determine by Combined Hydrology and Stability Model or CHASM and then converted to probability using Monte-Carlo simulation) and, if and when appropriate, expert knowledge (PWD, 2004). The following Equation 2 given below is an example of a twelve-parameter regression equation derived from stepwise discriminant function analysis and then converted into probability (P).

$$Y = 0.027(\text{height}) + 0.02(\text{angle}) + 0.163(\text{shape}) + 0.354(\text{plan profile}) + 0.278(\text{cutting topography}) + 0.202(\text{structure}) - 0.172(\text{main cover type}) + 0.472(\text{cover}) + 0.017(\%\ \text{rock exposure}) - 1.266\ (\text{corestone boulders}) + 0.249(\text{rock condition profile}) + 0.281(\text{ground saturation}) - 4.293 \qquad \text{- Eq.2}$$

where *Y* is regression function representing 'instability score' of the assessed slopes.

For the calculation of *Y*, the slope parameters in the bracket are replaced by a value or class of the slope variable~~s~~ as listed in Table 9.

Table 9: Variables / Parameters for cut slope determined as significant in SMART (PWD, 2004).

No.	Slope Variable	Range of Classes	Value / Classes
1	Height	Any value from 0 to 200 meters	0 to 200
2	Slope angle	Any value from 0 to 90 degrees	0 to 90
3	Slope shape	Simple	1
		Planar	2
		Asymmetrical	3
		Compound	4
4	Plan profile	Convex	1
		Concave	2
		Straight	3
5	Cutting topography	Top	1
		Middle	2
		Base	3
		Basin/Flat Ground	4
		Sidelong Embankment	5
6	Structure	None	1
		Crib Wall	2
		Piled Wall	3
		Surface Netting	4
		Soil Nailing	5
		Gabion Wall	6
		Rock Bolts / Stitching	7
		Concrete Wall	8
		Masonary Wall	9
		Others	10
7	Main cover type	Grass	1
		Shrub	2
		Fern	3
		Jungle	4
		Plantation	5
		Agricultural	6
		Others	7
8	Slope cover	Good (100%)	1
		Average (80 to 100%)	2
		Poor (< 80%)	3
9	Percentage rock exposure	Any number from 0 to 100 %	0 to 100

No.	Slope Variable	Range of Classes	Value / Classes
10	Corestone boulders	No	0
		Yes	-1
11	Rock condition profile	Majority < Grade III	1
		Partly < Grade III & Partly > Grade IV	2
		Predominantly Grade IV to Grade VI	3
		Predominantly Grade IV to Grade VI but with Corestone Boulders	4
		Predominantly Colluvium	5
12	Measure of ground saturation	Low	0
		Medium	1
		High	2
		Very High	3

The equations used to transform the data from individual discriminant function scores (Y) to probabilities of group membership (i.e. failed or not failed) were derived through curve fitting. An example is shown in Table 10 below.

Table 10: Conversion of Y into probability, P (PWD, 2004).

Value of Y	Calculation of probability, P
$Y < -2$	$P = 0.05$
$-2 < Y < 0.5$	$P = 0.0037Y^3 + 0.0891Y^2 + 0.3195Y – 0.3531$
$0.5 < Y < 4$	$P = 0.0105Y^3 – 0.1275Y^2 + 0.5152Y + 0.2952$
$Y > 4$	$P = 1$

The probabilities are then grouped into groups of qualitative terms of instability category for the purpose of interpretation and action. The instability or hazard rating categories designated for this purpose are Very Low, Low, Medium, High and Very High, as shown in Table 11.

Table 11: Probability and instability category use in SMART (PWD, 2004).

Probability, P	Instability Category
0.0 – 0.2	Very Low
0.2 – 0.4	Low
0.4 - 0.6	Medium
0.6 – 0.8	High
0.8 – 1.0	Very High

The Landslide Hazard and Risk Assessment (LHRA) was developed by Fiener (1999). Nine factors are selected for the purpose of hazard assessment namely lithology, degree of weathering, structure, slope condition, hydrology, erosion, physical properties, land use, land cover and slope history. A blind and sighted weighting method is used for establishing weightings for hazards of the assessed variables. Fiener (1999). defines the blind weighting method as the relative importance of each parameter rated according to personal experience and judgment of the person carrying out the hazard assessment, whereas a sighted weighting method uses information from existing slope failures to improve the weightings of the factors and the sub-factors used.

