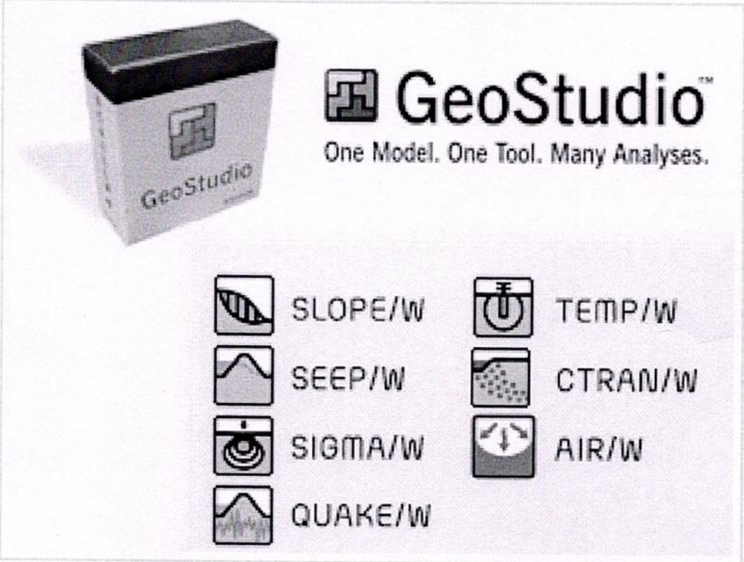
Kandula Srinivasa Reddy Memorial College of Engineering (Autonomous)

Kadapa-516003. AP

(Approved by AICTE, Affiliated to JNTUA, Ananthapuramu, Accredited by NAAC)

(An ISO 9001-2008 Certified Institution)

Department of Civil Engineering



Certification Course

on

Design of Slopes using GeoStudio

Course Instructor:

Sri P. Rajendra Kumar, Assistant Professor, Civil Engg. Dept., KSRMCE

Course Coordinators:

Mrs. K. Niveditha, Assistant Professor, Civil Engg. Dept., KSRMCE

Sri. D. Viswanatha, Assistant Professor, Civil Engg. Dept., KSRMCE

Date: 10/05/2021 to 27/05/2021

K.S.R.M. COLLEGE OF ENGINEERING
(UGC-AUTONOMOUS)
Kadapa, Andhra Pradesh, India– 516 003
Approved by AICTE, New Delhi & Affiliated to JNTUA, Ananthapuramu.
An ISO 14001:2004 & 9001: 2015 Certified Institution

Lr./KSRMCE/CE/2020-21/ Date: 04-05-2021

From
K. Niveditha and D. Viswanatha,
Asst. Professor,
Dept. of Civil Engineering,
KSRMCE,
Kadapa.

To
The Principal,
KSRMCE,
Kadapa.

Sub: Permission to Conduct Certificate Course – Reg.

Respected Sir,

The Department of Civil Engineering is planning to offer a certification course on “Design of Slopes using GeoStudio” for B. Tech. students of Civil Engineering. The course will start on 10th May. 2021 and the course will run for a total number of 30 hours. In this regard, I am requesting you to accept the proposal to conduct certification course.

Thanking you

Yours faithfully

(K. Niveditha and D. Viswanatha)

Permitted
V. S. S. Murty

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Cr./KSRMCE/CE/2020-21/ Date: 06/05/2021

Circular

The Department of Civil Engineering is offering a certification course on Design of Slopes using GeoStudio. The course will start on 10-05-2021 and the course will run for a total number of 30 hours. In this regard, interested students of Civil Engineering are required to register for the Certification Course. The registration link is given below.

https://docs.google.com/forms/f/g/KfeshuJSufmemgj24f5sHAEsdnfpof71jsQEdlfgmzpsq88JJldnnckoa/viewform

The Course Coordinators
K. Niveditha and D. Viswanatha,
Assistant Professor,
Department of Civil Engg.- KSRMCE.

V. S. S. Murty
Principal

PRINCIPAL
K.S.R.M. COLLEGE OF ENGINEERING
KADAPA - 516 003. (A.P.)

Cc to:

The Director, KSRMCE

The HoD-Civil, KSRMCE

IQAC-KSRMCE

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Department of Civil Engineering

Registration list of Certification course on "Design of Slopes using GeoStudio"

Sl. No.	Student Roll No.	Student Name	Sec.	Mail ID
1	189Y1A0108	Maheswari Bokkasam	A	189Y1A0108@ksrmce.ac.in
2	189Y1A0115	Satish Kumar Yadav Chennuboyina	A	189Y1A0115@ksrmce.ac.in
3	189Y1A0126	Venkata Jithendhar Reddy Duddekunta	A	189Y1A0126@ksrmce.ac.in
4	189Y1A0132	Lakshmi Prasad Reddy Guddila	A	189Y1A0132@ksrmce.ac.in
5	189Y1A0135	Sreeveni Hasti	A	189Y1A0135@ksrmce.ac.in
6	189Y1A0144	Bhanumanikanta Reddy Kannapu	A	189Y1A0144@ksrmce.ac.in
7	189Y1A0146	Govardhan Kaveti	A	189Y1A0146@ksrmce.ac.in
8	189Y1A0156	Sudheer Kumar Maadam	A	189Y1A0156@ksrmce.ac.in
9	189Y1A0158	Lokeshwar Reddy Mallireddy	A	189Y1A0158@ksrmce.ac.in
10	189Y1A0159	Ganesh Mandla	A	189Y1A0159@ksrmce.ac.in
11	189Y1A0163	Sampath Kumar Meka	B	189Y1A0163@ksrmce.ac.in
12	189Y1A0166	Siva Prasad Reddy Mitta	B	189Y1A0166@ksrmce.ac.in
13	189Y1A0171	Venkata Sai Poojith Nagalla Pati	B	189Y1A0171@ksrmce.ac.in
14	189Y1A0172	Venkatesh Nagirikanti	B	189Y1A0172@ksrmce.ac.in
15	189Y1A0175	Abhish Nanubala	B	189Y1A0175@ksrmce.ac.in
16	189Y1A0179	Jayachandra Sai Pandugolu	B	189Y1A0179@ksrmce.ac.in
17	189Y1A0187	Rakesh Prasanna Penubala	B	189Y1A0187@ksrmce.ac.in
18	189Y1A0193	Bindhu Rachamallu	B	189Y1A0193@ksrmce.ac.in
19	189Y1A0198	Afroz Shaik	B	189Y1A0198@ksrmce.ac.in
20	189Y1A01B0	Sateesh Kumar Reddy Thallapalle	B	189Y1A01B0@ksrmce.ac.in
21	189Y1A01B2	Siva Reddy Thatimakula	B	189Y1A01B2@ksrmce.ac.in
22	189Y1A01B4	Gayathri Thopudurthy	B	189Y1A01B4@ksrmce.ac.in

23	189Y1A01B8	Venkata Hemanth Usugari	B	189Y1A01B8@ksrmce.ac.in
24	189Y1A01C3	Ganga Swetha Vennapusa	B	189Y1A01C3@ksrmce.ac.in
25	189Y1A01C6	Naga Hema Pranitha Sree Yelikanti	B	189Y1A01C6@ksrmce.ac.in
26	189Y1A01C8	Sivanatha Reddy Yeturu	B	189Y1A01C8@ksrmce.ac.in
27	199Y5A0107	Vijay Kumar Reddy Basireddygari	C	199Y5A0107@ksrmce.ac.in
28	199Y5A0108	Sai Bonthalapalli	C	199Y5A0108@ksrmce.ac.in
29	199Y5A0112	Mahesh Babu Chinthakunta	C	199Y5A0112@ksrmce.ac.in
30	199Y5A0115	Sreenivasulu Dasari	C	199Y5A0115@ksrmce.ac.in
31	199Y5A0116	Pavan Kalyan Dokka	C	199Y5A0116@ksrmce.ac.in
32	199Y5A0117	Dastagiri Dudekula	C	199Y5A0117@ksrmce.ac.in
33	199Y5A0118	Premaraju Erapogu	C	199Y5A0118@ksrmce.ac.in
34	199Y5A0123	Ramu Gosetty	C	199Y5A0123@ksrmce.ac.in
35	199Y5A0125	Venkateshwarlu Judam	C	199Y5A0125@ksrmce.ac.in
36	199Y5A0127	Venkateswarlu Kashetty	C	199Y5A0127@ksrmce.ac.in
37	199Y5A0130	Vinodkumar Madhuranthakam	C	199Y5A0130@ksrmce.ac.in
38	199Y5A0132	Mahesh Mallepogu Budigi	C	199Y5A0132@ksrmce.ac.in
39	199Y5A0134	Sai Kumar Mannula	C	199Y5A0134@ksrmce.ac.in
40	199Y5A0138	Reddaiah Nagulugari	C	199Y5A0138@ksrmce.ac.in
41	199Y5A0144	Praveen Kumar Reddy Pathi	C	199Y5A0144@ksrmce.ac.in
42	199Y5A0149	Chandramouli Sambaturu	C	199Y5A0149@ksrmce.ac.in
43	199Y5A0150	Sambasivareddy Sanikommu	C	199Y5A0150@ksrmce.ac.in
44	199Y5A0155	Sravani Sirigiri	C	199Y5A0155@ksrmce.ac.in
45	199Y5A0156	Abhishek Kumar Reddy Suda	C	199Y5A0156@ksrmce.ac.in
46	199Y5A0157	Siva Krishna Suripaka	C	199Y5A0157@ksrmce.ac.in
47	199Y5A0159	Chandu Thoti	C	199Y5A0159@ksrmce.ac.in

Coordinators

HoD-Civil Engg.

Head
Department of Civil Engineering
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KADAPA 516 003. (A.P.)

Syllabus of Certification Course

Course Name: Design of Slopes using GeoStudio

Duration: 30 Hours

Module I:

Fundamentals on slopes, Types of slopes, Methods of analysis -Limit Equilibrium, Numerical Methods like Finite Element Methods, Finite Difference Methods, boundary Element methods, Universal Distinct Element Methods, Langranian Methods. Causes of Failures

Module II:

Different Limit equilibrium methods and its application to slopes, Introdcution about Geo Studio, Fundamentals on LE

Module III:

Different Shapes of Slip surfaces, Geometry of slope, various functions in Geo Studio, Material strength of different soils and evaluation of properties in lab and field

Module IV

Examples on various site conditions – slope, Embankment, Layered Soil

Text Books:

1. Slope Stability Modeling with Geo Studio by Geo Slope International, Ltd.
2. Slope Stability and Stabilization Methods Glenn M. Boyce, Thoms S.Lee, Sunil Sharma, Lee W. Abramson, John Wiley & Sons Publishers

References:

1. https://www.seequent.com/products-solutions/geostudio/slope/

Head
Department of Civil Engineering
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V. S. S.

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Department of Civil Engineering

Certification course on "Design of Slopes using GeoStudio"

Date	Timing	Course Instructor	Topic to be covered
10-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Fundamentals on slopes, Types of slopes
11-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Methods of analysis -Limit Equilibrium
12-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Numerical Methods like Finite Element Methods
13-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Finite Difference Methods
15-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	boundary Element methods, Universal Distinct Element Methods, Langranian Methods. Causes of Failures
17-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Different Limit equilibrium methods and its application to slopes
18-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Introdcution about Geo Studio, Fundamentals on LE
19-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Different Shapes of Slip surfaces, Geometry of slope
20-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	various functions in Geo Studio
21-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Material strength of different soils and evaluation of properties in lab and field
22-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Material strength of different soils and evaluation of properties in lab and field
24-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Material strength of different soils and evaluation of properties in lab and field
25-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Examples on various site conditions – slope, Embankment, Layered Soil
26-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Examples on various site conditions – slope, Embankment, Layered Soil
27-05-21	4 PM to 6 PM	Sri P. Rajendra Kumar	Examples on various site conditions – slope, Embankment, Layered Soil

V. S. S.

Principal

Instructor: P. Rajendra Kumar

Coordinators:

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K.S.R.M. COLLEGE OF ENGINEERING
KADAPA - 516 003. (A.P.)

Report

of

Certification Course on Design of Slopes using GeoStudio.

From 10/05/2021 to 27/05/2021

Target Group : **Students**
Details of Participants : **47 Students**
Co-coordinator(s) : **Mrs. K. Niveditha and Sri. D. Viswanatha**
Organizing Department : **Civil Engineering**
Venue : **Online (google meet)**
Link: https://meet.google.com/lookup/klaww5wfa

Description:

The Department of Civil Engineering offered the certification course on "Design of Slopes using GeoStudio" from 10-05-2021 to 27-05-2021 and the course was organized for a total number of 30 hours. The course was instructed by Dr. P. Rajendra Kumar (Assistant Professor, Dept. Civil Engg.) and coordinated by K Niveditha, D Viswanatha (Assistant Professor, Dept. of Civil Engg.).

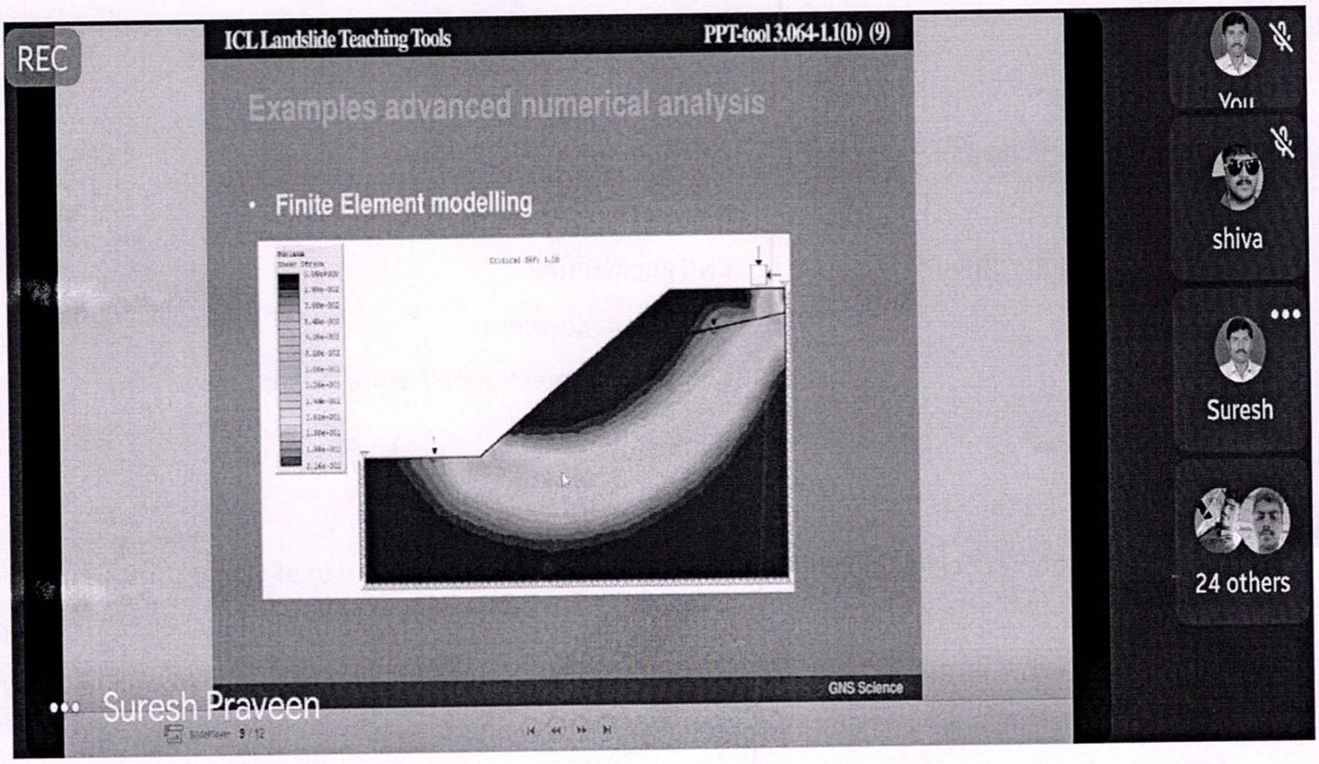
Geo Studio is one of the most widely used slope analysis and design software products worldwide. In this course students get a clear picture of the risks and complexities of projects involving rock and soil slopes. Apply multiple analysis methods and make better decisions with all the data consolidated in a visible model. Design more effective solutions and optimise engineering efforts using intuitive workflows. Designed for a large variety of projects to analyse stability problems for soil and rock slopes, construction and excavations, dams and levees, open-pit highwalls, tailings dams and more. Make safer design decisions based on thorough analysis of slip surface shapes, pore-water pressure conditions, soil properties, and loading conditions. Harness powerful analysis capability and test scenarios by changing condition parameters and definitions. Allow the rigorous solution algorithm to display difficult problems close up.

