Kandula Srinivasa Reddy Memorial College of Engineering (Autonomous)

Kadapa-516003. AP

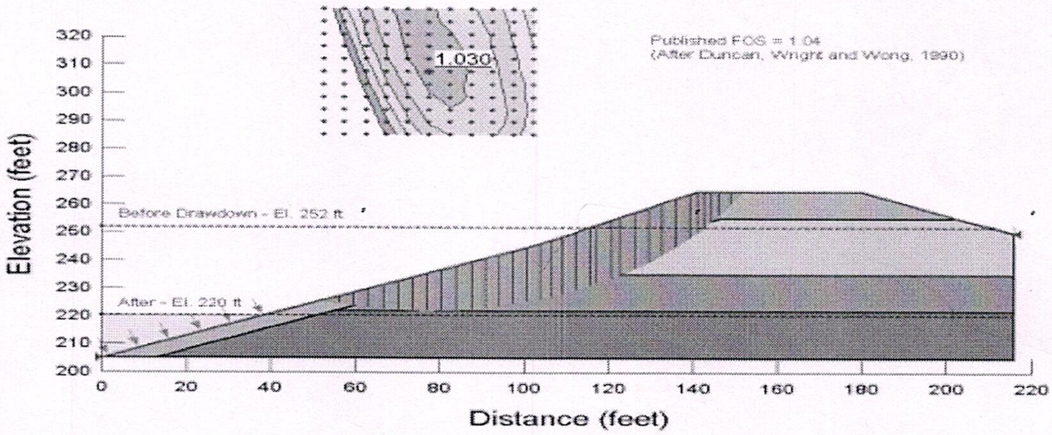
(Approved by AICTE, Affiliated to JNTUA, Ananthapuramu, Accredited by NAAC)

(An ISO 9001-2008 Certified Institution)

Department of Civil Engineering

Certification Course

On



Design of Slopes by using GeoStudio

Course Instructor:

Sri. P. Suresh Praveen Kumar, Assistant Professor, Civil Engg. Dept., KSRMCE

Course Coordinators:

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

Date: 02/10/2021 to 11/10/2021

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/2021-22/ Date: 25-09-2021

From
Sri P. Rajendra Kumar,
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 by using GeoStudio” for B. Tech. students of KSRMCE. The course will start on 2nd Oct. 2021 and the course will run in online mode. In this regard, I am requesting you to accept the proposal to conduct certification course.

Thanking you

Forwarded to principal sir

Yours faithfully

P. Rajendra Kumar
(Sri P. Rajendra Kumar)

Permitted
V.S.S.Murthy

Cr./KSRMCE/CE/2021-22/ Date: 27/09/2021

Circular

It is informed to the B.Tech. and M. Tech. students of KSRMCE that the Department of Civil Engineering is going to conduct a certificate course on "Design of Slopes by using GeoStudio" on the occasion of Karl von Terzaghi's 139th birth anniversary on 02nd October, 2021. In this connection we request the above said students to register their names with the department clerk or fill and submit the google form shared with your college mail ID.

https://docs.google.com/forms/f/g/dajbcwLQupfkyfa74f5sHAEsdnfpof3ajsddlfgmzpsq64EGQnckoa/viewform

The Course Coordinator
Sri P. Rajendra Kumar,
Assistant Professor,
Department of Civil Engg.- KSRMCE.

HoD-CE

Cc to:

IQAC-KSRMCE

Registration form for "Certification course on Design of Slopes by using GeoStudio"

Course Instructor:

Sri. P. Suresh Praveen Kumar, Assistant Professor, Civil Engg. Dept., KSRMCE

Course Coordinator:

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

Date: 02/10/2021 to 11/10/2021

reddysrinu@ksrmce.ac.in Switch account

Your email will be recorded when you submit this form

* Required

Student Roll No. *

Your answer

Student Name *

Your answer

Mail ID *

Your answer

Course *

Your answer

Submit

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Never submit passwords through Google Forms.

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Department of Civil Engineering

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

Sl. No.	Student Roll No.	Student Name	Mail ID	Course
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81	209Y1D1216	Yarram Yashwanth	yarramyaswanth98@gmail.com	M.Tech

P. Rajendra Kumar
Coordinator

HoD-Civil Engg.

Head
Department of Civil Engineering
K.S.R.M. College of Engineering
(Autonomous)
KADAPA 516 003. (A.P.)