Table 12 shows the nine factors of the LHRA and their maximum hazard ratings. Table 13 shows weightings of the sub-factors and further sub-factors for the slope. Table 14 shows the hazard value used in the LHRA.

Table 12: Adopted values for factor~~s~~ weighting used in the LHRA (Fiener, 1999).

Factor	Max. Hazard Rating
Lithology	6.00
Degree of weathering	4.00
Structure	4.00
Slope condition	6.00
Hydrology	6.00
Erosion	4.00
Physical / engineering properties	4.00
Land use and land cover	4.00
Slope history	2.00
Total	40.00

Table 13: Sub-factor~~s~~ weightings (Fiener, 1999).

For lithology

	Sub-factors	Rating
Rock Type	Quartzite and limestone	0.60
	Granite and gabbro	0.90
	Gneiss	1.20
	Well-cemented ferrigenuous sedimentary rocks, dominantly sandstones with minor beds of claystone	3.00
	Poorly cemented terrigenuous sedimentary rocks, dominantly sand with clayey shale beds	4.00
	Salt and phyllite	3.60
	Schist	4.00
	Shale with interbeded sandstone and quartzite	5.40
	Highly weathered shale, phyllite and schist typically with 60% of salt	6.00
Soil Type	Older well-compacted fluvial fill material (alluvial)	2.40
	Clayey soil with naturally formed surface (eluvial)	3.00
	Sandy soil with naturally formed surface (alluvial)	4.20
	Debris comprising mostly rock pieces mixed with clayey / sandy soil (colluvial):	
	- Older well compacted sandy soil	5.00
	- Younger loose material sandy soil or mining material	6.00

For degree of weathering

Sub-factors	Rating

Fresh	0.6
Slightly weathered	1.2
Moderately weathered	1.8
Highly weathered	2.4
Extremely weathered	3.0
Residual soil	4.0

For structure

Sub-factors		Rating
Spacing of discontinuities;	> 2m	0.2
	0.6m – 2m	0.4
	200 mm – 600 mm	0.6
	60 mm – 200 mm	0.8
	< 60 mm	1.0
Width and continuity of joints:	Very rough surface. Not continuous. No separation. Unweathered wall rock.	0.2
	Slightly rough surface. Separation < 1mm. Slightly weathered wall.	0.4
	Slightly rough surface. Separation < 1mm. Highly weathered wall.	0.6
	Slickensided surface. OR Gouge < 5mm thick. OR Separation 1 - 5mm continuous.	0.8
	Soft Gough > 5mm OR Separation > 5mm continuous.	1.0
Groundwater in joints:	Completely Dry	0.2
	Dry	0.4
	Wet	0.6
	Dripping	0.8
	Flowing	1.0
Soil depth:	< 5 m	0.4
	6 – 11 m	0.6
	12 – 20 m	0.8
	> 20 m	1.0

For slope condition

Sub-factors		Rating
Height, cut (m)	0 – 5 m	0.4
	5 – 10 m	0.8
	10 – 20 m	1.2
	20 – 30 m	1.6
	> 30 m	2.0
Height, fill (m)	0 – 5 m	0.8
	5 – 15 m	1.4
	15 – 30 m	2.0
Angle gradient (degree) (°)	0 – 5°	0.3
	5 – 15°	0.6
	15 – 30°	0.9
	30 – 40°	1.2
	40 – 60°	1.6
	> 60°	2.0
Horizontal profile	Concave	0.15
	Convex	0.2
	Straight	0.25

Sub-factors		Rating
Vertical profile	Down slope	0.1
	Complex	0.15
	Upslope	0.2
	Straight	0.25
Drainage at top	None	0.5
	Blocked	0.4
	Fair	0.3
	Good	0.2
Drainage at toe	None	0.5
	Blocked	0.4
	Fair	0.3
	Good	0.2
Berm drainage	None	0.5
	Blocked	0.4
	Fair	0.3
	Good	0.2