Build a clear picture of typical conditions, explore variables and design optimal stabilisation and reinforcement options that meet code requirements.

The course was designed by considering the student are new to the Geo studio Software. The course started by giving instruction to process of installing the software and brief on various installation problems. The course ended by designing a slope and embankment

Photo:

The picture taken during the course are given below:



ICL Landslide Teaching Tools

PPT-tool 3.064-1.1(b) (9)

Examples advanced numerical analysis

- Finite Element modelling

GNS Science

P-Rajendra Kumar

(Course Instructor)

(HoD, Civil Engg.)

Head
Department of Civil Engineering
K.S.R.M. College of Engineering
(Autonomous)
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V.S.S. Mu/5

Principal

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K.S.R.M COLLEGE OF ENGINEERING

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Kadapa, Andhra Pradesh, India- 516 003

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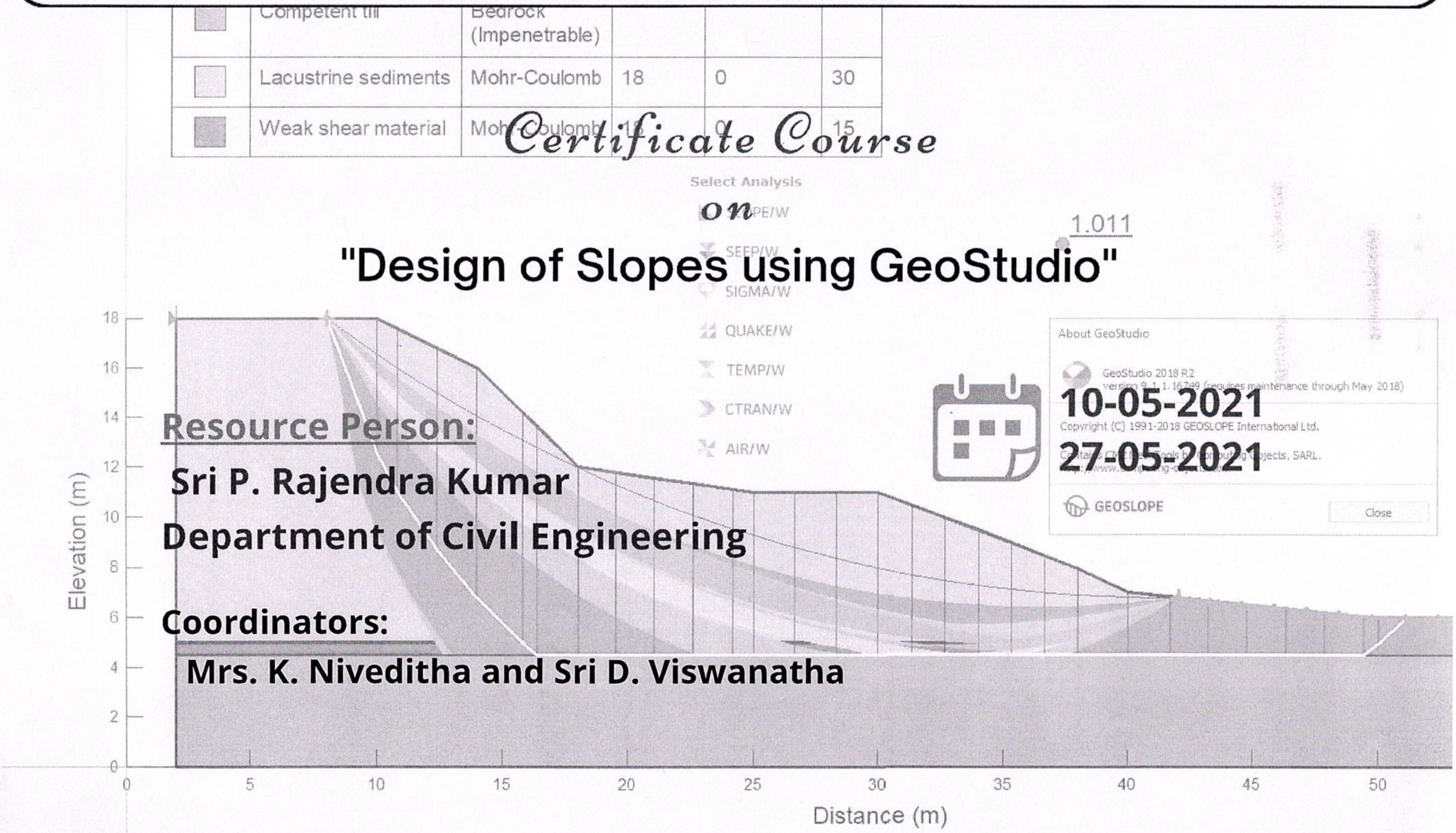
ESTD: 1980

DEPARTMENT OF CIVIL ENGINEERING



▨	Competent till	Bedrock (Impenetrable)			
▨	Lacustrine sediments	Mohr-Coulomb	18	0	30
▨	Weak shear material	Mohr-Coulomb	18	0	15

About GeoStudio

GeoStudio 2018 R2
version 9.1.1.16749 (requires maintenance through May 2018)
Copyright (C) 1991-2018 GEOSLOPE International Ltd.
Contains CGAL Tools by Computing Objects, SARL.

Certificate Course

on

"Design of Slopes using GeoStudio"

10-05-2021

27-05-2021

Resource Person:

Sri P. Rajendra Kumar

Department of Civil Engineering

Coordinators:

Mrs. K. Niveditha and Sri D. Viswanatha

Department of Civil Engineering

Attendance sheet of Certification course on Design of Slopes using GeoStudio

Sl. No.	Student Roll No.	Student Name	10/ 05	11/ 05	12/ 05	13/ 05	15/ 05	17/ 05	18/ 05	19/ 05	20/ 05	21/ 05	22/ 05	24/ 05	25/ 05	26/ 05	27/ 05
1	189Y1A0108	Maheswari Bokkasam	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	189Y1A0115	Satish Kumar Yadav Chennuboyina	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	A	✓	✓
3	189Y1A0126	Venkata Jithendhar Reddy Duddekunta	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	189Y1A0132	Lakshmi Prasad Reddy Guddila	✓	✓	✓	✓	✓	A	A	✓	✓	✓	✓	✓	✓	✓	✓
5	189Y1A0135	Sreeveni Hasti	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6	189Y1A0144	Bhanumanikanta Reddy Kannapu	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
7	189Y1A0146	Govardhan Kaveti	✓	✓	A	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	A
8	189Y1A0156	Sudheer Kumar Maadam	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
9	189Y1A0158	Lokeshwar Reddy Mallireddy	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
10	189Y1A0159	Ganesh Mandla	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	A	✓	✓	✓
11	189Y1A0163	Sampath Kumar Meka	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
12	189Y1A0166	Siva Prasad Reddy Mitta	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
13	189Y1A0171	Venkata Sai Poojith Nagalla Pati	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
14	189Y1A0172	Venkatesh Nagirikanti	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

15	189Y1A0175	Abhish Nanubala	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16	189Y1A0179	Jayachandra Sai Pandugolu	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
17	189Y1A0187	Rakesh Prasanna Penubala	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓
18	189Y1A0193	Bindhu Rachamallu	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A
19	189Y1A0198	Afroz Shaik	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
20	189Y1A01B0	Sateesh Kumar Reddy Thallapalle	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
21	189Y1A01B2	Siva Reddy Thatimakula	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓
22	189Y1A01B4	Gayathri Thopudurthy	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
23	189Y1A01B8	Venkata Hemanth Usugari	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	A	✓	✓	✓	✓
24	189Y1A01C3	Ganga Swetha Vennapusa	✓	✓	✓	A	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓
25	189Y1A01C6	Naga Hema Pranitha Sree Yelikanti	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A
26	189Y1A01C8	Sivanatha Reddy Yeturu	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
27	199Y5A0107	Vijay Kumar Reddy Basireddygari	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A
28	199Y5A0108	Sai Bonthalapalli	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
29	199Y5A0112	Mahesh Babu Chinthakunta	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓
30	199Y5A0115	Sreenivasulu Dasari	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
31	199Y5A0116	Pavan Kalyan Dokka	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

32	199Y5A0117	Dastagiri Dudekula	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓
33	199Y5A0118	Premaraju Erapogu	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A
34	199Y5A0123	Ramu Gosetty	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
35	199Y5A0125	Venkateshwarlu Judam	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
36	199Y5A0127	Venkateswarlu Kashetty	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
37	199Y5A0130	Vinodkumar Madhuranthakam	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
38	199Y5A0132	Mahesh Mallepogu Budigi	✓	✓	A	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
39	199Y5A0134	Sai Kumar Mannula	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓
40	199Y5A0138	Reddaiah Nagulugari	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
41	199Y5A0144	Praveen Kumar Reddy Pathi	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓
42	199Y5A0149	Chandramouli Sambaturu	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A
43	199Y5A0150	Sambasivareddy Sanikommu	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
44	199Y5A0155	Sravani Sirigiri	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
45	199Y5A0156	Abhishek Kumar Reddy Suda	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A
46	199Y5A0157	Siva Krishna Suripaka	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
47	199Y5A0159	Chandu Thoti	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Coordinator

HoD-Civil Engg.

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2 Limit Equilibrium Fundamentals

2.1 *Introduction*

In 2003, at the Canadian Geotechnical Conference in Calgary, Alberta, Krahn (2003) presented the R.M. Hardy Lecture. The title of the lecture was, *The Limits of Limit Equilibrium Analyses*. This chapter is in large part a replication of this Lecture and as published in the Canadian Geotechnical Journal, Vol. 40, pages 643 to 660.

The main message of the lecture was that limit equilibrium methods for assessing the stability of earth structures are now used routinely in practice. In spite of this extensive use, the fundamentals of the methods are often not that well understood and expectations exceed what the methods can provide. The fact and implications that limit equilibrium formulations are based on nothing more than equations of statics with a single, constant factor of safety is often not recognized. A full appreciation of the implications reveals that the method has serious limitations.

To use limit equilibrium methods effectively, it is important to understand and comprehend the inherent limitations. This chapter discusses the fundamentals of limit equilibrium formulations, points out the limitations, explores what can be done to overcome the limitations, and ends with general guidelines on the continued use of the method in practice.

2.2 *Background and history*

Limit equilibrium types of analyses for assessing the stability of earth slopes have been in use in geotechnical engineering for many decades. The idea of discretizing a potential sliding mass into vertical slices was introduced early in the 20th century and is consequently the oldest numerical analysis technique in geotechnical engineering.

In 1916, Petterson (1955) presented the stability analysis of the Stigberg Quay in Gothenberg, Sweden where the slip surface was taken to be circular and the sliding mass was divided into slices. During the next few decades, Fellenius (1936) introduced the Ordinary or Swedish method of slices. In the mid-1950s Janbu (1954) and Bishop (1955) developed advances in the method. The advent of electronic computers in the 1960's made it possible to more readily handle the iterative procedures inherent in the method, which led to mathematically more rigorous formulations such as those developed by Morgenstern and Price (1965) and by Spencer (1967). The introduction of powerful desktop personal computers in the early 1980s made it economically viable to develop commercial software products based on these techniques, and the ready availability today of such software products has led to the routine use of limit equilibrium stability analysis in geotechnical engineering practice.

Modern limit equilibrium software such as SLOPE/W is making it possible to handle ever-increasing complexity in the analysis. It is now possible to deal with complex stratigraphy, highly irregular pore-water pressure conditions, a variety of linear and nonlinear shear strength models, virtually any kind of slip surface shape, concentrated loads, and structural reinforcement. Limit equilibrium formulations based on the method of slices are also being applied more and more to the stability analysis of structures such as tie-back walls, nail or fabric reinforced slopes, and even the sliding stability of structures subjected to high horizontal loading arising, for example, from ice flows.

While modern software is making it possible to analyze ever-increasingly complex problems, the same tools are also making it possible to better understand the limit equilibrium method. Computer-assisted graphical viewing of data used in the calculations makes it possible to look beyond the factor of safety. For example, graphically viewing all the detailed forces on each slice in the potential sliding mass, or viewing the distribution of a variety of parameters along the slip surface, helps greatly to understand the details of the technique. From this detailed information, it is now becoming evident that the method has its limits and that it is perhaps being pushed beyond its initial intended purpose. Initially, the method of slices was conceived for the situation where the normal stress along the slip surface is primarily influenced by gravity (weight of the slice). Including reinforcement in the analysis goes far beyond the initial intention.

2.3 Method basics

Many different solution techniques for the method of slices have been developed over the years. Basically, all are very similar. The differences between the methods are depending on: what equations of statics are included and satisfied and which interslice forces are included and what is the assumed relationship between the interslice shear and normal forces? Figure 2-1 illustrates a typical sliding mass discretized into slices and the possible forces on the slice. Normal and shear forces act on the slice base and on the slice sides.

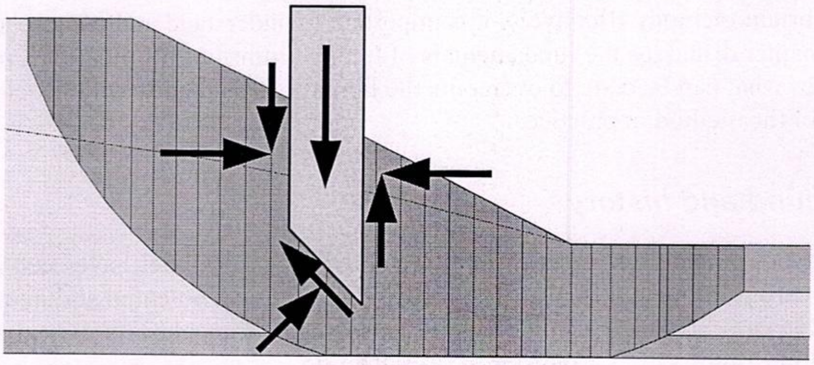

Figure 2-1 Slice discretization and slice forces in a sliding mass

The Ordinary, or Fellenius method was the first method developed. The method ignored all interslice forces and satisfied only moment equilibrium. Adopting these simplified assumptions made it possible to compute a factor of safety using hand calculations, which was important since there were no computers available.

Later Bishop (1955) devised a scheme that included interslice normal forces, but ignored the interslice shear forces. Again, Bishop's Simplified method satisfies only moment equilibrium. Of interest and significance with this method is the fact that by including the normal interslice forces, the factor of safety equation became nonlinear and an iterative procedure was required to calculate the factor of safety. The Janbu's Simplified method is similar to the Bishop's Simplified method in that it includes the normal interslice forces and ignores the interslice shear forces. The difference between the Bishop's Simplified and Janbu's Simplified methods is that the Janbu's Simplified method satisfies only horizontal force equilibrium, as opposed to moment equilibrium.

Later, computers made it possible to more readily handle the iterative procedures inherent in the limit equilibrium method, and this lead to mathematically more rigorous formulations which include all interslice forces and satisfy all equations of statics. Two such methods are the Morgenstern-Price and Spencer methods.

the factor of safety with respect to horizontal force equilibrium (F_f). The idea of using two factor of safety equations was actually first published by Spencer (1967).