Syllabus of Certification Course

Course Name: Design of Slopes by using GeoStudio

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/

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Certification course on "Design of Slopes by using GeoStudio"

Date	Timing	Course Instructor	Topic to be covered
02-10-21	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Fundamentals on slopes, Types of slopes
03-10-21	9 AM to 6 PM	Sri. P. Suresh Praveen Kumar	Methods of analysis -Limit Equilibrium, Numerical Methods like Finite Element Methods, Finite Difference Methods
04-10-21	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	boundary Element methods, Universal Distinct Element Methods, Langranian Methods. Causes of Failures
05-10-21	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Different Limit equilibrium methods and its application to slopes
06-10-21	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Introdcution about Geo Studio, Fundamentals on LE
07-10-21	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Different Shapes of Slip surfaces, Geometry of slope
08-10-21	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	various functions in Geo Studio
09-10-21	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Material strength of different soils and evaluation of properties in lab and field
10-10-21	9 AM to 6 PM	Sri. P. Suresh Praveen Kumar	Material strength of different soils and evaluation of properties in lab and field, Material strength of different soils and evaluation of properties in lab and field, Examples on various site conditions – slope, Embankment, Layered Soil, Examples on various site conditions – slope, Embankment, Layered Soil
11-10-21	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Examples on various site conditions – slope, Embankment, Layered Soil

Instructor: [signature]

Coordinator: [signature]

Department of Civil Engineering

Attendance sheet of Certification course on Design of Slopes by using GeoStudio

Sl. No.	Student Roll No.	Student Name	2/10	3/10	4/10	5/10	6/10	7/10	8/10	9/10	10/10	11/10
1	179Y1A0128	Gani Hyder Ali Khan	Ali	Ali	A	Ali	Ali	Ali	Ali	Ali	Ali	Ali
2	179Y1A0171	Pasupula Prathap Reddy	Prathap	Prathap	Prathap	A	Prathap	Prathap	A	Prathap	Prathap	Prathap
3	189Y1A0111	Vamsi B	Vamsi	Vamsi	Vamsi	Vamsi	A	Vamsi	Vamsi	Vamsi	Vamsi	Vamsi
4	189Y1A0112	Bysani Lokesh Kumar Reddy	Lokesh	Lokesh	Lokesh	Lokesh	A	Lokesh	Lokesh	Lokesh	Lokesh	Lokesh
5	189Y1A0114	Challa Jithendra Reddy	A	C.J.Reddy	C.J.Reddy	C.J.Reddy	C.J.Reddy	C.J.Reddy	C.J.Reddy	C.J.Reddy	C.J.Reddy	C.J.Reddy
6	189Y1A0117	Chilamakuru Venkata Mohan	A	C.V.Mohan	C.V.Mohan	C.V.Mohan	C.V.Mohan	C.V.Mohan	C.V.Mohan	C.V.Mohan	C.V.Mohan	C.V.Mohan
7	189Y1A0118	C Harish	Harish	Harish	A	Harish	Harish	Harish	Harish	Harish	Harish	Harish
8	189Y1A0123	Rama Mohan Derangula	Ram	Ram	A	Ram	Ram	A	Ram	Ram	Ram	Ram
9	189Y1A0124	Derangula Santhosh Kumar	Kumar	Kumar	Kumar	Kumar	Kumar	A	Kumar	Kumar	Kumar	Kumar
10	189Y1A0126	Duddekunta Venkata Jithendhar Reddy	Reddy	Reddy	Reddy	Reddy	Reddy	A	Reddy	Reddy	Reddy	Reddy
11	189Y1A0128	G Y Venkata Sainath Reddy	Y.V.Sai	Y.V.Sai	A	Y.V.Sai	A	Y.V.Sai	Y.V.Sai	Y.V.Sai	Y.V.Sai	Y.V.Sai
12	189Y1A0130	Gaddam Prem Kumar	Prem	Prem	Prem	Prem	A	Prem	Prem	A	Prem	Prem
13	189Y1A0133	Guduru Ajay Kumar	Ajay	Ajay	Ajay	Ajay	Ajay	Ajay	Ajay	A	Ajay	Ajay
14	189Y1A0137	Jamalla Gangaraju	J.Ga	J.Ga	A	J.Ga	J.Ga	J.Ga	A	J.Ga	J.Ga	J.Ga
15	189Y1A0140	J. Jahnavi	J.Jahnavi	J.Jahnavi	J.Jahnavi	J.Jahnavi	J.Jahnavi	J.Jahnavi	A	J.Jahnavi	J.Jahnavi	J.Jahnavi
16	189Y1A0141	Kaipu Uday Kumar	Uday	Uday	Uday	Uday	A	A	Uday	Uday	Uday	Uday