For hydrology

Sub-factors		Rating
Maximum daily precipitation (mm)	0 – 40	0.8
	40 – 100	1.0
	100 – 200	1.2
	200 – 300	1.4
	> 300	1.6
Maximum hourly precipitation (mm)	0 – 10	0.6
	10 – 20	0.8
	20 – 40	1.0
	40 – 60	1.2
	> 60	1.4
Permeability	Rapid	1.4
	Moderate to rapid	1.2
	Moderate	1.0
	Slow to moderate	0.8
	Slow	0.6
	Very slow	0.4
Seepage	None	0.2
	Heavy, at mid-height and above	1.6
	Heavy near toe	1.4
	Slight at mid-height and above	1.2
	Slight at toe	1.0

For erosion

Sub-factors		Rating
No appreciable erosion		0.2
Sheet erosion	Minor	0.6
	Moderate	0.8
	Severe	1.0
Rill erosion	Minor	0.6
	Moderate	0.8
	Severe	1.0
Gully erosion	Minor	1.2
	Moderate	1.6

Sub-factors		Rating
	Severe	2.0

For slope cover

Sub-factors	Rating
Thickly vegetated area	1.0
Moderately vegetated area	2.0
Artificially and vegetated area	2.2
Artificial covers	2.4
No cover	4.0

For physical properties

Sub-factors		Rating
Physical properties of Soil slope;		
Value of c (kN/m^2)	< 6	0.8
	6 – 12	1.0
	12 – 18	1.2
	> 18	1.4
Plasticity index	< 10	0.8
	10 – 23	1.0
	24 – 35	1.2
	> 35	1.4
Angle of friction (degrees)	0 – 11	0.8
	12 – 23	1.0
	24 – 35	1.2
Physical properties of Rock slope;		
Value of c (kN/m^2)	Lower c	0.5
	Mid c	0.6
	High c	0.7
Drill core quality (RQD); %	90 – 100	0.4
	75 – 90	0.6
	50 – 75	0.8
	25 – 50	1.0
	< 25	1.2
Angle of friction (degrees) (°)	24 – 32°	0.8
	33 – 41°	1.2
	42 – 50 °	1.4

For slope history

Sub-factors	Rating
No evidence of instability observed	0.5
Evidence of possible soil creep	1.0
Evidence of active soil creep or minor slip or rock face instability	1.5
Evidence of active or past landslip or surface failure	2.0

Table 14: Hazard values and ratings used in the LHRA (Fiener, 1999).

Hazard ratings	Hazard values
Very High Hazard	> 32.0
High Hazard	26.6 – 31.9
Moderate Hazard	20.4 – 26.5
Low Hazard	14.1 – 20.3
Very Low Hazard	< 14.0

FIELD STUDY SITES, SLOPES AND LANDSLIDES INVENTORIES

The roads are the main type of transportation system in Malaysia. About 30% of these roads traverse through or are located in hilly and mountainous areas. These mountainous roads experience numerous landslides, which cause disruptions, injuries and losses of life and to the economy.

