Pertanika J. Sci. & Technol. Supplement 9(1): 39 - 49 (2001)
ISSN: 0128-7680

Geological Rating for D-Slope

Husaini Omar[1], Mohamed Daud[2], Norwati Mustapha[3], Zainuddin Md. Yusof[1], M.R. Osman[4] & Ratnasamy M.[1]

[1]Department of Civil Engineering, Faculty of Engineering,
[2]Department of Biology and Agriculture, Faculty of Engineering,
[3]Department of Computer Science, Faculty of IT,
[4]Department of Mechanical Engineering, Faculty of Engineering,
Universiti Putra Malaysia,
43400 UPM, Serdang, Selangor

ABSTRACT

The purpose of this paper is to present the development of Geological Rating (GR) to carry out slope assessment. In this study, the D-Slope has been developed using geological, hydrological and geotechnical data to evaluate the potential failure of slopes. The geological complexity, the scale of the instability phenomena and the high number of interacting factors complicate most the natural and cut slope analysis. In order to be able to have a structured approach to such complexity, a comprehensive method based on the Geological Rating (GR) is proposed. A total of fourteen (14) parameters (12 geological parameters and 2 hydrological parameters) relating to the slopes have been considered. The slopes are divided into four categories: (I) Not Dangerous Slope (NDS), (II) Slightly Dangerous Slope (SDS), (III) Moderately Dangerous Slope (MDS), and (IV) Highly Dangerous Slope (HDS). The definitions of these categories are discussed.

Keywords: Geological rating, slope stability, expert system

INTRODUCTION

Large-scale instability phenomena in natural and/or cut slopes frequently occur in structurally and geologically complex regions, particularly in the mountainous areas. Most mountainous areas, the topography is very steep and slope failures are often caused by the construction of roads. But, very little attention has been given to the assessment of slope stability when planning roads in steep mountainous areas. In fact, techniques of planning roads in mountainous areas have not yet been generalized and, at present, success of such works depends on the individual knowledge and experience of experts.

The purpose of this study is to develop an expert system that can be used to evaluate the potential failure of slopes.

Expert System

An Expert System is a system that employs human knowledge captured in a computer to solve problems that normally require human expertise. It is used to propagate scarce knowledge resources for improvement and results.

Expert Systems were developed by the Artificial Intelligence (AI) community as early as the mid 1960s. During the 1970s expert system was mostly a laboratory curiosity. Researchers are focussed on developing ways of representing and reasoning about knowledge in a computer, and not designing the actual system. Very few applications especially for engineers were developed. Most of the expert systems in 1970s were developed on powerful workstations using languages such as LISP, PROLOG, and OPS (Durkin 1994).

In 1979, a group of individuals who were intimately involved with the development of earlier expert systems met a workshop chaired by Don Waterman and Frederick

Hayes-Roth. This workshop was to exchange ideas or knowledge in the field of expert systems and also to formulate a way of developing such systems (Hayes-Roth *et al.* 1983).

During 1980s, the number of expert systems developed had slightly increased with a report of 50 deployed systems by 1985. Now, the increase is very rapid due to the spreading of the success stories of the technology. At present, with the Personal Computers and the introduction of easy-to-use expert system software development tool which is called "shell" are available the opportunity to develop an expert system is now in the hands of many individuals from all disciplines (Fig. 1). For example, a system called EXOFS was constructed with an expert system shell named Xi Plus from Inference Corporation. The shell includes both frame and rule representation (Turban 1992).

According to Turban (1992), Expert Systems can provide major benefits to users such as increased output and productivity, increased quality, reduced downtime, flexibility, reliability, accessibility to knowledge, and increased capabilities of other computerized systems.

The development of expert system in engineering field is still in the early stage. According to Durkin (1994), 150 expert systems have been developed in the engineering area. Manufacturing, business and medicine showed the highest expert systems application being developed. Fig. 2 shows the number of expert systems that have been developed in each area.