17	189Y1A0143	K Sireesha	Sireesh	Sivre	A	A	Sive	Sive	Sive	Sire	Sive	Sire
18	189Y1A0144	K.Bhanu Manikanta Reddy	Bhanu	Bhanu	Bhanu	Bhanu	A	A	Bhanu	Bhanu	Bhanu	Bhanu
19	189Y1A0148	K.Sunil Kumar	Sunil	Sunil	Sunil	A	Sunil	Sunil	Sunil	A	Sunil	Sunil
20	189Y1A0152	K.Hari Jaswanth	K.hari Jaswanth	K.hari Jaswanth	K.hari Jaswanth	K.hari Jaswanth	K.hari Jaswanth	A	K.Hari Jaswanth	K.Hari Jaswanth	K.hari Jaswant	K.hari Jaswanth
21	189Y1A0155	Lingamdinne Veera Venkata Varaprasad Reddy	Prasad	Prasad	Prasad	Prasad	A	Prasad	Prasad	Prasad	Prasad	Prasad
22	189Y1A0156	Majjari Shiva Shankar	M. Siva	M.Siva	M.Siva	A	M.Siva	M.Siva	M.Siva	M.Siva	M.Siva	M.Siva
23	189Y1A0161	M.Sai Karthik	M.Sai	M.Sai	M.Sai	A	M.Sai	M.Sai	M.Sai	M.Sai	M.Sai	M.Sai
24	189Y1A0165	M. Purushotha Reddy	MP	M.Pu	MPu	MPu	A	MPu	Pu	MPu	MPu	MPu
25	189Y1A0166	Mitta Siva Prasad Reddy	MS	MSiv	MSiv	M	M	M	A	A	M	M
26	189Y1A0170	Niharika Nagalarapu	Niharika	Niharika	Niharika	A	Niharika	Niharika	Niharika	Niharika	Niharika	Niharika
27	189Y1A0171	N.V.Sai Poojith	A	N.Poojith	N.Poojith	N.Poojith	N.Poojitha	N.Poojitha	N.Poojitha	N.Poojitha	N.Poojitha	N.Poojitha
28	189Y1A0173	N.Siva Reddy	A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	189Y1A0174	Nallanukala Mahesh	A	Mahesh	A	Mahesh	A	Mahesh	Mahesh	Mahesh	Mahesh	Mahesh
30	189Y1A0176	Nukanaboina Naganaveen Yadav	Naveen	Naveen	A	Naveen	A	Naveen	Naveen	Naveen	Naveen	Naveen
31	189Y1A0177	Pagati Raga Sravani	Sravani	Sravani	Sravini	Sravini	A	Sravi	Sravini	A	A	Sravini
32	189Y1A0178	P.Nithish Chand	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	A	[illegible]	[illegible]	[illegible]	[illegible]
33	189Y1A0180	Panga Gangakishore Yadav	Kishore	Kishore	Kishore	Kishore	A	Kishore	Kishore	Kishore	Kishore	Kishore
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35	189Y1A0183	Pasupuleti Sivasai	Sivasai	A	Siva	Siva	Siva	Siva	Siva	Siva	Siva	Siva
36	189Y1A0185	Patil Praveen	Praveen	Praveen	Praveen	Praveen	A	Praveen	Praveen	Praveen	Praveen	Praveen

37	189Y1A0187	Penuabala Rakesh Prasanna	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	A	[signature]	[signature]
38	189Y1A0189	Naga Sai	[signature]	[signature]	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]
39	189Y1A0193	Rachamallu Bindhu	[signature]	[signature]	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]
40	189Y1A0194	S.Neeraj	[signature]	[signature]	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]
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42	189Y1A0198	Shaik.Afroz	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
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44	189Y1A01B4	T. Gayathri	[signature]	A	[signature]	[signature]	[signature]	[signature]	A	[signature]	A	[signature]
45	189Y1A01B5	T.Dasthagiri	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
46	189Y1A01B7	Uncha Pavan Kalyan	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
47	189Y1A01C2	V.Hemanth Kumar Reddy	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
48	189Y1A01C3	Vennapusa Ganga Swetha	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
49	189Y1A01C4	Vusuvandla Rajesh	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
50	189Y1A01C6	Yelikanti Naga Hema Pranitha Sree	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
51	189Y1A01C8	Y.Sivanatha Reddy	[signature]	A	[signature]	[signature]	[signature]	[signature]	A	[signature]	A	[signature]
52	199Y5A0102	Akula Malik	[signature]	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]
53	199Y5A0104	A Somasekhar	[signature]	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]
54	199Y5A0105	A.Venu Gopal Reddy	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
55	199Y5A0107	B. Vijay Kumar Reddy	[signature]	[signature]	[signature]	[signature]	[signature]	A	A	[signature]	[signature]	[signature]
56	199Y5A0109	Bukke Mahesh Naik	[signature]	[signature]	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]
57	199Y5A0111	Chinna Swami Gari Rohith	[signature]	[signature]	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]