The interslice shear forces in the GLE formulation are handled with an equation proposed by Morgenstern and Price (1965). The equation is:

$$X = E\lambda f(x)$$

where:

$f(x)$ = a function,

λ = the percentage (in decimal form) of the function used,

E = the interslice normal force, and

X = the interslice shear force.

Figure 2-2 shows a typical half-sine function. The upper curve in this figure is the actual specified function. The lower curve is the function used. The ratio between the two curves represents λ. Lambda (λ) in Figure 2-2 is 0.43. At Slice 10, f(x) = 0.83. If, for example, E = 100 kN, then X = E f(x) λ = 100 x 0.43 x 0.83 = 35.7 kN. Arc tan (35.7/100) = 19.6 degrees. This means the interslice resultant force is inclined at 19.6 degrees from the horizontal at Slice 10. One of the key issues in the limit equilibrium formulation, as will be illustrated later, is knowing how to define this interslice function.

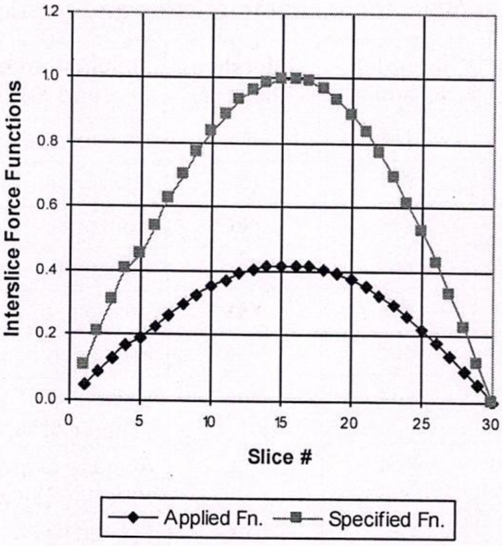

Figure 2-2 Half-sine interslice force function

The GLE factor of safety equation with respect to moment equilibrium is:

$$F_m = \frac{\sum (c'\beta R + (N - u\beta)R \tan\phi')}{\sum Wx - \sum Nf \pm \sum Dd}$$

The factor of safety equation with respect to horizontal force equilibrium is:

$$F_f = \frac{\sum (c'\beta \cos\alpha + (N - u\beta)\tan\phi' \cos\alpha)}{\sum N \sin\alpha - \sum D\cos\omega}$$

Table 2-1 lists the methods available in SLOPE/W and indicates what equations of statics are satisfied for each of the methods. Table 2-2 gives a summary of the interslice forces included and the assumed relationships between the interslice shear and normal forces.

Further details about all the methods are presented elsewhere.

Table 2-1 Equations of Statics Satisfied

Method	Moment Equilibrium	Force Equilibrium
Ordinary or Fellenius	Yes	No
Bishop's Simplified	Yes	No
Janbu's Simplified	No	Yes
Spencer	Yes	Yes
Morgenstern-Price	Yes	Yes
Corps of Engineers – 1	No	Yes
Corps of Engineers – 2	No	Yes
Lowe-Karafiath	No	Yes
Janbu Generalized	Yes (by slice)	Yes
Sarma – vertical slices	Yes	Yes

Table 2-2 Interslice force characteristics and relationships

Method	Interslice Normal (E)	Interslice Shear (X)	Inclination of X/E Resultant, and X-E Relationship
Ordinary or Fellenius	No	No	No interslice forces
Bishop's Simplified	Yes	No	Horizontal
Janbu's Simplified	Yes	No	Horizontal
Spencer	Yes	Yes	Constant
Morgenstern-Price	Yes	Yes	Variable; user function
Corps of Engineers – 1	Yes	Yes	Inclination of a line from crest to
Corps of Engineers – 2	Yes	Yes	Inclination of ground surface at top of slice
Lowe-Karafiath	Yes	Yes	Average of ground surface and slice base inclination
Janbu Generalized	Yes	Yes	Applied line of thrust and moment equilibrium of slice
Sarma – vertical slices	Yes	Yes	$X = C + E \tan \phi$

2.4 General limit equilibrium formulation

A general limit equilibrium (GLE) formulation was developed by Fredlund at the University of Saskatchewan in the 1970's (Fredlund and Krahn 1977; Fredlund et al. 1981). This formulation encompasses the key elements of all the methods listed in Table 1. The GLE formulation is based on two factors of safety equations and allows for a range of interslice shear-normal force conditions. One equation gives the factor of safety with respect to moment equilibrium (F_m) while the other equation gives

2.7 *Stress distributions*

The primary unknown in a limit equilibrium formulation is the normal at the base of the slice. Plotting the stresses along a slip surface gives an indication of the stress distribution in the slope. The computed stresses are, however, not always representative of the true stresses in the ground.

Consider the simple 45-degree slope in Figure 2-9 and Figure 2-10 with a slip surface through the toe and another deeper slip surface below the toe. The normal stress distribution along the slip surface from a limit equilibrium Morgenstern-Price analysis with a constant interslice force function is compared with the normal stress distribution from a linear-elastic finite element stress analysis. For the toe slip surface, the normal stresses are quite different, especially in the toe area. The normal stress distributions for the deeper slip surface are closer, but still different for a good portion of the slip surface.

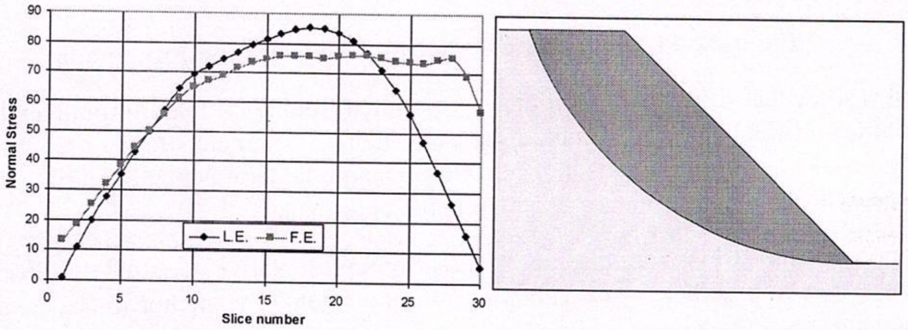

Figure 2-9 Normal stress distribution along a toe slip surface

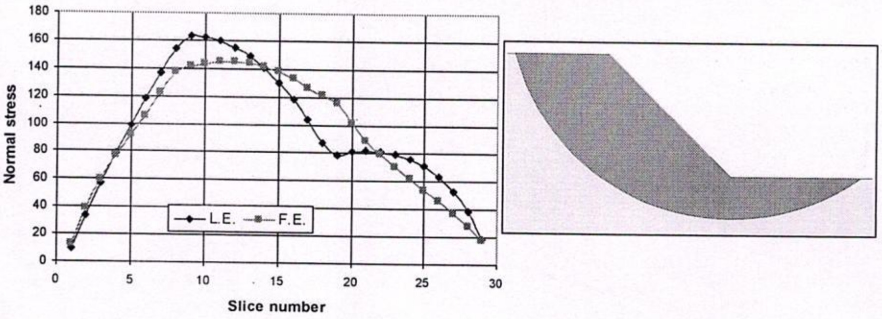

Figure 2-10 Normal stress distribution along a deep slip surface

Figure 2-11 presents a case with reinforcement. The reinforcement loads are applied at the point where the slip surface intersects the line of action. Again there are significant differences between the limit equilibrium normal stresses and the finite element stresses, particularly for the slices which include the reinforcement loads. The finite element stresses show some increase in normal stresses due to the nails, but not as dramatic as the limit equilibrium stresses.

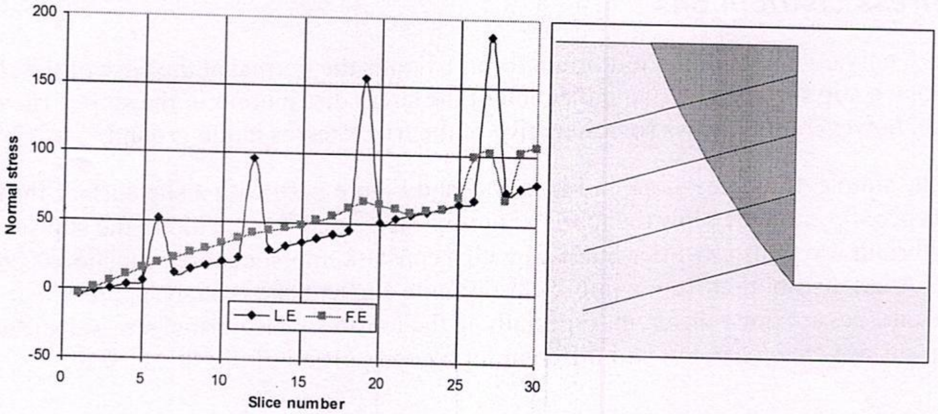

Figure 2-11 Normal stress distributions with reinforcement

These examples show that the stress conditions as computed from a limit equilibrium analysis may be vastly different from finite element computed stresses. The finite element stresses are more realistic and are much closer to the actual conditions in the ground. The implication is that the limit equilibrium computed stresses are not representative of actual field conditions.

The sliding mass internal stresses are also not necessarily representative of actual field conditions. Figure 2.12 presents the case of a tie-back wall with two rows of anchors. The anchor forces are applied where the slip surface intersects the anchor.

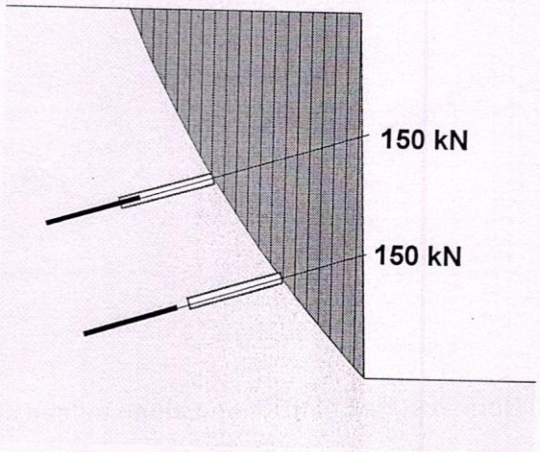

Figure 2-12 Tie-back wall example

The free body diagrams and force polygons for two different slices are presented in Figure 2-13 and Figure 2-14.

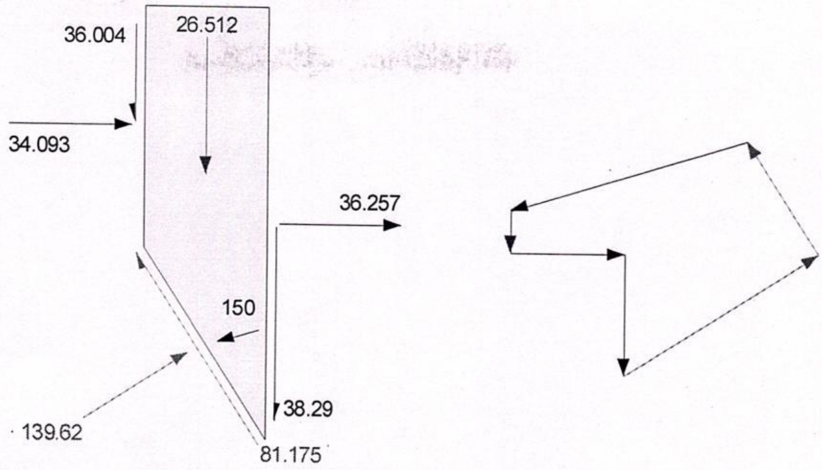

Figure 2-13 Free body and force polygon for upper anchor

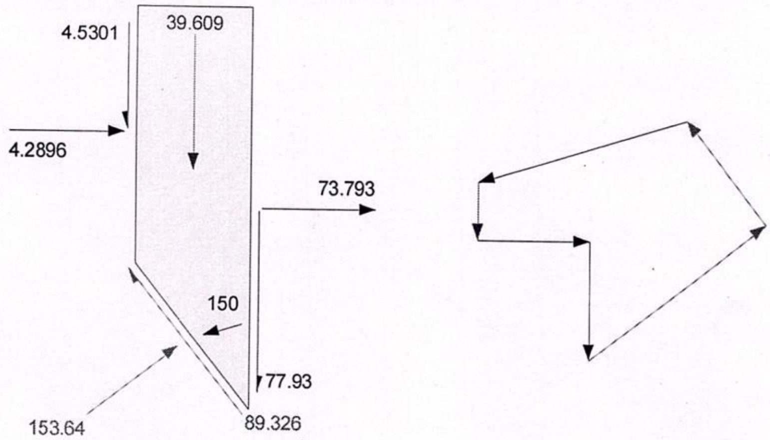

Figure 2-14 Free body and force polygon for lower anchor

Note that the interslice normals point away from the slice on the right side. This indicates tension between the slides, which is obviously not the case in the field. Plotting the interslice forces as in Figure 2-15 further highlights this difficulty. At each of the anchor locations, the interslice normals become negative and the interslice shear forces reverse direction. Of great significance, however, is the fact that the force polygons close signifying that the slices are in equilibrium. In this sense, the results fulfill in part the objectives of the limit equilibrium formulation.

When looking at the exact same situation, but with the anchor loads applied at the wall, the interslice forces are now completely different. Figure 2-16 again shows the interslice shear and normal forces. The normal force increases evenly and gradually except for the last two slices. Of interest is the interslice shear force. The direction is now the reverse of that which usually occurs when only the self weight of the slices is included (simple gravity loading). The shear stress reversal is a reflection of a negative lambda (λ).

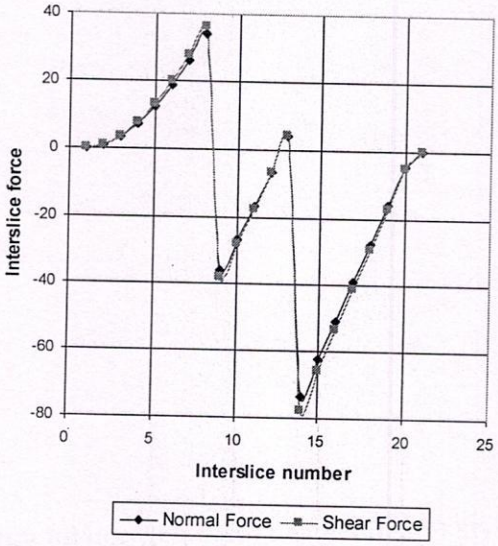

Figure 2-15 Interslice shear and normal forces with anchor loads applied at the slip surface

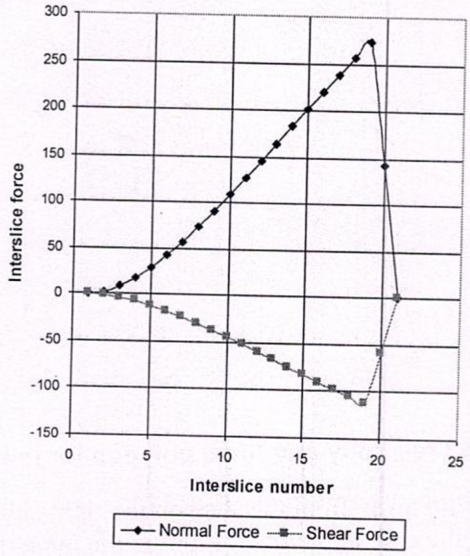

Figure 2-16 Interslice shear and normal forces with anchor loads applied at face of wall

The large differences in the interslice forces also lead to significantly different normal stress distributions along the slip surface, as shown in Figure 2-17. It was noted earlier that the equation for the normal at the base of the slices includes terms for the interslice shear forces. This example vividly illustrates this effect.

