

LB/DON/02/1991

3

DCE 02/01A

57

STABILITY OF NATURAL SLOPES

by

N. LOGANATHAN  
B.Sc. (Eng.) Hons.  
University of Peradeniya.  
Sri Lanka.

LIBRARY  
UNIVERSITY OF MORATUWA, SRI LANKA  
MORATUWA

A thesis submitted to the University of Moratuwa, Sri Lanka, for the degree of Master of Philosophy.

August, 1990

55246

um Thesis Coll.

University of Moratuwa



55246

62 "90"  
62 (043)

I

55246

This thesis has not been previously presented in whole or part, to any University or Institution for a higher degree.

***UOM Verified Signature***

N. Loganathan

August, 1990

## ACKNOWLEDGMENTS

At first, I would like to thank University of Moratuwa for enabling me to undertake this program of study leading to degree M.Phil and also to my employer, Director General, National Building Research Organization (NBRO) for allowing me to make use of some valuable data collected in Landslide Research Project.

I wish to express my indebtedness and deepest gratitude to Dr.D.K de S.Mampitiyarachchi for the guidance, encouragement and help given during the entire program, as a co-supervisor from University of Moratuwa. I wish to extend my sincere thanks to Dr.Suraj de Silva, program co-supervisor from NBRO, for his tremendous encouragement and advices.

I am grateful to Professors A.Thuraiajah and B.L.Tennekoon for assistance and encouragement given in various stages of this program.

I wish to acknowledge the following for their assistance and encouragements.

Dr. R.C.Kumarasuriar, UN National Consultant, NBRO, for the valuable guidance in statistical analysis part of the program.

Mr. K.S.Senanayaka, Head, GED-NBRO, for providing necessary advises in administrative procedures.

Mr.P,M.Sithamparapillai, Chief Technical Advisor, NBRO

Dr.T.Sivapatham, UN National Consultant, NBRO

Mr.A.Raviskanthan, Head, Computer Division, NBRO, for the assistance given for the computer application part of the program.

Dr.J.J.P.Amaratunghe, Senior Scientist,NBRO, for the encouragement at the initial stage of this program.

Mr. S.Nanthakumar, Marga Institute, for the assistance given in statistical & probability analysis.

Mr.T.Ragulan, for providing computer facilities in the final preparation of this thesis.

Mr. A.T. Fernando for the help given in the final preparation of the thesis.

Finally, I would be failing in my duty if I do not thank my colleagues who contributed in numerous ways in successful completion of this program.

N.Loganathan

## ABSTRACT

Most of the slopes in Sri Lanka are composed of residual formations derived as a result of in-situ weathering of parent rocks which are predominantly of metamorphic origin. Due to the heterogeneous and anisotropic nature of this slope forming material, a lot of uncertainties exists with regard to the suitability in popular standard methods in assessing degree of stability of such slopes.

The present study proposes two models in order to overcome these uncertainties. One model is the semi-empirical approach which is essentially based on statistical and probability techniques. This can be used for a quick assessment of a slope using some simple parameters which can be easily recognized in the field. The other model proposes an analytical approach to choose realistic strength parameters of slope forming materials to be used in the already available stability analysis techniques.

On application, the semi-empirical approach would be able to recognize and identify the potential of instability of a particular slope while the other approach provides an opportunity to carry out a detailed geotechnical investigation to determine the degree of instability of a slope.

For slopes that are found unstable, remedial measures have been proposed with a view to increase their degree of stability.

## LIST OF FIGURES

### CHAPTER 2

- Fig. 2.1- Geology of Sri Lanka.
- Fig. 2.2- Residual soil classification system with the weathering profile.
- Fig. 2.3- Tracks of cyclones and storms, 1901-1978.
- Fig. 2.4- Weather data from monthly summary - 1984.
- Fig. 2.5- Weather data from monthly summary - 1985.
- Fig. 2.6- Weather data from monthly summary - 1986.
- Fig. 2.7- Forces acting on a slice.
- Fig. 2.8- Janbu's correction factor chart.

### CHAPTER 3

- Fig. 3.1(a)- Probability distribution  $ER(1)$  for all 64 sites in ascending order.
- Fig. 3.1(b)- Probability frequency against the probability interval 0.0001 for  $ER(1)$ .
- Fig. 3.2- Probability distribution of  $ER(T)$  for 64 sites in ascending order.
- Fig. 3.3- Probability distribution of  $ER(D)$  for 64 sites in ascending order.
- Fig. 3.4- Probability distribution of  $ER(L)$  for 64 sites in ascending order.
- Fig. 3.5- Probability distribution of  $ER(V)$  for 64 sites in ascending order.
- Fig. 3.6- Probability distribution of  $ER(R)$  for 64 sites in ascending order.
- Fig. 3.7- Probability distribution of  $ER(F)$  for 64 sites in ascending order.
- Fig. 3.8- Probability distribution of  $ER(S)$  for 64 sites in ascending order.
- Fig. 3.9- Probability distribution of  $ER(P)$  for 64 sites in ascending order.
- Fig. 3.10- Probability distribution of  $ER(U)$  for 64 sites in ascending order.
- Fig. 3.11- Probability frequency against probability interval for  $ER(T)$ .
- Fig. 3.12- Probability frequency against probability interval for  $ER(D)$ .
- Fig. 3.13- Probability frequency against probability interval for  $ER(L)$ .
- Fig. 3.14- Probability frequency against probability interval for  $ER(V)$ .