58	199Y5A0117	Dudekula Dastagiri	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
59	199Y5A0122	G.Venkatesh	Venky	venky	A	Venky	venky	A	Venky	Venky	venky	venky
60	199Y5A0125	Judam Venkateshwarlu	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	A	[signature]	[signature]
61	199Y5A0127	Kashetty Venkateswarlu	venkat	venkat	venkat	A	venkat	venkat	venkat	venkat	venkat	venkat
62	199Y5A0128	Kunukuntla Viswanath	K.V.	K.V	K.V	K.V	K.V	A	K.V	K.V	K.V	K.V
63	199Y5A0138	Nagulugari Reddaiah	Reddaiah	Reddaiah	Reddaiah	Reddaiah	Reddaiah	Reddaiah	Reddaiah	Reddaiah	Reddaiah	Reddaiah
64	199Y5A0140	Nandyala Vinod Kumar	Nandyala	Nandyala	Nandyala	A	A	Nandyala	A	Nandyala	A	Nandyala
65	199Y5A0141	N Parameswara	Param	A	Param	Param	Param	Param	Param	Param	Param	Param
66	199Y5A0143	Pandeeti Kasanna	P.Kasanna	P.Kasanna	A	P.Kasanna	P.Kasanna	P.Kasanna	P.Kasanna	P.Kasanna	P.Kasanna	P.Kasanna
67	199Y5A0148	P.Vamsi Kumar	Vamsi	Vamsi	A	Vamsi	Vamsi	Vamsi	Vamsi	Vamsi	Vamsi	Vamsi
68	199Y5A0149	Sambaturu Chandra Mouli	chandra	chandra	A	chandra	A	chandra	chandra	chandra	chandra	chandra
69	199Y5A0151	Sannidanam Venkata Sai Kiran	Sai	Sai	Sai	A	Sai	Sai	Sai	Sai	Sai	Sai
70	199Y5A0152	Shaik.Mohammadarief	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
71	199Y5A0153	Shaik Mohammad Saleem	S.M.Saleem	S.M.Saleem	A	S.M.Saleem	A	S.M.Saleem	S.M.Saleem	S.M.Saleem	S.M.Saleem	S.M.Saleem
72	199Y5A0155	Sravani Sirigiri	Sravani	Sravani	Sravani	A	Sravani	Sravani	Sravani	Sravani	Sravani	Sravani
73	199Y5A0156	S. Abhishek Kumar Reddy	AKR	AKR	AKR	AKR	AKR	AKR	AKR	AKR	AKR	AKR
74	199Y5A0159	Thoti Chandu	Chandu	Chandu	Chandu	A	Chandu	Chandu	A	Chandu	Chandu	Chandu
75	199Y5A0160	Udayagiri Siva Sai	Sai	Sai	Sai	Sai	Sai	Sai	Sai	Sai	Sai	Sai
76	209Y1D1205	Mohammad Abdul Wahab	[signature]	[signature]	[signature]	A	[signature]	A	[signature]	[signature]	[signature]	[signature]
77	209Y1D1208	Obugani Siva Sankar	[signature]	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]
78	209Y1D1212	Shaik Nasrin	Nasrin	Nasrin	Nasrin	Nasrin	Nasrin	Nasrin	A	Nasrin	Nasrin	Nasrin

79	209Y1D1213	S Fowjiya Tasleem	Fowjiya	Fowjiya	Fowjiya	Fowjiya	Fowjiya	Fowjiya	Fowjiya	Fowjiya	Fowjiya	Fowjiya
80	209Y1D1214	T.Sai Srinivas	T.sai srinivas	A	sai srinivas	sai srinivas	A	sai srinivas	sai srinivas	sai srinivas	sai srinivas	sai srinivas
81	209Y1D1216	Yarram Yashwanth	yashwanth	yashwanth	A	A	yashwanth	yashwanth	yashwanth	yashwanth	yashwanth	yash

P. R
Coordinator

HoD-Civil Engg.

Head
Department of Civil Engineering
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K.S.R.M. COLLEGE OF ENGINEERING

(UGC - Autonomous)

Kadapa, Andhra Pradesh, India– 516 003

Approved by AICTE, New Delhi & Affiliated to JNTUA, Ananthapuramu.

KSNR

lives on..

Department of Civil Engineering

Certificate Course on

"Design of Slopes by using Geostudio"

on the occasion of

Karl von Terzaghi's birthday

on 2nd October, 2021.

Course Coordinator:
Suresh Praveen Kumar. P
Assistant Professor,
Department of Civil Engineering,
KSRMCE, Kadapa.

Course Co-coordinator:
Rajendra Kumar. P
Assistant Professor,
Department of Civil Engineering,
KSRMCE, Kadapa.

Course starting Date: 02.10.2021.

DR. N. AMARANATH REDDY (HOD) | *DR. V.S.S. MURTHY* (Principal) | *PROF. A. MOHAN* (Director) | *DR. KANDULA CHANDRA OBUL REDDY* (Managing Director) | *SMT. K. RAJESWARI* (Correspondent Secretary, Treasurer) | *SRI K. MADAN MOHAN REDDY* (Vice-chairman) | *SRI. K. RAJA MOHAN REDDY* (Chairman)

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KSNR lives on..