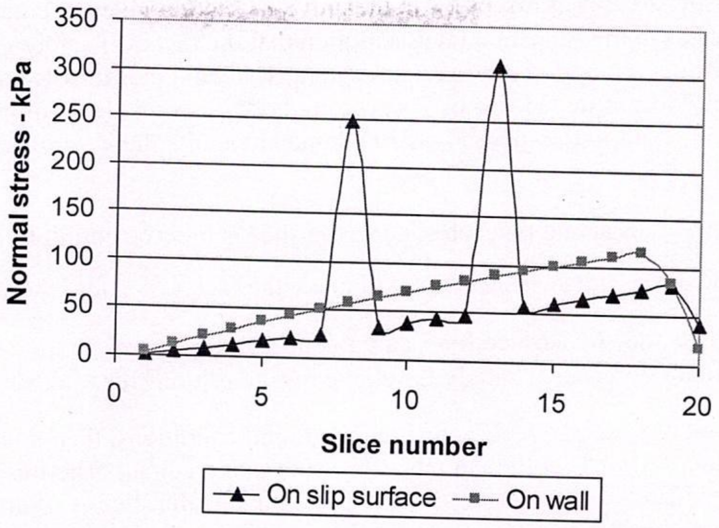

Figure 2-17 Comparison of normal stress distributions

Interestingly, in spite of the vastly different stresses between the slices and along the slip surface, the factors of safety are nearly identical for these two approaches of applying the anchor loads. With the anchors applied at the slip surface location, the factor of safety is 1.075 and when they are applied at the wall, the factor of safety is 1.076. The following table highlights this important and significant result.

Anchor Force Location	Factor of Safety
On slip surface	1.075
On wall	1.076

For all practical purposes they are the same. The reason for this is discussed later.

Another reason why the stresses do not represent field conditions is that in the limit equilibrium formulation the factor of safety is assumed to be the same for each slice. In reality this is not correct. In reality the local factor of safety varies significantly, as demonstrated in Figure 2-18.

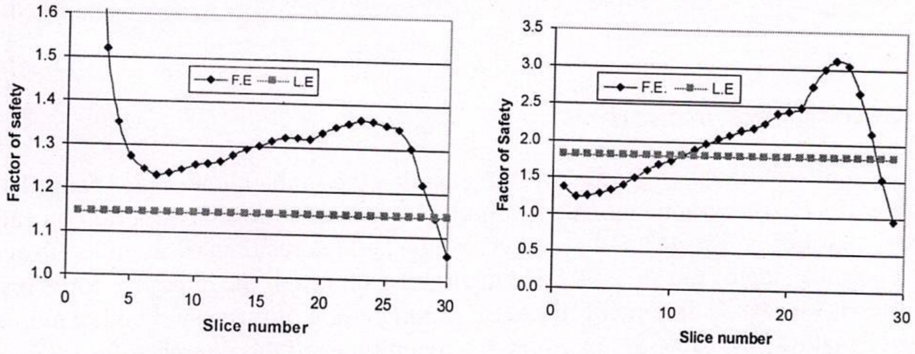

Figure 2-18 Local variation safety factors

Forcing the factor of safety to be the same for all slices over-constrains the problem, with the result that computed stresses are not always real.

2.8 Limit equilibrium forces and stresses

Why can such unrealistic stresses as discussed in the previous section give a seemingly reasonable factor of safety? The answer lies in the fundamental assumption that the factor of safety is the same for each slice. The limit equilibrium method of slices requires iterative techniques to solve the nonlinear factor of safety equations. In the Morgenstern-Price or Spencer methods, a second level of iterations is required to find the slice forces that result in the same F_m and F_f. Fundamentally, the iterations are required to meet two conditions, namely:

- To find the forces acting on each slice so the slice is in force equilibrium, and
- To find the forces on each slice that will make the factor of safety the same for each slice.

This means that interslice and slip surface forces are not necessarily representative of the actual insitu conditions, but they are the forces that satisfy the above two conditions for each slice.

If the slice forces are not representative of actual insitu ground conditions, then it is also not possible to determine a realistic line of thrust for the interslice shear-normal resultant. The forces on each slice that meet the above two conditions can result in a line of thrust outside the slice, a further indication that the slice forces are not always realistic.

Fortunately, even though the limit equilibrium statics formulation does not give realistic slice forces locally, the global factor of safety is nonetheless realistic. Once all the mobilized driving forces and base resisting shear forces are integrated, the local irregularities are smoothed out, making the overall factor of safety for the entire sliding mass quite acceptable.

As a footnote, it is interesting that the early developers of the method of slices recognized the limitations of computing realistic stresses on the slip surface. Lambe & Whitman (1969) in their text book *Soil Mechanics* point out that the normal stress at a point acting on the slip surface should be mainly influenced by the weight of the soil lying above that point. This, they state, forms the basis of the method of slices. Morgenstern and Sangrey (1978) state that one of the uses "… of the factor of safety is to provide a measure of the average shear stress mobilized in the slope." They go on to state that, "This should not be confused with the actual stresses." Unfortunately, these fundamental issues are sometimes forgotten as use of a method is gradually adopted in routine practice.

While the early developers of the method of slices intuitively recognized that the slice stress may not be real, they did not have finite element tools to demonstrate the way in which they differ from the actual ground stresses. Now, with the help of finite element analyses, it is possible to show that the difference is quite dramatic.

2.9 Janbu generalized method

In the context of stress distributions, it is of interest to examine the Janbu Generalized formulation (Janbu, 1954; Janbu, 1957). The Janbu Generalized method imposes a stress distribution on each slice. The interslice stress distribution is often assumed hydrostatic and the resultant is assumed to act on the lower third point along the side of the slice. A line which passes through the interslice force resultants on either side of the slice is known as the line of thrust. Assuming a line of thrust and taking moments about the base of each slice makes it possible to determine the magnitudes of the interslice force.

This approach works reasonably well provided the actual stress distribution in the ground is close to the imposed stress distribution, such as when the slip surface does not have sharp corners and the sliding mass is long relative to the slide depth. More generally, the approach works well when the potential sliding mass does not have significant stress concentrations. If stress concentrations exist which deviate

4 Slip Surface Shapes

4.1 Introduction and background

Determining the position of the critical slip surface with the lowest factor of safety remains one of the key issues in a stability analysis. As is well known, finding the critical slip surface involves a trial procedure. A possible slip surface is created and the associated factor of safety is computed. This is repeated for many possible slip surfaces and, at the end, the trial slip surface with the lowest factor of safety is deemed the governing or critical slip surface.

There are many different ways for defining the shape and positions of trial slip surfaces. This chapter explains all the procedures available in SLOPE/W, and discusses the applicability of the methods to various situations.

Finding the critical slip surface requires considerable guidance from the analyst in spite of the advanced capabilities of the software. The soil stratigraphy may influence the critical mode of potential failure and the stratigraphy therefore must be considered in the selected shape of the trial slip surfaces. In the case of a tie-back wall, it may be necessary to look separately at a toe failure and a deep seated failure. In an open pit mine the issue may be bench stability or overall high wall stability and each needs to be considered separately. Generally, not all potential modes of failure can necessarily be investigated in one analysis. In such cases the positions of the trial slip surfaces needs to be specified and controlled to address specific issues.

A general procedure for defining trial slips may result in some physically inadmissible trial slip surfaces; that is, the trial slip surface has a shape which cannot exist in reality. Often it is not possible to compute a safety factor for such unrealistic situations, due to lack of convergence. Sometimes, however, safety factors can be computed for unrealistic slips, and then it is the responsibility of the analyst to judge the validity of the computed factor of safety. The software cannot necessarily make this judgment. This is an issue that requires guidance and judgment from the analyst. This issue is discussed further toward the end of the chapter.

Another key issue that comes into play when attempting to find the position of the critical slip surface is the selection of soil strength parameters. Different soil strength parameters can result in different computed positions of the critical slip surface. This chapter discusses this important issue.

Presenting the results of the many trial slip surfaces has changed with time. This chapter also addresses the various options available for presenting a large amount of data in a meaningful and understandable way. These options are related to various slip surface shapes, and will consequently be discussed in the context of the trial slip surface options.

4.2 Grid and radius for circular slips

Circular trial slip surfaces were inherent in the earliest limit equilibrium formulations and the techniques of specifying circular slip surfaces has become entrenched in these types of analyses. The trial slip surface is an arc of circle. The arc is that portion of a circle that cuts through the slope. A circle can be defined by specifying the x-y coordinate of the centre and the radius. A wide variation of trial slip surfaces can be specified with a defined grid of circle centers and a range of defined radii. In SLOPE/W, this procedure is called the Grid and Radius method. Figure 4-1 shows a typical example.

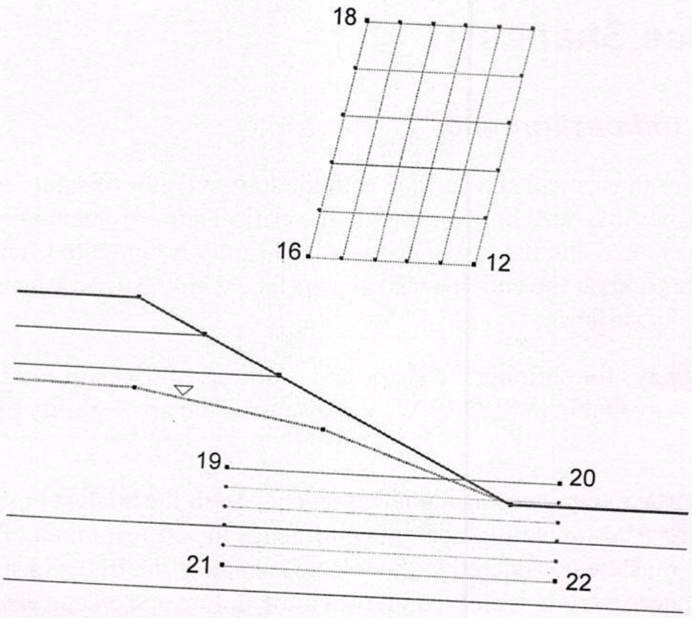

Figure 4-1 The grid and radius method of specifying trial slip surfaces

The grid above the slope is the grid of rotation centers. Each grid point is the circle center for the trial slips. In this example there are 36 (6 x 6) grid points or circle centers. In SLOPE/W, the grid is defined by three points; they are upper left (18), lower left (16) and lower right (12).

The trial circle radii are specified with radius or tangent lines. The lines are specified by the four corners of a box. In the above example, the four corners are 19 (upper left), 21 (lower left), 22 (lower right) and 20 (upper right). For the SLOPE/W main processor to interpret the radius line specification correctly, the four points need to start at the upper left and proceed in a counter-clockwise direction around the box. The number of increments between the upper and lower corners can be specified. In the above example there are five increments making the total number of radius lines equal to 6.

To start forming the trial slip surfaces, SLOPE/W forms an equation for the first radius line. Next SLOPE/W finds the perpendicular distance between the radius line and a grid centre. The perpendicular distance becomes the radius of the trial slip surface. The specified radius lines are actually more correctly tangent lines; that is, they are lines tangent to the trial circles. Figure 4-2 shows one imaginary circle. Note that the specified radius line is tangent to the circle. The trial slip surface is where the circle cuts the soil section. For this example, SLOPE/W will compute safety factors for 216 (36 x 6) trial slip surfaces.

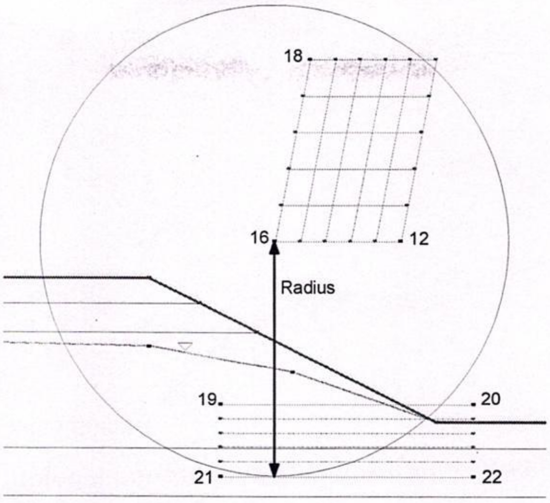

Figure 4-2 Imaginary trial slip surface

The radius line "box" (points 19, 21, 22, 20) can be located at any convenient position and can form any quadrilateral shape. The illustration in Figure 4-3 is entirely acceptable. Also, the position of the radius box does not necessarily need to be on the soil section. Usually it is most convenient for the box to be on the slope section, but this is not a requirement in the SLOPE/W formulation. It becomes useful when the trial slip surfaces have a composite shape as discussed below.

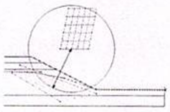

Figure 4-3 Specification of radius lines

Single radius point

The radius line box can be collapsed to a point. All four corners can have the same point or the same x-y coordinate. If this is the case, all trial slip surfaces will pass through a single point (Figure 4-4). This technique is useful when you want to investigate a particular mode of failure, such as the potential failure through the toe of a wall.

The grid of centers can also be collapsed to a single point. This makes it possible to analyze just one slip surface, which can be very useful for doing comparisons of various features or options.

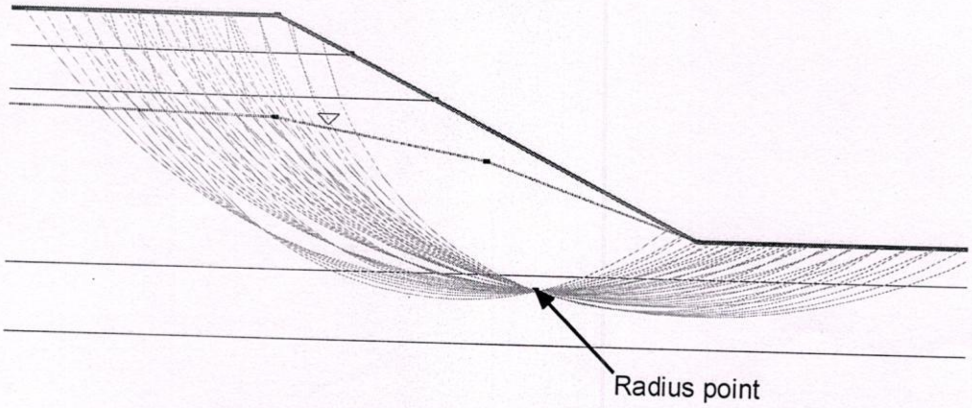

Figure 4-4 All slip surfaces through a point

Multiple radius points

The radius box can also be collapsed to a line with radius increments. This makes it possible to analyze trial slips that pass through a series if points. This can be done by making the upper two corners the same and the lower two corners the same. This is illustrated in Figure 4-5.

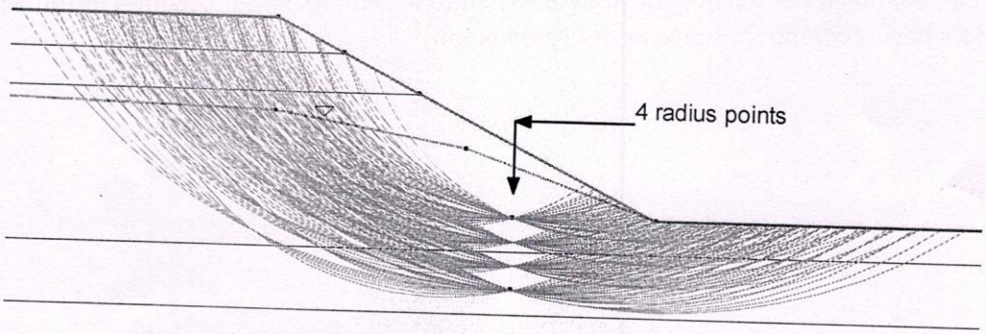

Figure 4-5 Slip surfaces though a series of radius points

Lateral extent of radius lines

The tangent or radius lines in SLOPE/W do not have lateral extents. The tangent lines are used to form the equation of a line, but the equation lines are not limited by the lateral extents of the specified lines. The two cases illustrated in Figure 4-6 result in exactly the same trial slip surfaces. This can sometimes result in unexpected trial slip surfaces that fall outside the intended range. A typical example may be a shallow slip that just cuts through the crest of the section as in a near vertical wall. This undesired outcome is one of the weaknesses of the Grid-Radius technique and the reason for other options for specifying trial slip surfaces. The Enter-Exit method, for example, discussed below does not have this shortcoming.