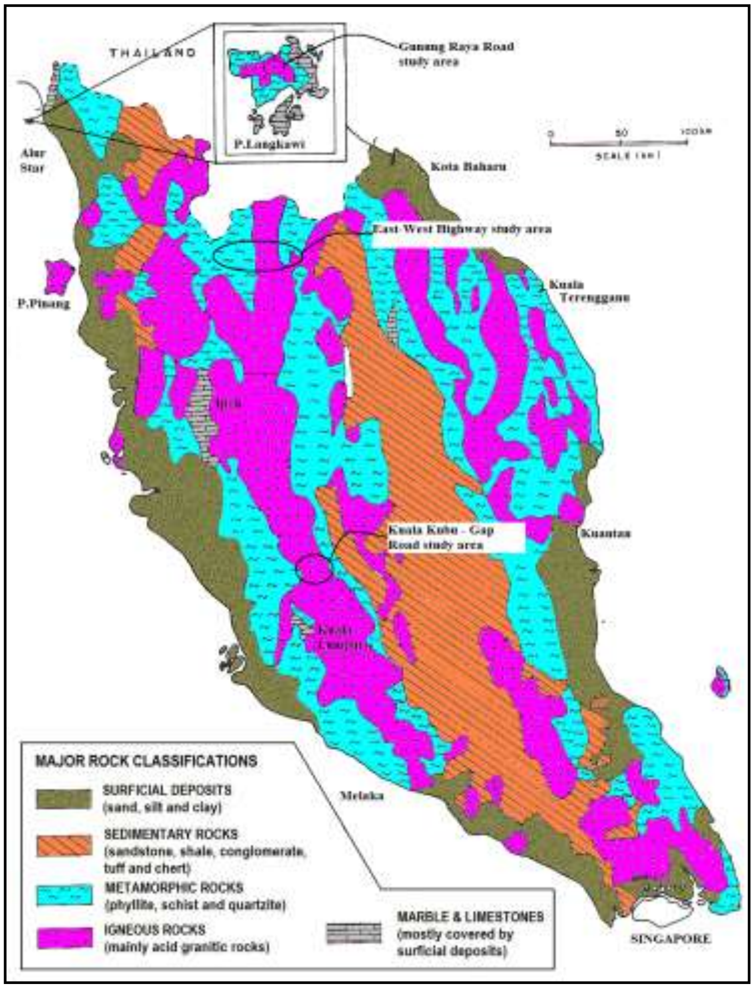

Figure 2: Locations of field sites (the general geology of West Malaysia is after Komoo and Mogana (1988).

Slope inventory data from 139 cut slopes in granitic formations along three different sites, namely the Gunung Raya road in Langkawi Island, the East-West Highway, Perak and the Kuala Kubu Baru – Gap road, Selangor, West Malaysia were used in the evaluation of the slope assessment systems (SAS) of cut slopes in the granitic formations. Whilst data from 47 cut slopes in meta-sediment formations along the Gunung Raya road and the East-West highway (West Malaysia) were used for evaluating the SAS in the meta-sediment formation. The slope inventory data such as slope height, slope angle, soil type and weathering grade were collected/compiled over a ten-year period, from 1994 to 2004. These data were obtained from previous records as well as through site visits (walkthrough survey).

The landslide occurrences used were those that had occurred after the initial slope inventory data was collected. They were determined from written historical records, differences seen on multi-date aerial photos or difference between older sketches of the data collection performa with the current site conditions. Tables 15 and 16 summarize the information on the 186 cut slopes considered in this study.

Table 15: Cut slopes in granitic formation in West Malaysia

Location	No. of cut slopes considered in the study	No. of slope failures	Date of initial data	Date of slope failures	General remarks on type of slope failures, reasons of failure
Gunung Raya road, Langkawi Island, West Malaysia	34	10	April 1996	Between April 1996 to November 2003	Mostly shallow slides except one deep seated slide at KM 5.9
East-West Highway, Perak, West Malaysia	53	12	March 1996	Between March 1996 to July 2001	Mostly shallow slides
Kuala Kubu Gap road, Selangor, West Malaysia	52	22	August 2000	Between August 2000 to November 2003	Mostly shallow slides except 2 debris flow at KM 23.44 and adjacent to it

Table 16: Cut slopes in meta-sediment formation in West Malaysia

Location	No. of cut slopes considered in the study	No. of slope failures	Date of initial data	Date of slope failures	General remarks on type of slope failures, reasons of failure
Gunung Raya road, Langkawi Island, West Malaysia	12	5	April 1996	Between April 1996 to November 2003	Mostly shallow slides
East-West Highway, Perak, West	35	24	March 1996	Between March 1996 to July 2001	Mostly shallow slides

Location	No. of cut slopes considered in the study	No. of slope failures	Date of initial data	Date of slope failures	General remarks on type of slope failures, reasons of failure
Malaysia					

Table 17 shows an example of the observed conditions and approximate size of the assessed parameters and sub-parameters of a failed slope in granitic formation at KM 9.33 of the Gunung Raya road in Langkawi Island, West Malaysia. The initial data was captured in 1996 as part of the Malaysian Engineered Hill Slopes Management System (MEHMS) study. A recent shallow slide had occurred during the rainy season in September to November 2003.