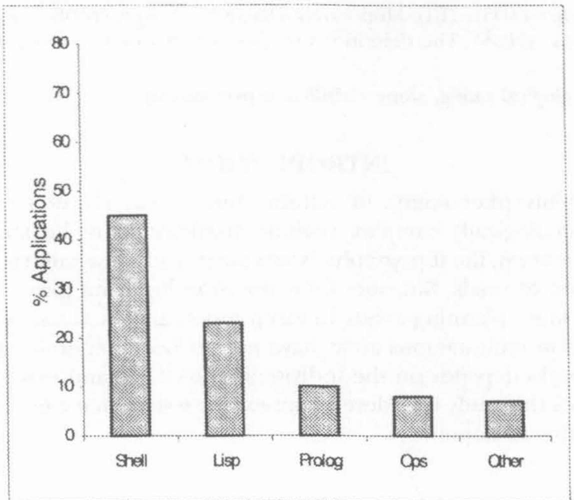

Fig 1. Software used in expert system development (Durkin J. 1994)

THE DEVELOPMENT OF D-SLOPE

The D-Slope is a system that imitates the reasoning processes experts used to solve slope stability problems. It is developed using three main types of data, namely:

1. Geological Data
2. Geotechnical Data
3. Hydrological Data

The aim of the D-Slope is to provide a technique for carrying out slope assessment in a proper manner. A number of steps have to be followed and these include the choice of parameters relevant to the problem and the rating assignment to different classes of

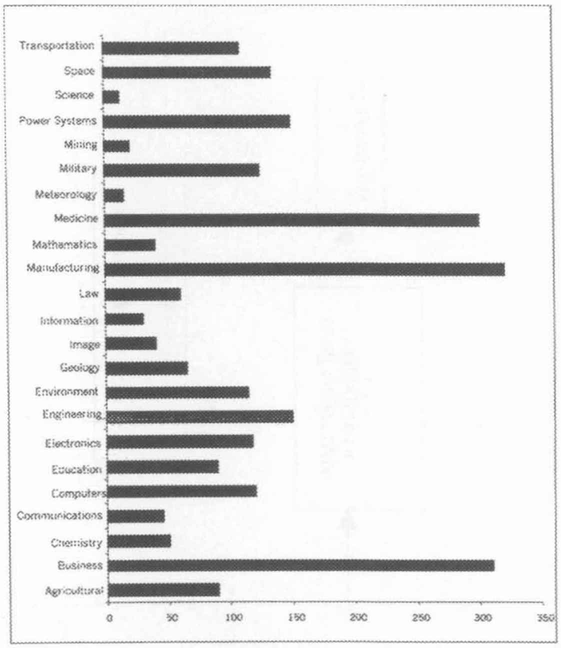

Fig 2. Number of developed expert systems in various application areas (Durkin J. 1994)

parameters. The progress chart for the development of D-Slope is shown in Fig. 3. The Geological Rating (GR) is proposed because of the need to incorporate these data into the analysis of the potential of slope instability. The proposed GR is discussed in detail in the next chapter.

Geological Data

Twelve (12) geological parameters are considered for the D-Slope and they are based on the of slope failures in tropical countries. The parameters are:

1. previous instability
2. faults
3. joints
4. folds
5. aperture
6. persistence
7. spacing
8. number of major sets
9. orientation
10. geology
11. weathering
12. slope dimension

According to Mazzoccola and Hudson (1996), the rating for the parameters is between 0 to 2. This is shown in Fig. 4.