- Fig. 3.15-Probability frequency against probability interval for ER(R).
- Fig. 3.16-Probability frequency against probability interval for ER(F).
- Fig. 3.17-Probability frequency against probability interval for ER(S).
- Fig. 3.18-Probability frequency against probability interval for ER(P).
- Fig. 3.19-Probability frequency against probability interval for ER(U)..
- Fig. 3.20- Variation of mean and STD for each trial.
- Fig. 3.21- Normalized frequency distribution for ER(1).
- Fig. 3.22- Normalized frequency distribution for ER(2).
- Fig. 3.23- Normalized frequency distribution for ER(3).
- Fig. 3.24- Normalized frequency distribution for ER(4).
- Fig. 3.25- Normalized frequency distribution for ER(5).
- Fig. 3.26- Normalized frequency distribution for ER(6).

#### CHAPTER 4

- Fig. 4.1- Variation of Factor of Safety (FS) with cohesion correlation factors ( $k_c$  &  $k_c^*$ ) and Friction angle correlation factors ( $k_\phi$  &  $k_\phi$ ).
- Fig. 4.2- Effect of the Global shear strength correlation factor in Laboratory test stress paths.
- Fig. 4.3- Vicinity map of Beragala-Haputale stretch on A-16 road.
- Fig. 4.4- Countour map of Beragala earthslip.
- Fig. 4.5- A Typical Stress - Strain plot of Multi-Stage Consolidated Undrained Triaxial Test (CU).
- Fig. 4.6- A Typical Total and Effective stress paths of Multi-Stage Consolidated Undrained Triaxial Test (CU).
- Fig. 4.7- Subsurface soil profile and the slip surface along the centre line A-A at the slope of Beragala earthslip.
- Fig. 4.8- Variation of Factor of safety (FS) with cohesion correlation factors ( $k_c$  &  $k_c^*$ ) and Friction angle correlation factors ( $k_\phi$  &  $k_\phi^*$ ).
- Fig. 4.9- Variation of Friction angle correlation factors ( $k_\phi$  &  $k_\phi^*$ ) and Cohesion Correlation factors ( $k_c$  &  $k_c^*$ ) for the case of FS=1.
- Fig. 4.10- Vicinity map of Kahagalla earthslip.
- Fig. 4.11- Countour map of Kahagalla earthslip.
- Fig. 4.12- Subsurface soil profile and the slip surface along the centre line A-A at Kahagalla earthslip.

- Fig. 4.13- Variation of factor of safety (FS) with cohesion correlation factor ( $k_c$  &  $k_c^*$ ) and friction angle correlation factors ( $k_\phi$  &  $K_\phi^*$ ).
- Fig. 4.14- Variation of Friction angle correlation factors ( $k_\phi$  &  $k_\phi^*$ ) and Cohesion Correlation factors ( $k_c$  &  $k_c^*$ ) for the case of FS=1.
- Fig. 4.15- Vicinity map of Beckington earthslip - Kirklees estate.
- Fig. 4.16- Contour map of Beckington earthslip.
- Fig. 4.17- Subsurface profile along the centre line A-A at Beckington earthslip.
- Fig. 4.18- Variation of factor of safety (FS) with cohesion correlation factor ( $k_c$  &  $k_c^*$ ) and friction angle correlation factors ( $k_\phi$  &  $K_\phi^*$ ).
- Fig. 4.19- Variation of Friction angle correlation factors ( $k_\phi$  &  $k_\phi^*$ ) and Cohesion Correlation factors ( $k_c$  &  $k_c^*$ ) for the case of FS=1.
- Fig. 4.20- Sensitivity analysis - Friction angle.  
(For different moisture conditions)
- Fig. 4.21- Variation of Cohesion Correlation Factors ( $k_c$ ) with Friction angle Correlation Factor ( $k_\phi$ ) for all 3 sites.
- Fig. 4.22- Typical sketches of failure mechanism.

#### CHAPTER 5

- Fig. 5.1- Subsurface profile of upper slope along the centre line B-B.

## LIST OF TABLES

### CHAPTER 1

Table 1.1 - Landslide occurrences since 1947.

### CHAPTER 2

Table 2.1 - Geological history of Sri Lanka.

Table 2.2 - Residual soil classification system.

Table 2.3 - ISSMFE landslide classification system, 1988.