Table 17: Observed condition/estimated size of the assessed parameters/sub-parameters of a failed slope at KM 9.33 of the Gunung Raya road, Langkawi Island, West Malaysia

Parameter / Sub-Parameter	Size / Condition	Parameter / Sub-Parameter	Size / Condition
Location of slope or cutting topography	Middle	Weathering grade of exposed rock	IV
Age of cut	10 yrs	Presence of rock discontinuity	No
Slope height	9m	Presence of core-stone boulders	No
Slope angle (°)	50	Overall weathering of whole slope mass	Residual soil
Slope aspect (°)	280	Rock condition profile	Grade III to Grade VI
Plan profile	Straight	Presence of bench drain	Yes
Cross profile	Straight	Presence of culvert	Yes
Feature area	$3500m^2$	Presence of toe drain	Yes
Distance to ridge	300m	Presence of horizontal drain	No
Berm height	6m	Surface drain conditions	Blocked
Slope shape	Compound	Presence of natural water path	Yes
Main cover type	Shrub	Number of water courses	2
% uncover	15	Presence of water ponding	No
Soil depth	< 5m	Presence of water seepage	No
Soil type	Silty / Sandy	Sign of erosion	Moderate gully
Approx. soil strength	Firm (40 to 75 kPa)	Sign of previous slide	No
Approx. Plasticity Index	10 to 20	Monthly highest rainfall	675mm
Approx. Angle of friction (°)	20 to 30	Daily highest rainfall	242mm
Rock type / formation	Granite	Hourly highest rainfall	65mm
Presence of rock exposure	Yes	Permeability	Slow to moderate
% of rock exposure	15	Presence of up-slope human activity	No

HAZARD ASSESSMENT OF THE SLOPE AND ACCURACY EVALUATION OF THE SAS

The accuracy or reliability in predicting future landslides determines the efficacy of any slope assessment systems (SAS). In this study, the accuracy of the SAS was determined by comparing the hazard rating of each of the slopes evaluated based on the initial (earlier) slope inventory data with the later set of data, i.e. after the landslide occurrences in some cases. The accuracy in percentage was determined by comparing the number of slopes classified as high and very high hazard that actually failed with the total number of actually failed slopes.

During data compilation stage, firstly, the available data was obtained and the format of this available data was transformed to the range or classes of all the SAS. Secondly, some categories of data which was not available especially the permanent parameters related to the geometry and geological features of the assessed slope were collected and determined through site visits (walkthrough survey). Some estimates were made for the parameter values needed in each SAS such as strength parameters of soil and rock, soil depth, permeability etc.

The next stage, firstly, involved the assessment of the failed slope instability score and hazard rating according to each of the five SAS using slope parameters and sub-parameters shown in Table 17 then followed by their comparison. Table 18 shows an example of the results of hazard assessment using the five SAS on a failed slope at KM 9.33 of the Gunung Raya road (West Malaysia) cut slope in a granitic formation. A hazard rating of high and very high hazard is considered to indicate failure. In this case, only the SPRS and SMART appear to be able to give a correct prediction.

Table 18. Instability scores and hazard ratings of the failed slope at KM 9.33 of Gunung Raya road, Langkawi Island, West Malaysia

No.	Slope Assessment System	Instability Score	Hazard Rating
1	Slope Management System (SMS)	4.69	Low Hazard
2	Slope Priority Ranking System (SPRS)	8	High Hazard
3	Slope Information and Management System (SIMS)	47	Low Hazard
4	Slope Management and Risk Tracking System (SMART)	0.83	Very High Hazard
5	Landslide Hazard and Risk Assessment (LHRA)	24.00	Moderate Hazard

A summary of the prediction accuracy of the five SAS considered in the study, for cut slopes in both granitic and meta-sediment formations, determined is given Table 19.