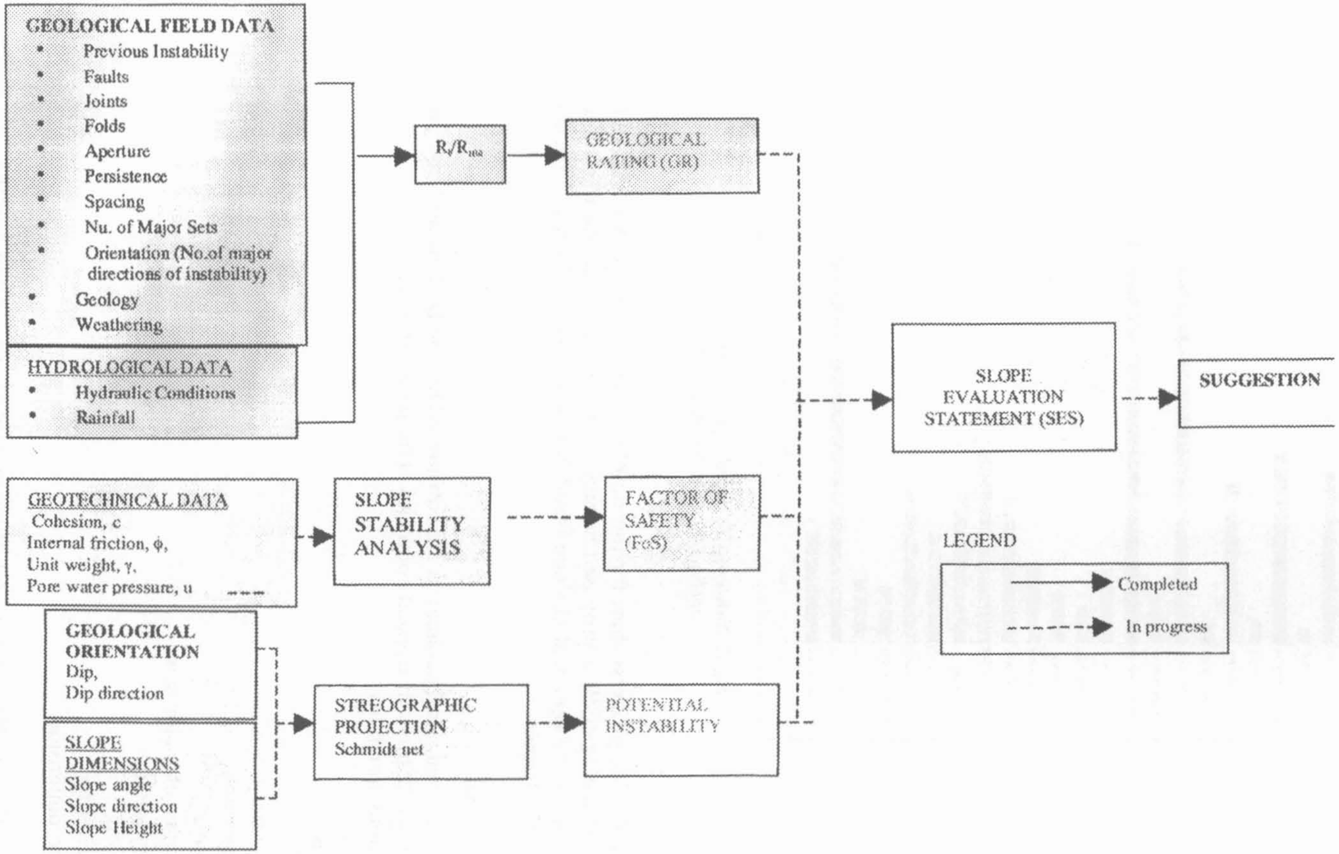

Fig 3. The progress chart for development of D-Slope

Geological Data

Faults	
on	Rating
Not present	0
Minor	1
Major	2

Spacing	
Description	Rating
Not present	0
Minor	1
Major	2

Geology	
Description	Ratii
Granite gneiss	0
Metasedimentary gneiss	1
Complex intercalations	2

Aperture	
Description	Rating
< 10 mm	0
10-50 mm	1
> 50 mm	2

Number Of Major Sets	
Description	Rating
1	0
1-3	1
4	2

Slope Dimensions	
Description	Ratir
4 m	0
4 m-100 m	1
> 100 m	2

Persistence	
Description	Rating
< 5 m	0
5-10 m	1
> 10 m	2

Weathering	
Description	Rating
Unweathered	0
Discolored	1
Infilling material	2

Orientation (no. of major directions of instability)	
Description	Rating
< 2	0
2-5	1
> 5	2

Mechanical properties (JRC)	
Description	Rating
> 14	0
7-14	1
<7	2

b) Hydrological Data

Hydraulic Conditions	
Description	Ratir
Dry	0
Wet	1
Flow	2

Rainfall		
Description		
3 days	10 days	Ratir
< 110 mm	170 mm	0
110-220m m	170-330 mm	1
>220 mm	> 330mm	2

Fig 4. The rating parameters (Mazzoccolla and Hudson 1996)

Geotechnical Data

Four geotechnical parameters are considered which are cohesion, internal friction, unit weight and pore water pressure. These parameters are needed to calculate the Factor of Safety of the slopes. The Factor of Safety of the slope is part of the criteria that determines the slope condition.