Table 2.4 - Comparison of safety factors obtained by different methods of slices.

### CHAPTER 3

Table 3.1 - Frequency distribution of selected causative factors.

Table 3.2 - Weightage of each factor.

Table 3.3 - Probability distribution for each factor.

Table 3.4 - Probability distribution for each trial.

### CHAPTER 4

Table 4.1 - Cohesion correlation and friction angle factors for all three sites.

### CHAPTER 5

Table 5.1- Risk Assessment Form.



Thesis title	I
Declaration	II
Acknowledgment	III
Abstract	IV
List of Figures	V
List of Tables	VIII
Table of Contents	IX
CHAPTER 1 INTRODUCTION	1
1.1 Impact of landslides	2
1.2 Scope of the study	3
CHAPTER 2 LITERATURE SURVEY	9
2.1 Geological aspects of landslides in Sri Lanka	9
2.2 Engineering geological aspects	12
2.3 Geotechnical aspects	14
2.4 Residual soil classification and Geotechnical parameters	14
2.5 Climatic aspects	17
2.5.1 Introduction	17
2.5.2 Climate and landslides in Sri Lanka - Case study	19
2.6 Landuse and Topographical aspect	19
2.6.1 Introduction	19
2.6.2 Landuse history associated with landslides in Sri Lanka	24
2.6.3 Hazard maps	25
2.7 Seismicity and microtremors	26
2.8 Landslide classifications	26
2.9 Slope stability analysis	28
2.9.1 Classical methods of slope analysis	29
2.9.2 Features of different slope stability methods	30
2.10 Summary of study	36
CHAPTER 3 RELIABILITY APPROACH IN SLOPE STABILITY	38
3.1 Introduction	38
3.2 Landslide Database	39
3.2.1 Field data collection	39
3.2.2 Computer data storage and sorting	40
3.3 Semi-Empirical approach in slope stability problem	54
3.3.1 Method of analysis	55

3.3.2 Methodology used to find the relative weightage of each parameters.	61
3.3.3 Check for the interrelationship of parameters.	73
3.4 Result and discussion	80
 CHAPTER 4 GEOTECHNICAL INVESTIGATION AND BACK ANALYSIS	 86
4.1 Introduction	86
4.1.1 Objective	88
4.1.2 Scope of the work	88
4.2 Computer software	89
4.2.1 GEOSOFT	89
4.2.2 STABL.	92
4.2.3 Selection of suitable software	93
4.3 Stability analysis	94
4.3.1 Back analysis concept	95
4.3.2 Case studies	98
4.3.2.1 Beragala Earthslip	98
4.3.2.2 Kahagalla Earthslip	108
4.3.2.3 Beckington Earthslip	119
4.3.3 Results and Discussion	128
4.4 Conclusion	135
 CHAPTER 5 UNSTABLE SLOPES : Recognition and stabilization	 137
5.1 Introduction	137
5.2 Standard methods adapted in natural slope designs	138
5.3 Problems in adopting standard methods in residual slopes	139
5.4 Methodology for stability assessment of Sri Lankan residual soil slopes	140
5.4.1 Reliability approach	140
5.4.2 Questionnaire for slope assessment.	141
5.5 Slope stabilization techniques	145
5.6 Case study - Stabilization of Beragala Earthslip	146
5.6.1 Stability analysis - upper (creeping) slope	147
5.6.2 Remedial measures for stabilization	148
5.6.3 Results and discussion	151
 CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS	 152
 Appendix I References	 156

## ANNEXURES

- I Form for field data collection
- II Triaxial test procedures
- III Data input format of STABL computer software
- IV Borelogs
- V Laboratory testing summary

SYNOPSIS

The first part of the book deals with the general principles of the theory of the structure of the atom. It is shown that the structure of the atom is determined by the laws of quantum mechanics. The second part of the book deals with the application of the theory of the structure of the atom to the study of the properties of matter. It is shown that the properties of matter are determined by the laws of quantum mechanics.

The third part of the book deals with the application of the theory of the structure of the atom to the study of the properties of light. It is shown that the properties of light are determined by the laws of quantum mechanics. The fourth part of the book deals with the application of the theory of the structure of the atom to the study of the properties of heat. It is shown that the properties of heat are determined by the laws of quantum mechanics.

The fifth part of the book deals with the application of the theory of the structure of the atom to the study of the properties of sound. It is shown that the properties of sound are determined by the laws of quantum mechanics. The sixth part of the book deals with the application of the theory of the structure of the atom to the study of the properties of electricity. It is shown that the properties of electricity are determined by the laws of quantum mechanics.

CHAPTER 1

The first chapter of the book deals with the general principles of the theory of the structure of the atom. It is shown that the structure of the atom is determined by the laws of quantum mechanics. The second chapter of the book deals with the application of the theory of the structure of the atom to the study of the properties of matter. It is shown that the properties of matter are determined by the laws of quantum mechanics.