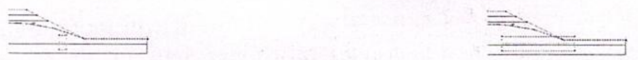

Figure 4-6 Effect of radius line lengths

Another side effect of the Grid-Radius method is that trial slips can fall outside the extents of the geometry. All trial slips must enter and exit along the Ground Surface line. If trial slips enter or exit outside the Ground Surface line, they are considered invalid and no factor of safety is computed. A typical case may be a trial slip that enters or exits the vertical ends of the defined geometry. Such trial slips are invalid. No safety factors are displayed at the Grid centers for which no valid trial slip surface exists.

Factor of Safety contours

In the early days of limit equilibrium stability analyses, the only way to graphically portray a summary of all the computed safety factors was to contour the factors of safety on the Grid, as illustrated in Figure 4-7. The contours provide a picture of the extent trial slip surfaces analyzed, but more importantly the contours indicate that the minimum safety factor has been found. The ideal solution is when the minimum falls inside a closed contour like the 1.240 contour in Figure 4-7.

The technique of contouring the safety factors on the Grid has become deeply entrenched in slope stability analyses. This has come about partly because of early developments and presentations, and partly because all related textbooks present this as an inherent requirement.

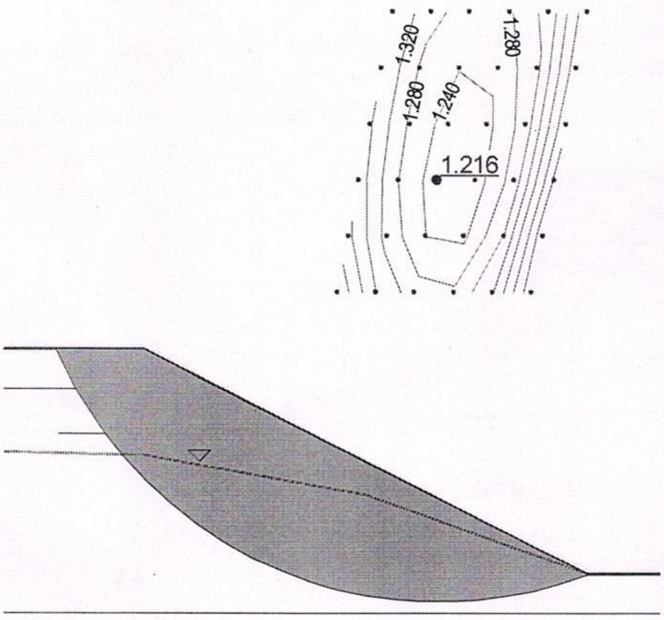

Figure 4-7 Factor of safety contours on grid of rotation centers

Unfortunately, the ideal solution illustrated in Figure 4-7 is not always attainable; in fact the number of situations where the ideal contour picture can be attained is considerably less than the situations where it is not attainable. The ideal solution can usually be obtained for conventional analyses of fairly flat slopes (2h:1v or flatter), with no concentrated point loads, and with *c* and ϕ effective strength parameters. A common case where the ideal cannot be attained is for purely frictional material ($c = 0$; $\phi > 0$) as discussed in detail further on in this Chapter. Another typical case is the stability analysis of vertical or near vertical walls.

Recognizing that the ideal textbook case of the minimum safety factor falling in the middle of the Grid is not always attainable is vitally important in the effective use of a tool like SLOPE/W.

Now there are other ways of graphically portraying a summary of computed safety factors. One way is to display all the trial slip surfaces as presented in Figure 4-8. This shows that the critical slip surface falls inside the range of trial slips and it shows the extent of the trial slips.

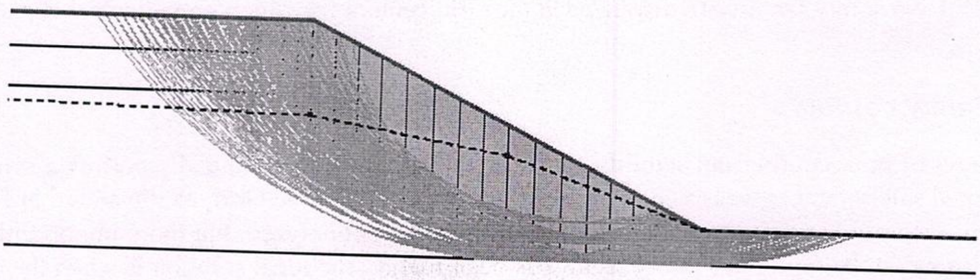

Figure 4-8 Display of multiple trial slip surfaces

Another effective way of graphically viewing a summary of the trial slip surfaces is with what is called a safety map. All the valid trial slip surfaces are grouped into bands with the same factor of safety. Starting from the highest factor of safety band to the lowest factor of safety band, these bands are painted with a different color. The result is a rainbow of color with the lowest factor of safety band painted on top of the rest of the color bands. Figure 4-9 illustrates an example of the safety map.

In this example, the red color is the smallest factor of safety band, and the white line is the critical slip surface. This type of presentation clearly shows the location of the critical slip surface with respect to all trial slip surfaces. It also shows zone of potential slip surfaces within a factor of safety range.

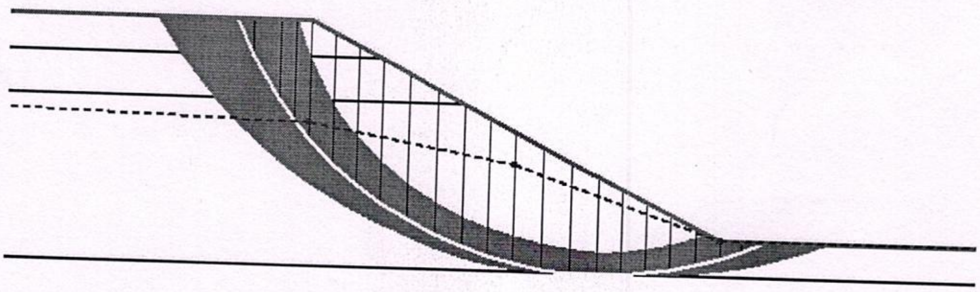

Figure 4-9 Display of safety map

4.3 Composite slip surfaces

Stratigraphic conditions have a major influence on potential slip surfaces. Circular slip surfaces are fairly realistic for uniform homogeneous situations, but this is seldom the case in real field cases. Usually there are multiple layers with varying strength and varying pore-water pressure conditions which can have an effect on the shape of the critical slip surface.

A common situation is where surficial soils overlie considerably stronger material at depth. There is the potential for the surficial soils to slide along the contact between the two contrasting materials. This type of case can be analyzed with what is called a composite slip surface. The stronger underlying soil is flagged as being impenetrable (or bedrock). The trial slip surface starts as an arc of the circle until it intersects the impenetrable surface. The slip surface then follows the impenetrable surface until it intersects the circle, and then again follows the arc of a circle up to the surface as illustrated in Figure 4-10. The circular portion of the trial slip surfaces is controlled by the Grid and Radius method discussed above.

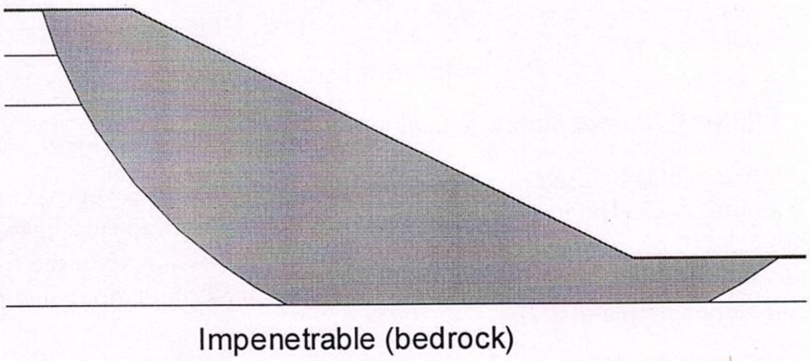

Figure 4-10 Composite slip surface controlled by impenetrable layer

The portion of the slip surface that follows the impenetrable material takes on the soil strength of the material just above the impenetrable layer. This can always be verified by graphing the strength along the slip surface.

The impenetrable surface does not have to be a straight line – it can have breaks as in Figure 4-11. However, extreme breaks may make the slip surface inadmissible, and it usually results in an unconverged solution.

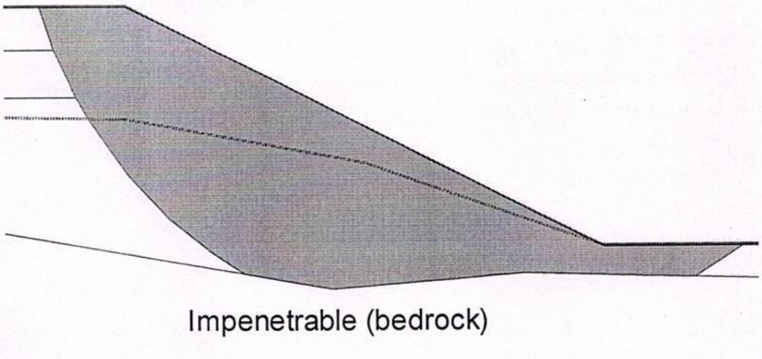

Figure 4-11 Irregular impenetrable layer

The impenetrable material feature is useful for analyzing cases with a weak, relatively thin layer at depth. Figure 4-12 shows such an example. In this case, the portion of the slip surface that follows the impenetrable takes on the strength assigned to the weak layer.

For practical reasons, there is no need to make the weak layer too thin. The portion of the slip surface in the weak layer that does not follow the impenetrable contact is relatively small and therefore has little influence on the computed factor of safety. The effort required in making the weak layer very thin is usually not warranted.

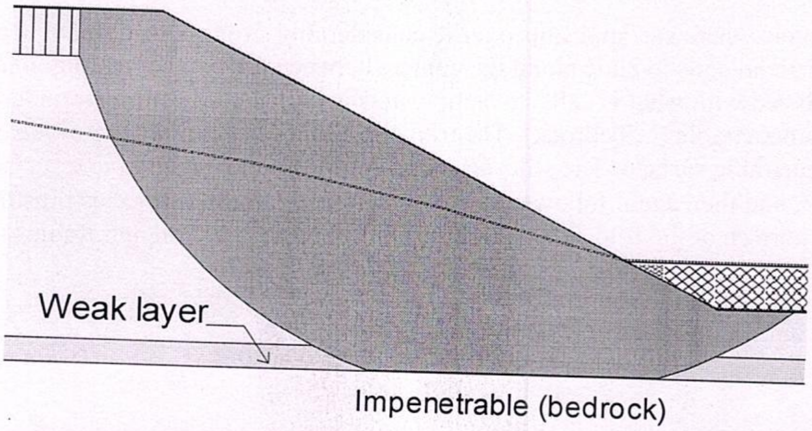

Figure 4-12 Impenetrable layer forces slip along weak layer

The impenetrable feature can also be used to analyze the sliding stability of cover material on a synthetic liner, as illustrated in Figure 4-13. The impenetrable layer causes the trial slip surface to follow the liner. A thin region just above the impenetrable material has properties representative of the frictional sliding resistance between the cover material and the liner. This is the shear strength along that portion of the slip surface that follows the impenetrable material.

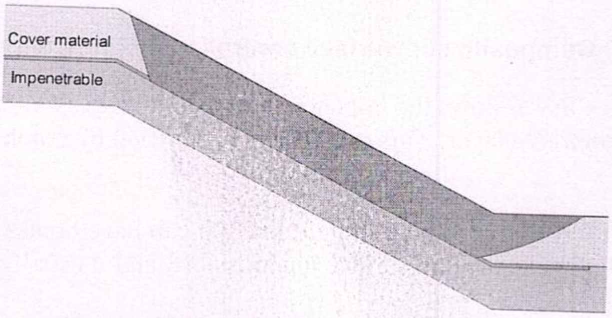

Figure 4-13 Sliding on a synthetic liner

Again this can be verified by graphing the strength along the slip surface. In this illustration the cover material has a friction angle of 30 degrees and the friction angle between the liner and the cover material is 15 degrees. This is confirmed by the SLOPE/W graph in Figure 4-14.

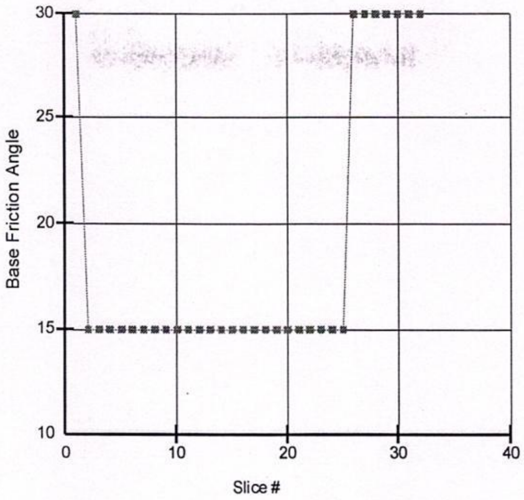

Figure 4-14 Variation of friction angle along slip surface

Note that the tensile capacity of the liner does not come into play in this cover sliding analysis. Considering the tensile strength would require a different setup and a different analysis.

In SLOPE/W, the concept of an impenetrable material is just a mechanism to control the shape of trial slip surfaces – it is not really a material.

4.4 Fully specified slip surfaces

A trial slip surface can be specified with a series of data points. This allows for complete flexibly in the position and shape of the slip surface. Figure 4-15 illustrates a fully-specified slip surface.

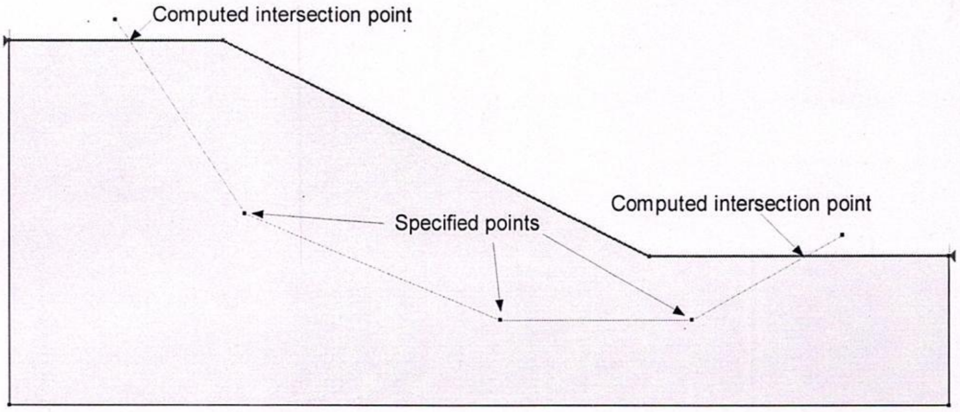

Figure 4-15 Fully specified slip surface

Note that the specified surface starts and ends outside the geometry. SLOPE/W can then compute the ground surface intersection points. Allowing SLOPE/W to compute these intersection points is better than trying to place a point on the ground surface, which can sometimes lead to some numerical confusion.

A point needs to be created about which to take moments. This is called the Axis Point (Figure 4-16). The Axis Point should be specified. In general, the Axis Point should be in a location close to the approximate center of rotation of all the specified slip surfaces. It is usually somewhere above the slope crest and between the extents of the potential sliding mass.