Report

of

Certification Course on Design of Slopes by using GeoStudio.

From 02/10/2021 to 11/10/2021

Target Group	:	**Students**
Details of Participants	:	**81 Students**
Co-coordinator(s)	:	**Sri P. Rajendra Kumar**
Organizing Department	:	**Civil Engineering**
Venue	:	**Online (google meet)**
		Link: https://meet.google.com/lookup/hbaetq1jsq

Description:

The Department of Civil Engineering organized a certificate course on "Design of Slopes by using GeoStudio" for both B.Tech 7th Semester and M.Tech students on the occasion of Karl von Terzaghi's 139th birth anniversary on 02nd October, 2021. In this regard, Prof. A. Mohan, Director of Kandula Group of Institutions, Prof. V. S. S. Murthy, Principal and Management praised the work and services of Karl von Terzaghi towards the field of Geotechnical Engineering. Dr. N. Amaranatha Reddy, Head of the department addressed regarding the importance of the protection of the soil slopes and its design by using GeoStudio software. For this thirty hours' certification course Sri. P. Suresh Praveen Kumar acted as course instructor and Sri. P. Rajendra Kumar acted as course Coordinator.

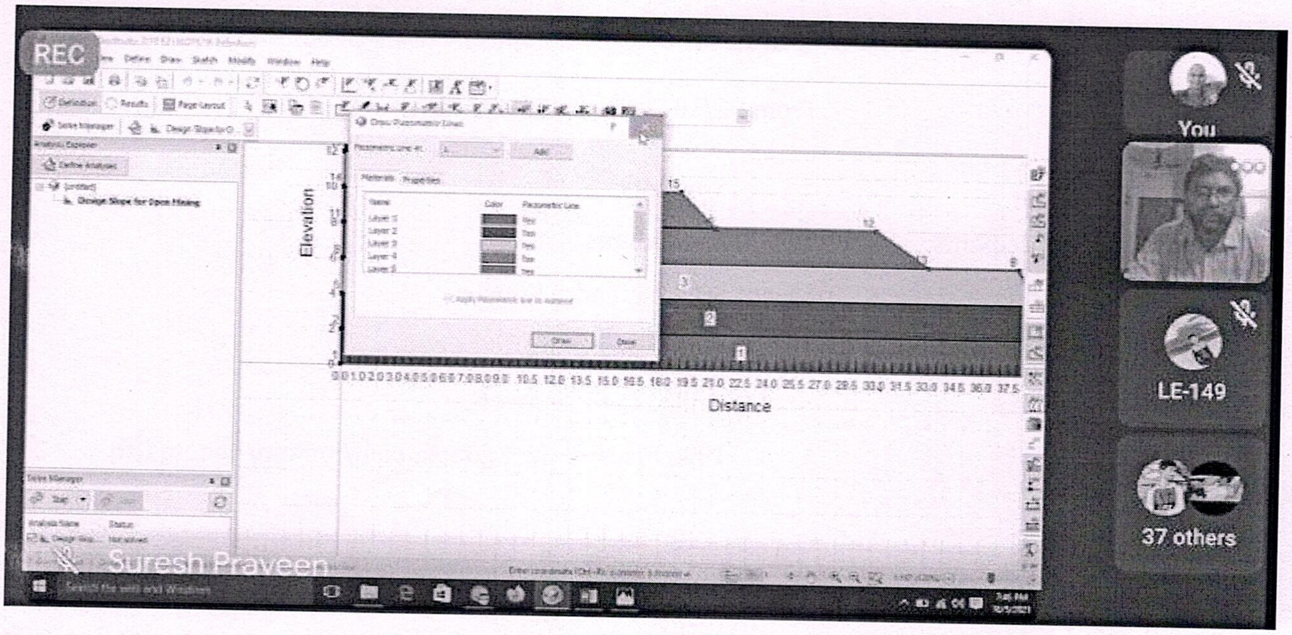
The schedule or list of topics covered in the certificate course is

- Infinite and finite Slopes
- Types and Causes of Failure
- Standard Method of Slices
- Bishop's Simplified Method
- Introduction about GeoStudio
- Limit Equilibrium Fundamentals
- Factor of Safety Methods

- Slip Surface Shapes
- Geometry
- Functions in GeoStudio
- Material Strength
- Illustrated Examples

Photo:

The picture taken during the course is given below:



(Course Coordinator)

(HoD, Civil Engg.)

Head
Department of Civil Engineering
K.S.R.M. College of Engineering
(Autonomous)
KADAPA 516 003. (A.P.)

K.S.R.M COLLEGE OF ENGINEERING

(AUTONOMOUS)

KADAPA-516003, A.P, INDIA

Department of Civil Engineering

Certificate of Participation

This is to Certify that

KASHETTY VENKATESWARLU

Bearing Roll No: 199Y5A0127

Student of **B.Tech 7th Semester** successfully completed the Certificate Course on **"Design of Slopes by using GeoStudio"** in online mode from 02nd October to 11th October, 2021, organized by Department of Civil Engineering, KSRMCE (A), Kadapa.