Table 19: Accuracy of the slope assessment systems in predicting landslides

Cut slopes in granitic formations

Prediction	SMS	SPRS	SIMS	SMART	LHRA
(1) Number of slopes assessed	139	139	139	139	139
(2) Number of recent landslides or failed slopes	44	44	44	44	44
(3) Number of slopes classified as High and Very High Hazard that actually failed	17	23	1	27	1
(4) Percentage of (3) compared with (2)	39%	52%	2%	61%	2%

Cut slopes in meta-sediment formations

Prediction	SMS	SPRS	SIMS	SMART	LHRA
(1) Number of slopes assessed	47	47	47	47	47
(2) Number of actual landslides or failed slopes	29	29	29	29	29
(3) Number of slopes classified as High and Very High Hazard that actually failed	13	17	5	26	0
(4) Percentage of (3) compared with (2)	45%	59%	17%	90%	0%

Note: SMS - Slope Maintenance System (SMS), SPRS - Slope Priority Ranking System, SIMS-Slope Information Management System SMART - Slope Management and Risk Tracking System, LHRA - Landslide Hazard and Risk Assessment.

As shown in Table 19, none of the existing slope assessment systems (SAS) appeared to be satisfactory in predicting landslides in cut slopes in granitic formations. Satisfactory in this case is defined as percentage of accuracy of greater than 70% as achieved by other models (see Table 20). The reasons for this could perhaps be explained as follows.

Table 20: Accuracy of the landslide assessment models from previous works by other researches

No.	Country	Accuracy (%)	References
1	Canada	83	Rice *et al*. (1985)
2	Italy	83.8	Carrara *et al*. (1991)
3	Italy	72.7 and 80.7	Carrara *et al*. (1995)
4	Italy	72.0	Guzzetti *et al*. (1999)
5	Bolivia	78 to 89	Péloquin & Gwyn (2000)

For the case of the SMS (Slope Maintenance System), it appeared that the development of SMS using 74 cut slopes database that was limited to one site, that is the East-West Highway, was not sufficient. For the case of the SPRS (Slope Priority Ranking System), it uses a too simplified approach of assigning hazard score with only 0, 1 and 2. For the case of SIMS (Slope Information Management Systems), its using a hazard score developed from other country (Japan) in a different climatic zone appears to be its main weakness. For the case of the SMART (Slope Management and Risk Tracking Systems), its current database derived mainly from the meta-sediment formations is apparently not suitable to be extrapolated to cut slopes in other rock/soil formations. While for the case of the LHRA (Landslide Hazard and Risk Assessment), it is not clear how the instability values are derived, but it seems that its instability values are insignificant for the cut slopes under consideration.

However, for case of cut slope in meta-sediment formation, SMART appears to be satisfactory with a prediction accuracy of 90%, but not the other four SAS, namely, the SMS, SPRS, SIMS and LHRA. This is perhaps not so surprising as the current SMART database is derived mainly from the a similar lithology of meta-sediment formations from the Kundasang area in Sabah, East Malaysia. This seems to reinforce the earlier argument that slope assessment system developed for one rock/soil formation cannot be extrapolated to other rock/soil formations.

CONCLUSIONS

From the result of this study, it is found that none of the five slope assessment systems, namely, the Slope Maintenance System (SMS), the Slope Priority Ranking System (SPRS), the Slope Information Management System (SIMS), the Slope Management and Risk Tracking System (SMART), and the Landslide Hazard and Risk Assessment (LHRA), was satisfactory for predicting landslides in cut slopes in granitic formations, based on the slope inventory data from 139 cut slopes. The reasons for this range from the use of hazard score developed from another country, to insufficient database information, to the use of an oversimplified approach, and to the use of a database derived from a different rock/soil formation.

However for the case of cut slope in meta-sediments, the Slope Management and Risk Tracking System (SMART) is found to be satisfactory with 90% prediction accuracy. The current database of the SMART is based on meta-sediment formation.

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