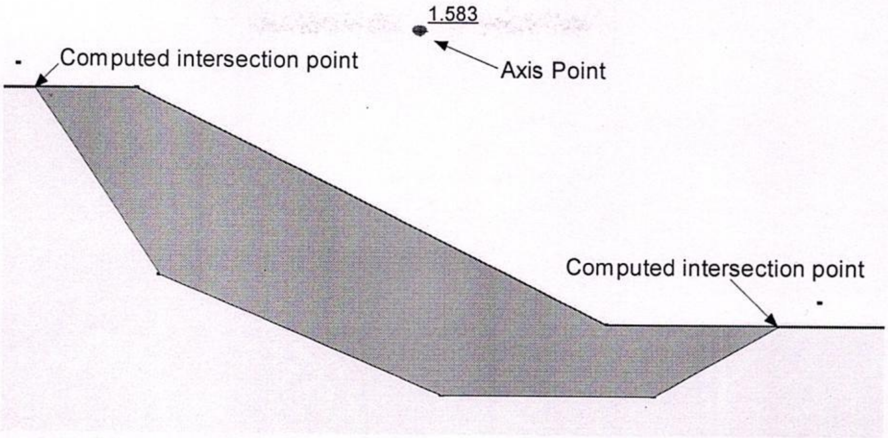

Figure 4-16 Axis point about which to compute moments

The factor of safety calculations are not sensitive to the position of the Axis point, for methods that satisfy both moment and force equilibrium (e.g., Spencer and Morgenstern-Price methods). However, for simplified methods (e.g., Ordinary and Simplified Bishop), the factor of safety calculations can be sensitive to the position of the Axis Point.

A common axis point for taking moment should be defined. The Axis Point should be in a location close to the approximate center of rotation of the fully specified slip surfaces. When missing, SLOPE/W estimates an axis point based on the geontry and the specified slip surfaces.

The Fully Specified method has a unique feature that any points on the slip surface can be specified as "Fixed". When a point is fixed, the point will not be allowed to move during the slip surface optimization process.

The Fully Specified method is useful when large portions of the slip surface position are known from slope inclinometer field measurements, geological stratigraphic controls and surface observations. The option may also be useful for other cases such as the sliding stability of a gravity retaining wall (Figure 4-17).

While the Fully Specified method is completely flexible with respect to trial slip surfaces shapes and position, it is limited in that each and every trial slip surface needs to be specified. The method is consequently not suitable for doing a large number of trials to find the critical slip surface.

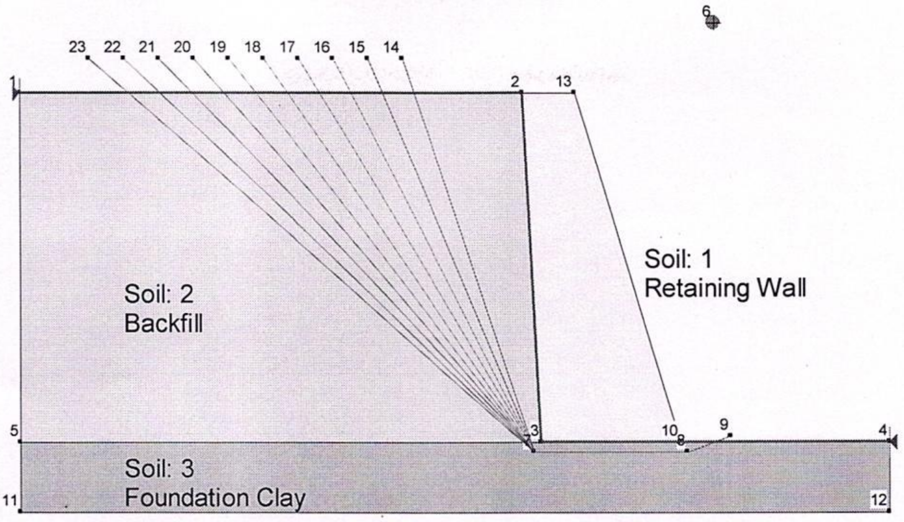

Figure 4-17 Sliding analysis of a gravity retaining wall

4.5 *Block specified slip surface*

General cross-over form

Block shaped analyses can be done by specifying two grids of points as shown in Figure 4-18. The grids are referred to as the left block and the right block. The grids are defined with an upper left point, a lower left point and a lower right point. In the example here the right block is defined by Points 11, 12 and 13.

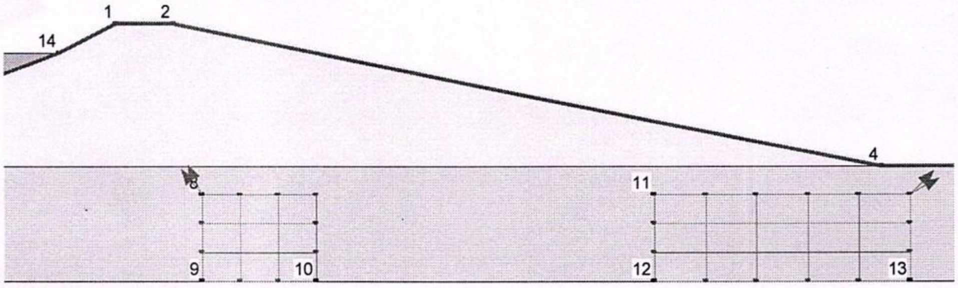

Figure 4-18 Grids in Block Specified method

The slip surface consists of three line segments. The middle segment goes from each grid point on the left to each grid point on the right. The other two segments are projections to the ground surface at a range of specified angles. Figure 4-19 presents the type of trial slip surface created.

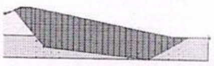

Figure 4-19 Slip surface shape in the Block method

By allowing the middle segments to go from each grid point on the left to each point on the right, the middle line segments cross over each other when multiple slips are viewed simultaneously, and hence the cross-over designation. An option where this is not allowed is also an option available within SLOPE/W that is discussed later in this chapter.

The end projections are varied, depending on the specified angles and the incremental variation in the angles. Arrows are drawn at the upper left and right corners as in Figure 4-20 to graphically portray the specified angles.

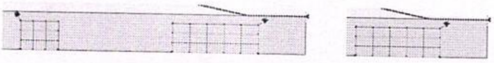

Figure 4-20 Projection angles in the Block method

The situation in the toe area is similar to a passive earth pressure condition where the sliding mass is being pushed outward and upward. In the crest area, the situation is analogous to active earth pressure conditions. From lateral earth pressure considerations, the passive (toe) slip surface rises at an angle equal to $(45 - \phi/2)$ and the active slip line dips at an angle of $(45 + \phi/2)$. These considerations can be used to guide the selection of the projection angles.

In SLOPE/W, geometric angles are defined in a counterclock-wise direction from the positive x-coordinate axis. An angle of zero means a horizontal direction to the right, an angle of 90 degrees means an upward vertical direction; an angle of 180 degrees means a horizontal direction in the negative x-coordinate direction, and so forth.

In the above example, the right toe (passive) projection angles vary between 30 and 45 degrees, and the left crest (active) projection angles vary between 115 and 130 degrees (between 65 and 50 degrees from the horizontal in the clock-wise direction).

Like the Fully Specified method, the Block method also needs a defined Axis about which to take moments. If the Axis point is not defined, SLOPE/W will compute an Axis location based on the geometry of the problem and the positions of the left and right blocks.

This method of creating trial slip surfaces can lead to a very large number of trials very quickly. For the illustrative example here the left block has 16 (4x4) grid points and the right block has 24 (4x6) grid points. At each end there are three different projection angles. The total number of trial slips is 16 x 24 x

5 Geometry

5.1 Introduction

SLOPE/W uses the concept of regions to define the geometry. Basically this simply means drawing a line around a soil unit or stratigraphic layer to form a closed polygon, similar to what we would do when sketching a problem to schematically explain a particular situation to someone else. In this sense, it is a natural and intuitive approach.

Regions are a beneficial aid for finite element meshing. SLOPE/W by itself does not need a finite element mesh, but regions defined in SLOPE/W can also be used to create a mesh for an integrated finite element analysis. In GeoStudio the objective is to only define the geometry once for use in many different types of analyses. Using regions in SLOPE/W as well as in the finite element products makes this possible even though SLOPE/W uses slice discretization instead of finite element discretization. SLOPE/W can then use the results readily from other analyses, such as SEEP/W and SIGMA/W in a stability analysis.

This chapter describes the basics of regions and shows some examples of how they can be used to define various geometric conditions. Included as well are descriptions and discussions on how to define SLOPE/W specific features including point loads, surface surcharge pressures, tension crack and ponded water.

5.2 Regions

Regions are in essence n-sided polygons. Polygons with three sides are triangles and polygons with four sides are quadrilaterals. Figure 5-1 shows some representative basic regions.

Figure 5-1 Representative basic regions

All regions need to be connected to form a continuum. This is done with the use of Points. The small black squares at the region corners in Figure 5-1 are the points. The regions are connected by sharing the points. In Figure 5-2, Points 6 and 7 are common to the two regions and the two regions consequently behave as a continuum.

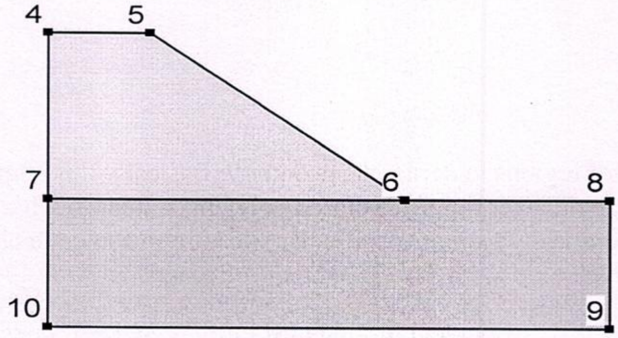

Figure 5-2 Region points

Figure 5-3 shows a typical slope stability case defined with regions. Here Points 2 and 8 are common to the top two regions. Points 3, 7 and 10 are common to the bottom two regions.

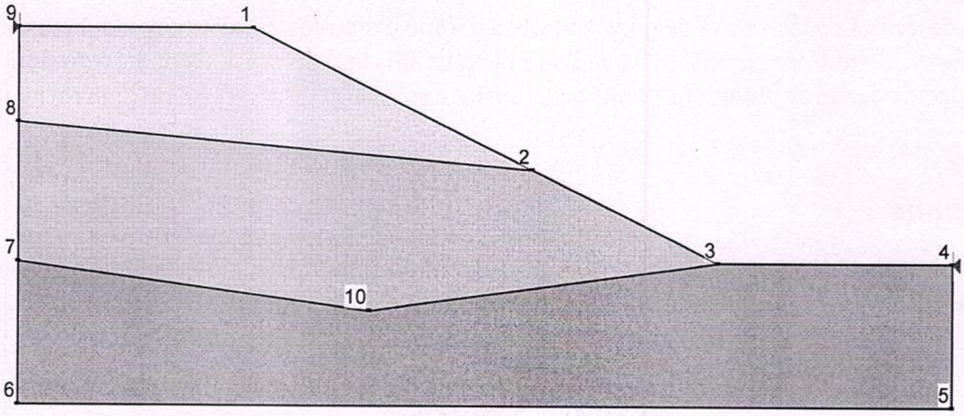

Figure 5-3 Typical regions for a slope stability analysis

Figure 5-4 shows a case where the triangular region on the left represents a soil layer that pinches out in the slope. Region 2-3-11-10 represents water impounded up against the slope.

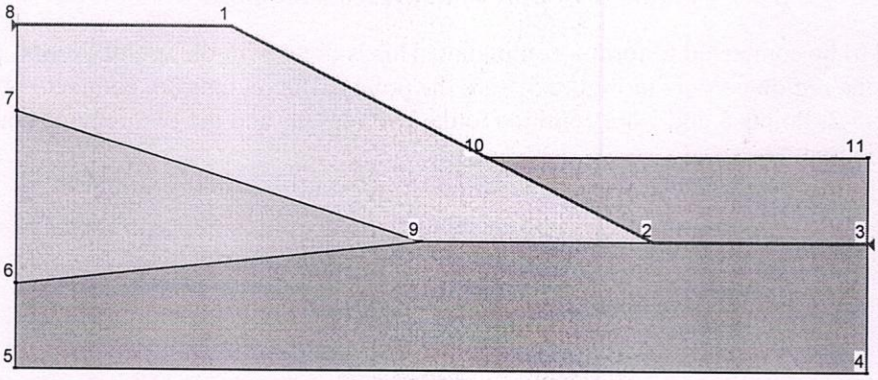

Figure 5-4 Example of pinching out region and water region

Figure 5-5 illustrates a typical tailings impoundment case. The quadrilateral regions on the left represent dykes, and the upper dyke sits on top of tailings; that is, the tailings under-cut the upper dyke.

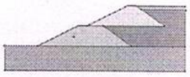

Figure 5-5 Example of an under-cutting region.

From these few examples, it is easy to see how almost any stratigraphic section can be easily and quickly defined with regions.

One of the attractions of regions is that the geometry can be so easily modified by moving the points. The regions do not necessarily have to be redrawn – only the points have to be moved make modification to the geometry.

Regions do have a couple of restrictions. They are:

- A region can have only one material (soil) type. The same soil type can be assigned to many different regions, but each region can only be assigned one soil type.
- Regions cannot overlap.

An island of a particular soil type can be defined by dividing the surrounding soil into more than one region. Figure 5-6 illustrates this. Two regions of the same soil type are drawn such that they encompass the isolated quadrilateral of a different soil type. There may be other ways of defining this particular situation, but at no time can regions overlap. In other words, the pinching out layer in Figure 5-6 cannot be drawn on top of the other soil.

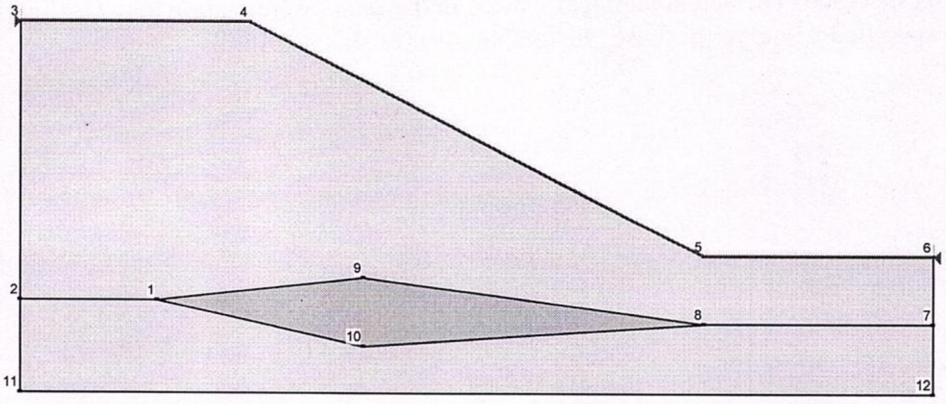

Figure 5-6 Section with an island of soil of a different type

5.3 *Slice discretization*

SLOPE/W uses a variable slice width approach in the sliding mass discretization. In other words, SLOPE/W will discretize the soil mass with slices of varying widths to ensure that only one soil type exists at the bottom of each slice. In also is used to prevent a ground surface break occurring along the top of the slice and to prevent the phreatic line from cutting through the base of a slice. The objective is to have all the geometric and property changes occur at the slice edges.

Initially SLOPE/W divides the potential sliding mass into section as shown in Figure 5-7. The first section starts on the left where the slip surface enters the ground surface. Other sections occur where (1) the slip surface crosses the piezometric line, (2) the slip surface crosses a stratigraphic boundary, (3) wherever there is a region point, and (4) where the piezometric line crosses a soil boundary. The last section ends on the right where the slip surface exits the ground surface.

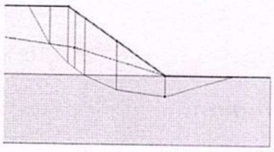

Figure 5-7 Sections in the slice discretization process

As a next step, SLOPE/W finds the horizontal distance from slip surface entrance to exit and divides this distance by the number of desired slices specified by the user (the default is 30). This gives an average slice width. The last step is to compute how many slices of equal width approximately equal to the average width can fit into each section. The end result is as shown in Figure 5-8 when the specified number of slices is 15.