P. Rajasekhar Kumar
Course Coordinator

HoD, CE

V. S. S. Murthy
Principal

K.S.R.M COLLEGE OF ENGINEERING
(AUTONOMOUS)
KADAPA-516003, A.P, INDIA

NAAC B+ GRADE

LIGHTED TO LIGHTEN ESTD : 1980

UGC-AUTONOMOUS

Department of Civil Engineering

Certificate of Participation

This is to Certify that

K.SUNIL KUMAR

Bearing Roll No: 189Y1A0148

Student of **B.Tech 7th Semester** successfully completed the Certificate Course on **"Design of Slopes by using GeoStudio"** in online mode from 02nd October to 11th October, 2021, organized by Department of Civil Engineering, KSRMCE (A), Kadapa.

Course Coordinator | HoD, CE | Principal

K.S.R.M COLLEGE OF ENGINEERING

(AUTONOMOUS)

KADAPA-516003, A.P, INDIA

NAAC B GRADE

ESTD : 1980

UGC AUTONOMOUS

Department of Civil Engineering

Certificate of Participation

This is to Certify that

NALLANUKALA MAHESH

Bearing Roll No: 189Y1A0174

Student of B.Tech 7th Semester successfully completed the Certificate Course on **"Design of Slopes by using GeoStudio"** in online mode from 02nd October to 11th October, 2021, organized by Department of Civil Engineering, KSRMCE (A), Kadapa.

Course Coordinator | HoD, CE | Principal

K.S.R.M COLLEGE OF ENGINEERING

(AUTONOMOUS)

KADAPA-516003, A.P, INDIA

NAAC B GRADE

ESTD : 1980

UGC-AUTONOMOUS

Department of Civil Engineering

Certificate of Participation

This is to Certify that

T. SAI SRINIVAS

Bearing Roll No: 209Y1D1214

Student of **M.Tech.** successfully completed the Certificate Course on **"Design of Slopes by using GeoStudio"** in online mode from 02nd October to 11th October, 2021, organized by Department of Civil Engineering, KSRMCE (A), Kadapa.

P. Rajendra Kumar
Course Coordinator

HoD, CE

V. S. S. Murthy
Principal

Feedback form for "Certification course on Design of Slopes by using GeoStudio)"

reddysrinu@ksrmce.ac.in Switch account

Your email will be recorded when you submit this form

* Required

Name of The Student *

Your answer

Roll. No. *

Your answer

Is this course enhanced your knowledge on Geo-technical? *

- ◯ Yes
- ◯ No

Can you do slope stability analysis using GioStudio? *

- ◯ Yes
- ◯ No

Rate the course instructor *

1-Low, 5-High

1 ○

2 ○

3 ○

4 ○

5 ○

Is this course useful for your Carrier? *

○ Yes

○ No

○ May be

Rate the entire course? *

1-Low, 5-High

1 ○

2 ○

3 ○

4 ○

5 ○

Submit

Clear form

Department of Civil Engineering

Feedback of students on Certification Course on "Design of Slopes by using GeoStudio"

Sl. No.	Roll. No.	Name of the Student	Is this course enhanced your knowledge on Geo-technical?	Can you do slope stability analysis using GioStudio?	Rate the course instructor	Is this course useful for your Carrier?	Rate the entire course?
1	179Y1A0128	Gani Hyder Ali Khan	Yes	Yes	5	Yes	5
2	179Y1A0171	Pasupula Prathap Reddy	Yes	Yes	5	Yes	5
3	189Y1A0111	Vamsi B	Yes	Yes	5	Yes	5
4	189Y1A0112	Bysani Lokesh Kumar Reddy	Yes	Yes	5	Yes	5
5	189Y1A0114	Challa Jithendra Reddy	Yes	Yes	5	Yes	5
6	189Y1A0117	Chilamakuru Venkata Mohan	Yes	Yes	5	Yes	5
7	189Y1A0118	C Harish	Yes	Yes	5	Yes	5
8	189Y1A0123	Rama Mohan Derangula	Yes	Yes	5	Yes	5
9	189Y1A0124	Derangula Santhosh Kumar	Yes	Yes	5	Yes	5
10	189Y1A0126	Duddekunta Venkata Jithendhar Reddy	Yes	Yes	5	Yes	5
11	189Y1A0128	G Y Venkata Sainath Reddy	Yes	Yes	5	Yes	5
12	189Y1A0130	Gaddam Prem Kumar	Yes	Yes	5	Yes	4
13	189Y1A0133	Guduru Ajay Kumar	Yes	Yes	5	Yes	5
14	189Y1A0137	Jamalla Gangaraju	Yes	Yes	5	Yes	5
15	189Y1A0140	J. Jahnavi	Yes	Yes	5	Yes	5
16	189Y1A0141	Kaipu Uday Kumar	Yes	Yes	5	Yes	5
17	189Y1A0143	K Sireesha	Yes	Yes	5	Yes	5
18	189Y1A0144	K.Bhanu Manikanta Reddy	Yes	Yes	5	Yes	5