Hydrological Data

There are two hydrological parameters they are hydraulic condition and rainfall. The rating of these two parameters are shown in Fig. 4.

THE GEOLOGICAL RATING (GR)

Based on the three main types of data for the D-Slope, a total of 14 parameters (12 geological parameters and 2 hydrology parameters) are selected to develop the Geological Rating (GR). The data for the parameters was collected at Pos Selim Highway. This highway is still under construction by MTD Capital Bhd. The sample of field data is shown in Fig. 5.

DATA SHEET: 1
CHAINAGE : CH 3+370 TO CH 3+430 DATE : 14.4.1999
LOCATION : CH 3+400 TIME : 10.00A.M.
GEOLOGICAL AFFECTED AREA (GA): 402 m^2 ANGLE OF FRICTION (φ): 34.65°
INVESTIGATED AREA (IA): 1110 m^2 DENSITY OF SOIL (γ): kg/m^3
COHESION (C): 11.9 kg/m^2 WATER LEVEL: m

	DESCRIPTIONS	RATING	REMARKS
GEOLOGY	GRANITE	2	COMPLEX
ORIENTATION	3	1	
SLOPE DIMENSIONS	37m	1	
WEATHERING	MODERATELY TO COMPLETELY	2	
HYDRAULIC CONDITIONS	FLOW	2	
PREVIOUS INSTABILITY	ACTIVE	2	
RAINFALL	175mm(3days) 300(10days)	1	

GEOLOGICAL STRUCTURES	MAJOR/ MINOR	APERTURE (mm)	PERSISTENCE (m)	NO. OF SETS	SPACING (m)
JOINTS	MAJOR	1-15	8-30	3	0.34-1.75
RATING	2	0	2	1	0

DIP(°)	DIP DIRECTION(°)
50	120
58	240
30	070

Fig 5. Pos Selim data sheet

The individual parameter rating based on Mazzaccolla and Hudson (1996) is then assigned to the field data. The total rating for each location of the slope, R_t, is calculated. The maximum rating, R_{max}, is 28. The Rt at each location is tabulated in Table 1.

The formula for Geological Rating (GR) is shown below.

$$GR = R_t/R_{max} \tag{1}$$

where,

GR = Geological Rating

R_t = Total individual rating collected at site

R_{max} = Maximum rating

Thus, based on the above formula, the GR then calculated and is shown in Table 2.

TABLE 1
The total individual rating collected at site

Location	Slope Height	R_t
CH 3400	37	16
CH5080	28	14
CH6800	17	11
CH8870	48	16
CH9100	49	15
CH10360	24	15
A	8	10
B	12	15
C	13	17
1UPM	8	11
2UPM	7	14
3UPM	7	11

TABLE 2
The Geological Rating

Location	Slope Height	GR
CH 3400	37	0.667
CH5080	28	0.583
CH6800	17	0.458
CH8870	48	0.667
CH9100	49	0.625
CH10360	24	0.625
A	8	0.417
B	12	0.625
C	13	0.708
1UPM	8	0.458
2UPM	7	0.583
3UPM	7	0.458

The graph GR versus Slope Height is plotted below (Fig. 6). From the graph of correlation between GR and Slope Height, there is an indication showing that the GR increases with the increase of the Slope Height.

The data for Geological Affected Area, GA, is obtained at the site. The Area Ratio,