Depending on the spacing of the sections, the variable slice approach will not always lead to the exact number of slices specified. The actual number of slices in the final discretization may be slightly higher or lower than the specified value. In this case, the total number of slices is 16.

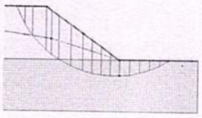

Figure 5-8 Discretization when the specified number is 15 slices

The variable slice width approach makes the resulting factor of safety relatively insensitive to the number of slices. Specifying the number of slices to be greater than the default number of 30 seldom alters the factor of safety significantly. Specifying the number of slices lower than the default value of 30 is not recommended unless you want to investigate a specific issue like, for example, comparing the SLOPE/W results with hand calculations. Making the number of slices too high simply creates an excessive amount of unnecessary data without a significant improvement in safety factor accuracy. Figure 5-9 shows the discretization when the number of specified slices is 30.

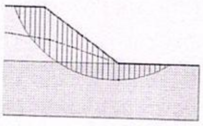

Figure 5-9 Discretization when specified number is 30 slices

5.4 *Ground surface line*

A special geometric object in GeoStudio is the ground surface line. It is a necessary feature for controlling what happens at the actual ground surface. Climate conditions, for example, can only act along the ground surface line.

In SLOPE/W, the ground surface line is used to control and filter trial slip surfaces. All trial slip surfaces must enter and exit along the ground surface. Trial slip surfaces that enter or exit along the perimeter of the problem outside of the designated ground surface are considered inadmissible. Triangular markers indicating the extents of ground surface line can be moved along the ground surface as illustrated on Figure 5-10.

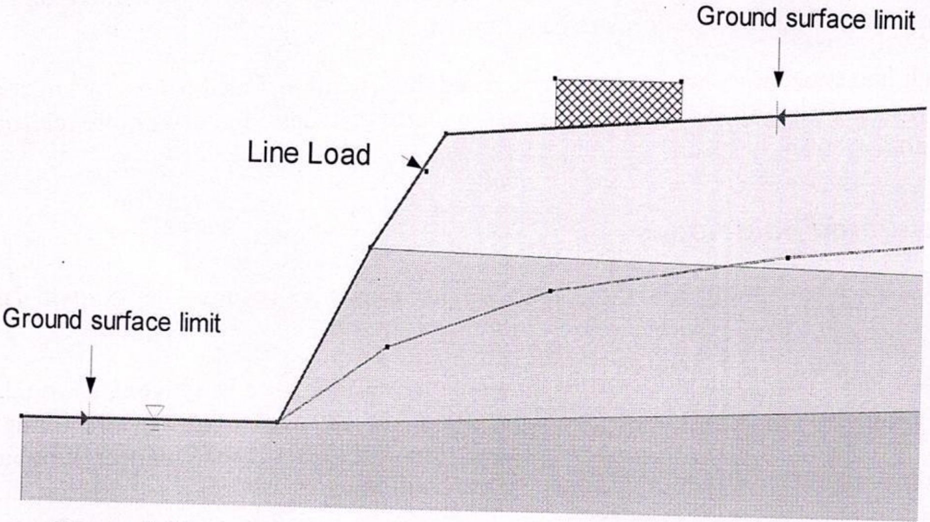

Figure 5-10 Example of a ground surface line and limit markers

SLOPE/W has a particular technique for specifying trial slip surfaces called “enter-exit”. Line segments can be specified which designate specific locations where all trial slip surfaces must enter and exit. These line segments are attached to the ground surface line. The specifics of this technique are discussed in more detail in the chapter on Slip Surface Shapes.

SLOPE/W computes the ground surface line and displays it as a heavy green line. Some care is required in the definition of the geometry to ensure that the computed line is the actual ground surface. For example, if the intended vertical extents of a problem are not truly vertical, the ground surface line may follow the near vertical ends of the problem. This can happen when there are small numerical differences in the x-coordinates in the points along the ends. The smallest and largest x-coordinates in the problem are used to identify the ends of the intended ground surface line.

5.5 Tension crack line

A tension crack can be specified with a tension crack line, as illustrated in Figure 5-11. When a tension crack line is specified, the slip surface is vertical in the tension crack zone. The tension crack can have water in it, which results in a lateral force being applied to the end slice. Procedural details on this feature are in the online help. The tension crack line option is discussed here because it is, in essence, a geometric definition.

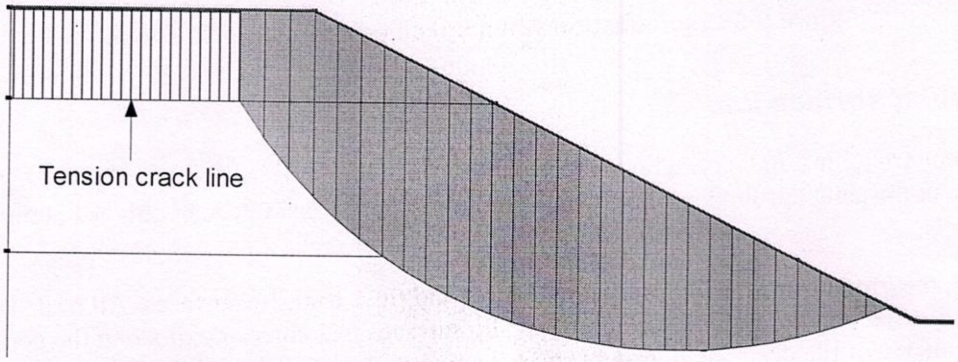

Figure 5-11 Tension crack line

There are other more advanced ways of including the possibility or presence of a tension crack in a stability analysis. A better way is to assume a tension crack exists if the slice base inclination becomes too steep. The angle at which this occurs needs to be specified.

The tension crack line concept is now somewhat outdated, but is still included for backward compatibility and for historic reasons. The other two options are more recent concepts, and offer more realistic behavior, particularly the angle specification method.

5.6 Concentrated point loads

Like the tension crack line, concentrated point loads are discussed here because they contain a geometric aspect.

Concentrated point loads must be applied inside the potential sliding mass. Intuitively, it would seem that the point loads should be applied on the surface. This is possible, but not necessary. Attempting to apply the point load on the surface is acceptable, provided it is done with care. Due to numerical round-off, a point load can sometimes be ignored if the computed application point is slightly outside the sliding mass.

The possibility of missing the point load in an analysis can be mitigated by ensuring the application of the pint load is inside the sliding mass (Figure 5-12). Remember that a point load is included in the force equilibrium of a particular slice. All that is required is to ensure the point load is inside a slice, and slight differences in precisely where the point loads are placed within the mass are negligible to the solution.

7 Material Strength

7.1 Introduction

There are many different ways of describing the strength of the materials (soil or rock) in a stability analysis. This chapter describes and discusses all the various models available in SLOPE/W.

7.2 Mohr-Coulomb

The most common way of describing the shear strength of geotechnical materials is by Coulomb's equation which is:

$$\tau = c + \sigma_n \tan\phi$$

where:

τ = shear strength (i.e., shear at failure),

c = cohesion,

σ_n = normal stress on shear plane, and

ϕ = angle of internal friction (phi).

This equation represents a straight line on a shear strength versus normal stress plot (Figure 7-1). The intercept on the shear strength axis is the cohesion (c) and the slope of the line is the angle of internal friction (ϕ).

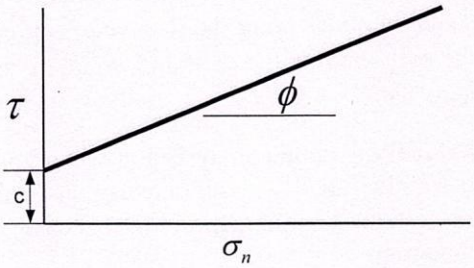

Figure 7-1 Graphical representation of Coulomb shear strength equation

The failure envelope is often determined from triaxial tests and the results are presented in terms of half-Mohr circles, as shown in Figure 7-2, hence the failure envelope is referred to as the Mohr-Coulomb failure envelope.

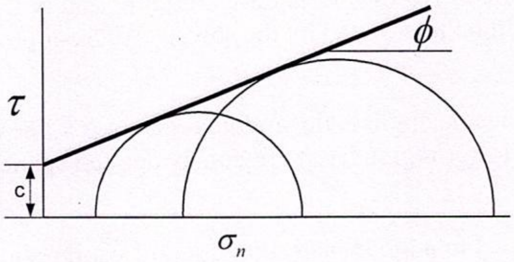

Figure 7-2 Mohr-Coulomb failure envelope

For undrained conditions when ϕ is zero, the failure envelope appears as shown in Figure 7-3. The soil strength then is simply described by *c*.

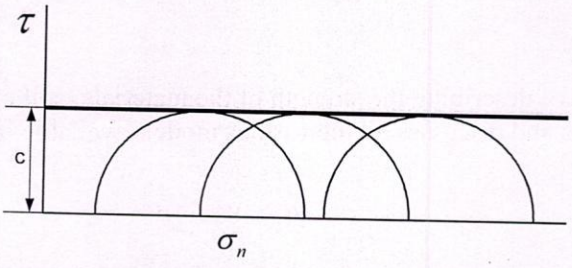

Figure 7-3 Undrained strength envelope

The strength parameters *c* and ϕ can be total strength parameters or effective strength parameters. SLOPE/W makes no distinction between these two sets of parameters. Which set is appropriate for a particular analysis is project-specific, and is something you as the software user, need to decide. The software cannot do this for you.

From a slope stability analysis point of view, effective strength parameters give the most realistic solution, particularly with respect to the position of the critical slip surface. The predicted critical slip surface position is the most realistic when you use effective strength parameters. When you use only undrained strengths in a slope stability analysis, the position of the slip surface with the lowest factor of safety is not necessarily close to the position of the actual slip surface if the slope should fail. This is particularly true for an assumed homogeneous section. This issue is discussed further in the Chapter on Slip Surface Shapes and Positions.

When you are doing a "Staged Rapid Drawdown" analysis or a "Staged Pseudo-Static" analysis using undrained strengths, you must use the Mohr-Coulomb strength model in SLOPE/W. In this case, *c* and ϕ are the effective strength parameters and you must enter the R-envelope strength values, c_R and ϕ_R, to represent the undrained strength of the soil. Setting the c_R and ϕ_R equal to zero signifies that the soil is a "free drained" material in a staged analysis.

Furthermore, if you have done a QUAKE/W dynamic analysis and when you want to use the QUAKE/W pore water pressure condition in your stability analysis, you may use the Mohr-Coulomb strength model to consider the reduced strength of the soil due to liquefaction. In this case, you may specify the "steady-state strength" of the soils due to liquefaction.

7.3 Spatial Mohr-Coulomb model

It is now possible to specify a spatial function for C, Phi, and unit weight as functions of both x and y geometry coordinates. Once a spatial function is defined, it can be applied to the Spatial Mohr-Coulomb model and then applied to any geometry region. The new Contour option in DEFINE can be used to view the actual applied values as they will be interpreted by the solver. An example of a spatial function for cohesion is shown in Figure 7-4.

The upper region has a constant cohesion applied, the middle region has a linear variation of cohesion as a function of x-coordinate, and the lower region has a previously defined spatial function for cohesion in terms of both x and y coordinate.

Once a function is defined and applied to a model and subsequently a soil region, it is possible to return to the Key In function command and change values while viewing a live update of the function on screen.

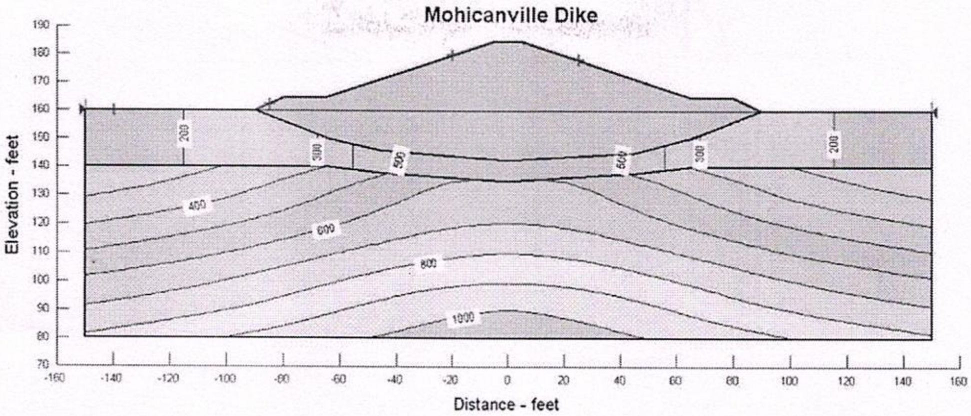

Figure 7-4 Example of spatial function assigned to bottom soil region material

7.4 *Undrained strength*

The Undrained strength option is a convenient way in SLOPE/W of setting ϕ to zero in the Mohr-Coulomb model (Figure 7-3). With this option, the shear strength of the material is only described by the *c* value and the pore-water pressure has no effect to the shear strength of the material.

7.5 *High strength*

A High strength material is an easy way to model materials with very high strength such as a concrete retaining wall. The strength is assumed to be infinity, therefore, any slip surfaces passing through the high strength material is considered very stable and consequently not consideied. You will be asked to specify the unit weight of the high strength material which will be used to compute the total overburden stress for the materials beneath the high strength material.

7.6 *Impenetrable (Bedrock)*

The Impenetrable strength option is really not a strength model, but a flag for the software to indicate that the slip surface cannot enter this material. It is an indirect mechanism for controlling the shape of trial slip surfaces. This soil model type is also sometimes referred to as bedrock. The Chapter on Slip Surface Shapes and Positions discusses this soil model option as to how it can be used to simulate certain field conditions.

7.7 *Bilinear*

Figure 7-5 shows the form of the Bilinear model. The failure envelope is described by two ϕ values, a cohesion value and a normal stress at which the break occurs.

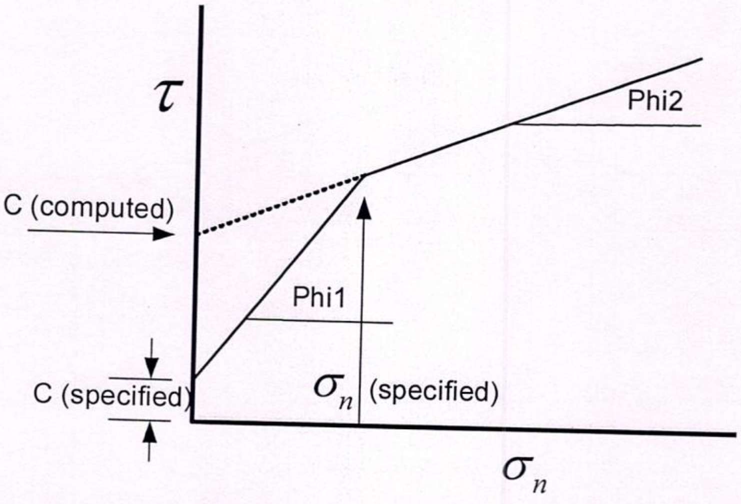

Figure 7-5 Bilinear shear strength envelope

For slice base normal stresses greater than the specified normal stress, SLOPE/W projects the Phi2 ($\phi 2$) line segment back to the shear strength axis and computes an equilivalent cohesion intercept. When you look at slice forces or plot strength along the slip surface you will see Phi2 ($\phi 2$) and the computed cohesion intercept. Internally, SLOPE/W treats the Bilinear model as two Mohr-Coulomb models.

The Bilinear strength model was the first attempt in SLOPE/W to accommodate a nonlinear strength envelope. Since then better options have been implemented for specifying nonlinear strength envelopes and the Bilinear model has lost some of its usefulness. The model is still included and available primarily for historic and backward compatibility reasons.

7.8 General data-point strength function

A completely general strength envelope can be defined using data points. A smooth spline curve is drawn through the specified points as shown in Figure 7-6.

For each slice, SLOPE/W first computes the normal stress at the slice base. Next SLOPE/W computes the slope of the spline curve at the slice base normal stress. The spline-curve slope (tangent) is taken to be ϕ for that particular slice. The tangent is projected to the origin axis to compute an intercept, which is taken to be c. Each slice consequently has a c and ϕ relative to the slice base normal stress.