19	189Y1A0148	K.Sunil Kumar	Yes	Yes	5	May be	5
20	189Y1A0152	K.Hari Jaswanth	Yes	Yes	5	Yes	5
21	189Y1A0155	Lingamdinne Veera Venkata Varaprasad Reddy	Yes	Yes	5	Yes	5
22	189Y1A0156	Majjari Shiva Shankar	Yes	Yes	5	Yes	5
23	189Y1A0161	M.Sai Karthik	Yes	Yes	5	Yes	5
24	189Y1A0165	M. Purushotha Reddy	Yes	Yes	5	Yes	5
25	189Y1A0166	Mitta Siva Prasad Reddy	Yes	Yes	5	May be	5
26	189Y1A0170	Niharika Nagalarapu	Yes	Yes	5	Yes	5
27	189Y1A0171	N.V.Sai Poojith	Yes	Yes	5	Yes	4
28	189Y1A0173	N.Siva Reddy	Yes	Yes	5	Yes	5
29	189Y1A0174	Nallanukala Mahesh	Yes	Yes	5	Yes	5
30	189Y1A0176	Nukanaboina Naganaveen Yadav	Yes	Yes	5	Yes	5
31	189Y1A0177	Pagati Raga Sravani	Yes	Yes	5	Yes	5
32	189Y1A0178	P.Nithish Chand	Yes	Yes	5	Yes	5
33	189Y1A0180	Panga Gangakishore Yadav	Yes	Yes	5	Yes	5
34	189Y1A0181	P Muni Kumar	Yes	Yes	5	Yes	5
35	189Y1A0183	Pasupuleti Sivasai	Yes	Yes	5	Yes	5
36	189Y1A0185	Patil Praveen	Yes	Yes	5	Yes	5
37	189Y1A0187	Penuabala Rakesh Prasanna	Yes	Yes	5	Yes	5
38	189Y1A0189	Naga Sai	Yes	Yes	5	Yes	5
39	189Y1A0193	Rachamallu Bindhu	Yes	Yes	5	Yes	5
40	189Y1A0194	S.Neeraj	Yes	Yes	5	May be	5

41	189Y1A0195	Seelam. Swarnalatha	Yes	Yes	4	Yes	5
42	189Y1A0198	Shaik.Afroz	Yes	Yes	5	Yes	5
43	189Y1A01B1	Thati Sukumar	Yes	Yes	5	Yes	5
44	189Y1A01B4	T. Gayathri	Yes	Yes	5	Yes	5
45	189Y1A01B5	T.Dasthagiri	Yes	Yes	5	Yes	5
46	189Y1A01B7	Uncha Pavan Kalyan	Yes	Yes	5	Yes	5
47	189Y1A01C2	V.Hemanth Kumar Reddy	Yes	Yes	5	Yes	5
48	189Y1A01C3	Vennapusa Ganga Swetha	Yes	Yes	5	Yes	5
49	189Y1A01C4	Vusuvandla Rajesh	Yes	Yes	5	Yes	5
50	189Y1A01C6	Yelikanti Naga Hema Pranitha Sree	Yes	Yes	5	Yes	5
51	189Y1A01C8	Y.Sivanatha Reddy	Yes	Yes	5	Yes	5
52	199Y5A0102	Akula Malik	Yes	Yes	5	Yes	5
53	199Y5A0104	A Somasekhar	Yes	Yes	5	Yes	5
54	199Y5A0105	A.Venu Gopal Reddy	Yes	Yes	5	Yes	5
55	199Y5A0107	B. Vijay Kumar Reddy	Yes	Yes	5	Yes	5
56	199Y5A0109	Bukke Mahesh Naik	Yes	Yes	5	Yes	4
57	199Y5A0111	Chinna Swami Gari Rohith	Yes	Yes	5	Yes	5
58	199Y5A0117	Dudekula Dastagiri	Yes	Yes	5	Yes	5
59	199Y5A0122	G.Venkatesh	Yes	Yes	4	Yes	5
60	199Y5A0125	Judam Venkateshwarlu	Yes	Yes	5	Yes	5
61	199Y5A0127	Kashetty Venkateswarlu	Yes	Yes	5	Yes	5
62	199Y5A0128	Kunukuntla Viswanath	Yes	Yes	5	Yes	5
63	199Y5A0138	Nagulugari Reddaiah	Yes	Yes	5	Yes	5