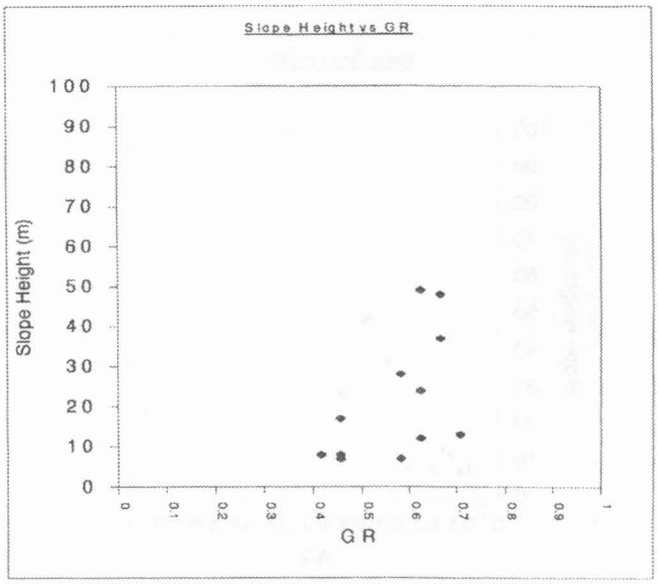

Fig. 6. Slope height vs geological rating

AR is calculated by dividing GA with Investigated Area, IA.

$$AR = GA/IA \quad (2)$$

where,

AR = Area Ratio
GA = Geological Affected Area
IA = Investigated Area

The results of AR are summarized in Table 3 below. Correlation is made between AR and the Slope Height. This is shown in Fig. 7. From the graph, the AR increases with the increase of the Slope Height.

TABLE 3
The results of calculated Area Ratio

Location	Slope Height	AR
CH 3400	37	0.300
CH5080	28	0.429
CH6800	17	0.526
CH8870	48	0.361
CH9100	49	0.347
CH10360	24	0.952
A	8	0.075
B	12	0.129
C	13	0.149
1UPM	8	0.250
2UPM	7	0.178
3UPM	7	0.101

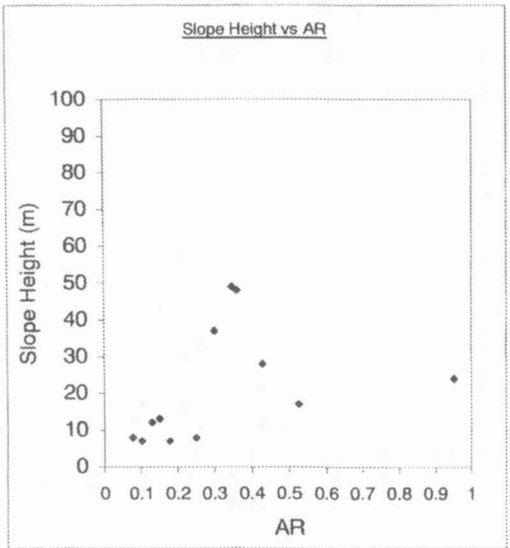

Fig. 7. Slope height vs area ratio

Slope Category

For the D-Slope to perform the assessment, the slope category is required. A correlation between GR and AR is developed. This is shown in Fig. 8. From the graph, a simple slope category is proposed. The proposed slope categories are:

I Not Dangerous Slope (NDS)
II Slightly Dangerous Slope (SDS)
III Moderately Dangerous Slope (MDS)
IV Highly Dangerous Slope (HDS)

Based on Fig. 8, the range of GR for each category is selected. This is summarized in the Table 4 below.

The definition of each slope category is described below.

TABLE 4
The slope category and the range of GR

Slope Category	Geological Rating (GR)
Not Dangerous	0 < GR ≤ 0.4
Slightly Dangerous	0.4 < GR ≤ 0.5
Moderately Dangerous	0.5 < GR ≤ 0.6
Highly Dangerous	0.6 < GR ≤ 1.0

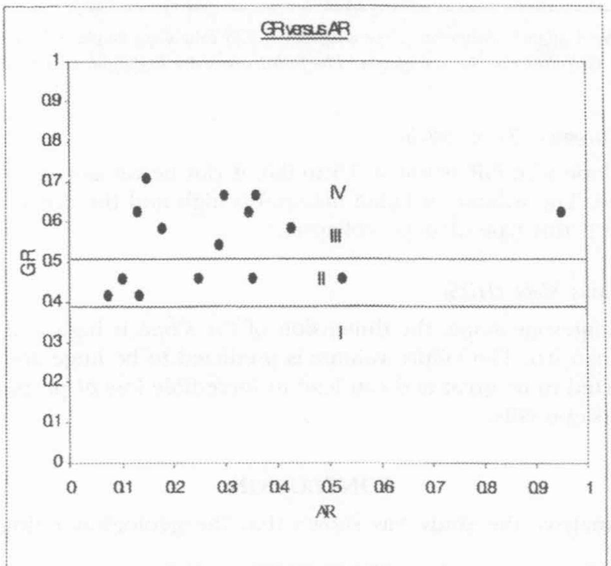

Fig. 8. Geological rating versus area ratio

I Not Dangerous Slope (NDS)

For a slope with GR less than 0.4, it is categorized into Not Dangerous Slope because the destruction is not significant enough to cause damage to the highway even if the slope collapses.