8 Pore-water

8.1 Introduction

In the previous chapter, it was noted that the most realistic position of the critical slip surface is obtained when effective strength parameters are used in the analysis. Effective strength parameters, however, are only meaningful when they are used in conjunction with pore-water pressures. In this sense, the pore-water pressures are as important in establishing the correct shear strength as the shear strength parameters themselves.

Due to the importance of pore-water pressures in a stability analysis, SLOPE/W has various ways of specifying the pore-water pressure conditions. This chapter gives an overview of the options available, and presents some comments on the applicability of the various methods.

8.2 Piezometric surfaces

The most common way of defining pore-water pressure conditions is with a piezometric line. With this option, SLOPE/W simply computes the vertical distance from the slice base mid-point up to the piezometric line, and multiplies this distance times the unit weight of water to get the pore-water pressure at the slice base. This is graphically illustrated in Figure 8-1.

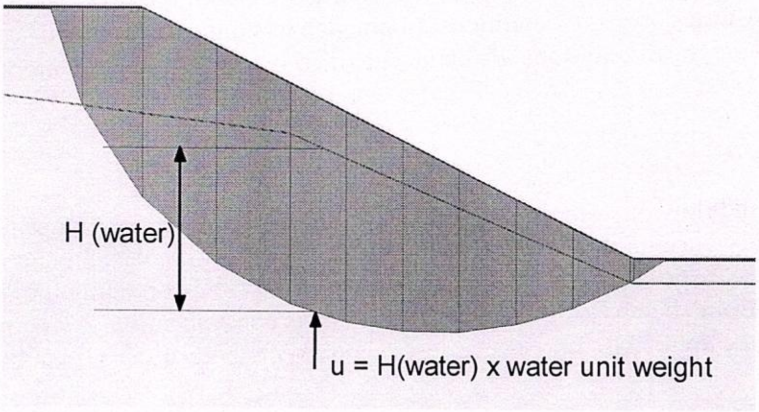

Figure 8-1 Pore pressure from a piezometric line

When thinking about pore-water pressures in SLOPE/W, it is vitally important to recognize that pore-water pressures only come into play in the calculation of the shear strength at the base of each slice – they do not enter into the interslice force calculations.

When the slice base mid-point is located above the piezometric line, the negative pore-water pressures are presented in SLOPE/W RESULT, but additional strength due to the matric suction is assumed to be zero unless ϕ^b (Phi B) or a volumetric water content function is also assigned to the material strength model. This is explained further in this chapter under the topic of negative pore-water pressures.

Single piezometric line

Usually a profile has only one piezometric line and it applies to all soils. However, sometimes more complex pore-water pressures exist and in SLOPE/W, it is possible to be more selective and precise, if necessary. For example, a piezometric line can be applied only to selected soil layers and not to the entire profile. Consider the case of a sand embankment on soft clay soil as shown in Figure 8-2. Assume we want to make the pore-water pressures equal to zero in the sand, but we want to represent the pore-water pressure in the clay by a piezometric line that exists above the clay surface due to some excess pressure in the clay. A piezometric line can be drawn and assigned only to the clay layer. As a result, pore-water pressures will not exist in the sand layer. This option is useful when it is combined with a Ru or B-bar value.

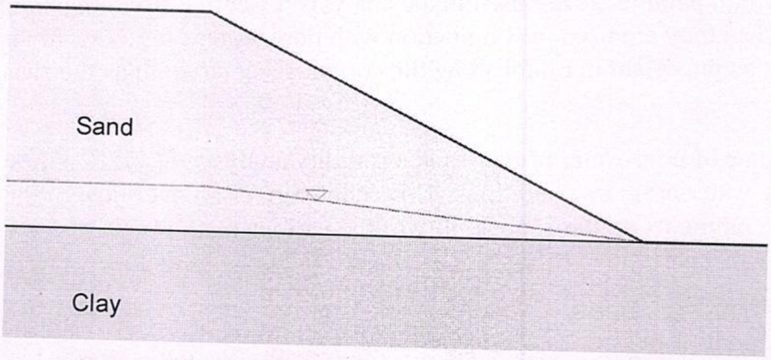

Figure 8-2 Piezometric assigned only to the clay

Multiple piezometric lines

In SLOPE/W, each soil type can have its own piezometric line making it possible to represent irregular non-hydrostatic pore-water pressure conditions. In practice this option is not all that applicable. Highly irregular pore-water pressure conditions are better specified by one of the other more advanced methods discussed below.

Phreatic correction

In a sloping profile, the flow of water is usually from the uplands towards the slope toe which results in the piezometric surface curving downwards. As we know from flow net design, under these conditions the equipotential lines are not vertical. The assumption in SLOPE/W of relating the pore-water pressure to the vertical distance from slice base to the piezometric line is consequently not strictly correct. A correction factor can be applied to more accurately represent the pore-water pressure, if this is deemed important.

Figure 8-3 illustrates how phreatic correction is applied. The equipotential lines are perpendicular to the piezometric line. The inclination of the phreatic surface is at an angle A. Without phreatic correction, H_w is the height used to compute the pore pressure at the base center of the slice. With phreatic correction, H_w is corrected and H_c is used to compute the pore pressure at the base center of the slice.

$$H_c = H_w \cos^2 A$$

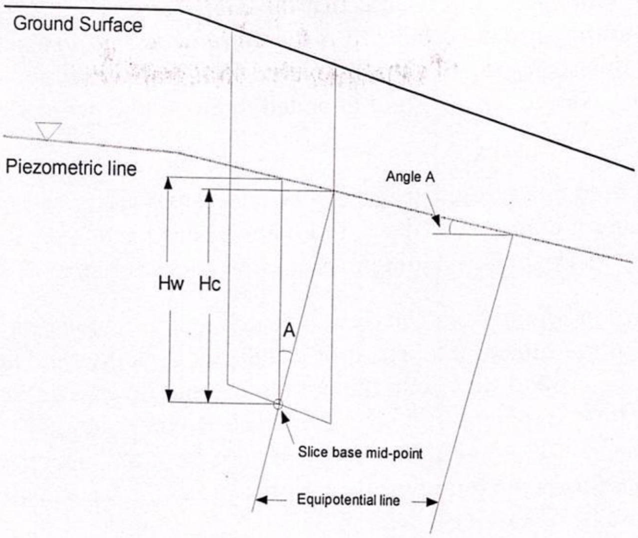

Figure 8-3 Phreatic surface correction

Note that when the piezometric line is horizontal (A=0), the phreatic correction factor (cos^2A) is 1 and H_c is equal to H_w. When the piezometric line is approaching a vertical line, the correction factor is approaching 0. Since the correction factor is always between 0 and 1, applying the phreatic correction always generates a pore water pressure smaller or equal to a non-corrected condition. In other words, the computed factor of safety is always the same or higher when the phreatic correction is applied.

8.3 R_u Coefficients

The pore-water pressure ratio R_u is a coefficient that relates the pore-water pressure to the vertical overburden stress. The coefficient is defined as:

$$R_u = \frac{u}{\gamma_t H_s}$$

where:

u = the pore-water pressure

γ_t = the total unit weight

H_s = the height of the soil column.

The denominator of the R_u equation includes external loads (Budhu, 2007). Accordingly, SLOPE/W includes the effect of ponded water or surcharge loads in the calculation of pore-water pressure at the base of a slice. By rearranging the variables, the pore-water pressure u becomes:

$$u = R_u \, \gamma_t H_s$$

The concept of R_u was developed primarily for use with stability charts (Bishop and Morgenstern, 1960) and is included in SLOPE/W mainly for historical reasons. Attempting to make use of the option is not recommended, except in simple cases that are consistent with the original intention of the method.

One of the difficulties with the R_u approach is that the coefficient varies throughout a slope if the phreatic surface is not parallel to the ground surface. It is therefore necessary to establish R_u at a number of points within the domain for this scenario. In a multi-layered stratigraphic section, R_u can be applied selectively to each of the soil units. Moreover, R_u is not intended to model the generation of excess pore-water pressures due to loading.

Pore-water pressures based on R_u calculations can be added to conditions represented by a piezometric line. This action is different than B-bar (discussed below) because R_u uses the the total overburden stress; B-bar uses only soil layers flagged as adding to the pore-water pressure.

Consider slice 10 shown in Figure 8-4. The piezometric line is located at the clay-sand contact and the clay has been assigned a R_u value of 0.2. The unit weight for both the sand and clay is 20 kN/m^3. The vertical distance from the ground surface to the bottom of sand layer is 7.22m. The vertical distance from the slice base center to the piezometric line is 2.14m. The R_u component of the water pressure is (7.22m + 2.14m) x 20.0 kN/m^3 x 0.2 = 37.44 kPa. The pore pressure from the piezometric line is 2.14m x 9.81 kN/m^3 = 20.99 kPa. Therefore, the total pore-water pressure at the base center when R_u is used together with the piezometric line is 58.43 kPa.

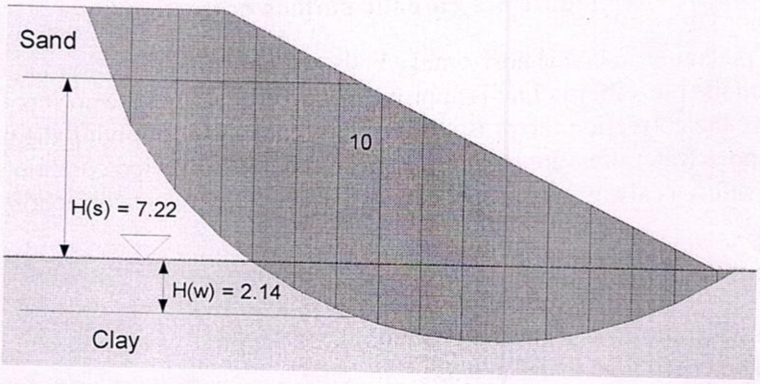

Figure 8-4 Combination of R$_u$/B-bar with piezometric pore-water pressures

Combining R_u computed pore-water pressures with piezometric pore-water pressures can be confusing and is incongruous with the original intention of the method. It is therefore highly recommended that the pore-water pressure distribution along the slip surface be verified using a graph.

8.4 B-bar coefficients

B-bar ($\overline{B}$) is a pore-water pressure coefficient related to the major principal stress. In equation form:

$$\overline{B} = \frac{\Delta u}{\Delta \sigma_1}$$

In many situations, the major principal stress is near vertical and, consequently, σ_1 can be approximated from the overburden stress. This approximation is used in the B-bar application in SLOPE/W.

The distinguishing feature about B-bar in SLOPE/W is that individual soil layers can be selected for computing the overburden stress. Consider the same case as shown in the previous section, but now instead of a R_u value, the clay is assigned a B-bar value of 0.2 (Figure 8-4). Only the sand has been flagged as adding to the pore-water pressure. The pore-water pressure from the sand weight is 7.22m x 20.0 kN/m^3 x 0.2 = 28.88 kPa. The pore-water pressure from the piezometric line is 2.14m x 9.81 kN/m^3

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Course Duration: 30 Hours;
From 10/05/2021 to 27/05/2021

Course Instructor:
Sri P. Rajendra Kumar,
Assistant Professor, CE, KSRMCE-Kadapa

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1	189Y1A0108	Maheswari Bokkasam	Yes	Yes	5	Yes	5
2	189Y1A0115	Satish Kumar Yadav Chennuboyina	Yes	Yes	5	Yes	5
3	189Y1A0126	Venkata Jithendhar Reddy Duddekunta	Yes	Yes	5	Yes	5
4	189Y1A0132	Lakshmi Prasad Reddy Guddila	Yes	Yes	5	Yes	5
5	189Y1A0135	Sreeveni Hasti	Yes	Yes	5	Yes	5
6	189Y1A0144	Bhanumanikanta Reddy Kannapu	Yes	Yes	5	Yes	5
7	189Y1A0146	Govardhan Kaveti	Yes	Yes	5	Yes	5
8	189Y1A0156	Sudheer Kumar Maadam	Yes	Yes	5	Yes	5
9	189Y1A0158	Lokeshwar Reddy Mallireddy	Yes	Maybe	5	Yes	4
10	189Y1A0159	Ganesh Mandla	Yes	Yes	5	Yes	5
11	189Y1A0163	Sampath Kumar Meka	Yes	Yes	5	Yes	5
12	189Y1A0166	Siva Prasad Reddy Mitta	Yes	Yes	4	Yes	5
13	189Y1A0171	Venkata Sai Poojith Nagalla Pati	Yes	Yes	5	Yes	5
14	189Y1A0172	Venkatesh Nagirikanti	Yes	Yes	5	Yes	5
15	189Y1A0175	Abhish Nanubala	Yes	Yes	5	Yes	5
16	189Y1A0179	Jayachandra Sai Pandugolu	Yes	Yes	5	Yes	5

17	189Y1A0187	Rakesh Prasanna Penubala	Yes	Yes	5	Yes	5
18	189Y1A0193	Bindhu Rachamallu	Yes	Yes	5	Yes	5
19	189Y1A0198	Afroz Shaik	Yes	Yes	5	May be	5
20	189Y1A01B0	Sateesh Kumar Reddy Thallapalle	Yes	Yes	5	Yes	5
21	189Y1A01B2	Siva Reddy Thatimakula	Yes	Yes	5	Yes	4
22	189Y1A01B4	Gayathri Thopudurthy	Yes	Yes	5	Yes	5
23	189Y1A01B8	Venkata Hemanth Usugari	Yes	Yes	5	Yes	5
24	189Y1A01C3	Ganga Swetha Vennapusa	Yes	Yes	4	Yes	5
25	189Y1A01C6	Naga Hema Pranitha Sree Yelikanti	Yes	Yes	3	Yes	5
26	189Y1A01C8	Sivanatha Reddy Yeturu	Yes	Yes	5	Yes	5
27	199Y5A0107	Vijay Kumar Reddy Basireddygari	Yes	Yes	5	Yes	5
28	199Y5A0108	Sai Bonthalapalli	Yes	Yes	5	Yes	5
29	199Y5A0112	Mahesh Babu Chinthakunta	Yes	Yes	5	Yes	5
30	199Y5A0115	Sreenivasulu Dasari	Yes	Yes	5	May be	4
31	199Y5A0116	Pavan Kalyan Dokka	Yes	Yes	5	Yes	5
32	199Y5A0117	Dastagiri Dudekula	Yes	Yes	5	Yes	5
33	199Y5A0118	Premaraju Erapogu	Yes	Yes	5	Yes	5
34	199Y5A0123	Ramu Gosetty	Yes	Yes	5	Yes	5
35	199Y5A0125	Venkateshwarlu Judam	Yes	Yes	5	Yes	5

36	199Y5A0127	Venkateswarlu Kashetty	Yes	Yes	5	Yes	5
37	199Y5A0130	Vinodkumar Madhuranthakam	Yes	Yes	5	Yes	5
38	199Y5A0132	Mahesh Mallepogu Budigi	Yes	Yes	5	Yes	5
39	199Y5A0134	Sai Kumar Mannula	Yes	Yes	5	Yes	5
40	199Y5A0138	Reddaiah Nagulugari	Yes	Yes	5	May be	5
41	199Y5A0144	Praveen Kumar Reddy Pathi	Yes	Yes	4	Yes	5
42	199Y5A0149	Chandramouli Sambaturu	Yes	Yes	5	Yes	5
43	199Y5A0150	Sambasivareddy Sanikommu	Yes	Yes	5	Yes	5
44	199Y5A0155	Sravani Sirigiri	Yes	Yes	5	Yes	5
45	199Y5A0156	Abhishek Kumar Reddy Suda	Yes	Yes	5	Yes	5
46	199Y5A0157	Siva Krishna Suripaka	Yes	Yes	5	Yes	5
47	199Y5A0159	Chandu Thoti	Yes	Yes	5	Yes	5

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