II Slightly Dangerous Slope (SDS)

For a slope to be rated as Slightly Dangerous Slope, its GR is normally between 0.4 to 0.5. It is said to be slightly dangerous because the failure of this kind of slope would only be a temporary nuisance to the highway by partially closing the road and in addition the remedial cost is low. Fig. 9 shows a slope rated as SDS is situated at CH6800 Pos Selim Highway.

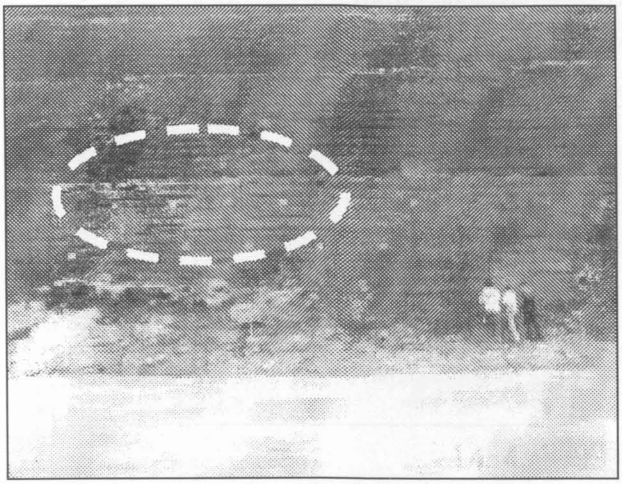

Fig. 9. A slightly dangerous slope with GR 0.458 and slope height 17m located at CH6800 Pos Selim highway. The failed areas are highlighted in circle.

III Moderately Dangerous Slope (MDS)

Basically for a slope with GR between 0.5 to 0.6, it can be categorized as a Moderately Dangerous Slope. The volume of failed material is high and the degree of hazard and risk is moderate if this type of slope collapses.

IV Highly Dangerous Slope (HDS)

For a Highly Dangerous Slope, the dimension of the slope is high and the geological rating is more than 0.6. The failure volume is predicted to be huge and the severity of damage is expected to be great and can lead to incredible loss of properties and heavy casualties if the slope fails.

CONCLUSION

Based on the analysis, the study has shown that the geological rating (GR) can be expressed as:

$$GR = R_t/R_{max}$$

where,

GR = Geological Rating

R_t = Total individual rating collected at site

R_{max} = Maximum rating

The slope categories can be expressed with GR as follows:

I	Not Dangerous Slope,	$0 < GR \leq 0.4$
II	Slightly Dangerous Slope,	$0.4 < GR \leq 0.5$
III	Moderately Dangerous Slope,	$0.5 < GR \leq 0.6$
IV	Highly Dangerous Slope,	$0.6 < GR \leq 1.0$

NOTATION

GR	Geological Rating
Rt	field affected geological rating
R_{max}	maximum rating for the geological parameters
AR	Area Ratio
GA	Geological Affected Area
IA	Investigated Area

ACKNOWLEDGEMENTS

The authors wish to thank MTD Capital Berhad and its subsidiaries for the assistance accorded in giving the data and support throughout this study.

REFERENCES

DURKIN, J. 1994. *Expert Systems, Design and Development.* Prentice-Hall, Inc.

HAYES-ROTH, F., D.A WATERMAN and D.B LENAT. 1983. *Building Expert Systems.* Reading, Mass: Addison-Wesley.

MAZZOCCOLA D.F. and J.A. HUDSON. 1996. A comprehensive method of rock mass characterization for indicating natural slope instability. *Quart. J. Engi Geo.* **29**: 37-56.

TURBIN, E. 1992. *Expert Systems and Applied Artificial Intelligence.* Macmillan Publishing Company Inc.