64	199Y5A0140	Nandyala Vinod Kumar	Yes	Yes	5	Yes	5
65	199Y5A0141	N Parameswara	Yes	Yes	5	Yes	5
66	199Y5A0143	Pandeeti Kasanna	Yes	Yes	5	Yes	5
67	199Y5A0148	P.Vamsi Kumar	Yes	Yes	5	Yes	5
68	199Y5A0149	Sambaturu Chandra Mouli	Yes	Yes	4	Yes	5
69	199Y5A0151	Sannidanam Venkata Sai Kiran	Yes	Yes	5	Yes	5
70	199Y5A0152	Shaik.Mohammadarief	Yes	Yes	5	Yes	5
71	199Y5A0153	Shaik Mohammad Saleem	Yes	Yes	5	Yes	5
72	199Y5A0155	Sravani Sirigiri	Yes	Yes	5	Yes	5
73	199Y5A0156	S. Abhishek Kumar Reddy	Yes	Yes	5	Yes	5
74	199Y5A0159	Thoti Chandu	Yes	Yes	5	Yes	5
75	199Y5A0160	Udayagiri Siva Sai	Yes	Yes	5	May be	5
76	209Y1D1205	Mohammad Abdul Wahab	Yes	Yes	5	Yes	5
77	209Y1D1208	Obugani Siva Sankar	Yes	Yes	5	Yes	4
78	209Y1D1212	Shaik Nasrin	Yes	Yes	5	Yes	5
79	209Y1D1213	S Fowjiya Tasleem	Yes	Yes	5	Yes	5
80	209Y1D1214	T.Sai Srinivas	Yes	Yes	4	Yes	5
81	209Y1D1216	Yarram Yashwanth	Yes	Yes	3	Yes	5

Coordinator

HoD-Civil Engg.

Head
Department of Civil Engineering
K.S.R.M. College of Engineering
(Autonomous)
KADAPA 516 003. (A.P.)

K.S.R.M. COLLEGE OF ENGINEERING (AUTONOMOUS), KADAPA-516003
DEPARTMENT OF CIVIL ENGINEERING
CERTIFICATE COURSE ON
DESIGN OF SLOPES BY USING GEOSTUDIO
MARKS AWARD LIST

S.No	Roll Number	Name of the Student	Marks Obtained
1	179Y1A0128	Gani Hyder Ali Khan	16
2	179Y1A0171	Pasupula Prathap Reddy	16
3	189Y1A0111	Vamsi B	13
4	189Y1A0112	Bysani Lokesh Kumar Reddy	18
5	189Y1A0114	Challa Jithendra Reddy	15
6	189Y1A0117	Chilamakuru Venkata Mohan	17
7	189Y1A0118	C Harish	15
8	189Y1A0123	Rama Mohan Derangula	17
9	189Y1A0124	Derangula Santhosh Kumar	19
10	189Y1A0126	Duddekunta Venkata Jithendhar Reddy	15
11	189Y1A0128	G Y Venkata Sainath Reddy	14
12	189Y1A0130	Gaddam Prem Kumar	18
13	189Y1A0133	Guduru Ajay Kumar	13
14	189Y1A0137	Jamalla Gangaraju	15
15	189Y1A0140	J. Jahnavi	12
16	189Y1A0141	Kaipu Uday Kumar	13
17	189Y1A0143	K Sireesha	15
18	189Y1A0144	K.Bhanu Manikanta Reddy	13
19	189Y1A0148	K.Sunil Kumar	7
20	189Y1A0152	K.Hari Jaswanth	16
21	189Y1A0155	Lingamdinne Veera Venkata Varaprasad Reddy	19
22	189Y1A0156	Majjari Shiva Shankar	10
23	189Y1A0161	M.Sai Karthik	15
24	189Y1A0165	M. Purushotha Reddy	8
25	189Y1A0166	Mitta Siva Prasad Reddy	12
26	189Y1A0170	Niharika Nagalarapu	18

27	189Y1A0171	N.V.Sai Poojith	12
28	189Y1A0173	N.Siva Reddy	14
29	189Y1A0174	Nallanukala Mahesh	15
30	189Y1A0176	Nukanaboina Naganaveen Yadav	6
31	189Y1A0177	Pagati Raga Sravani	19
32	189Y1A0178	P.Nithish Chand	16
33	189Y1A0180	Panga Gangakishore Yadav	14
34	189Y1A0181	P Muni Kumar	13
35	189Y1A0183	Pasupuleti Sivasai	17
36	189Y1A0185	Patil Praveen	11
37	189Y1A0187	Penuabala Rakesh Prasanna	6
38	189Y1A0189	Naga Sai	19
39	189Y1A0193	Rachamallu Bindhu	12
40	189Y1A0194	S.Neeraj	13
41	189Y1A0195	Seelam. Swarnalatha	16
42	189Y1A0198	Shaik.Afroz	13
43	189Y1A01B1	Thati Sukumar	13
44	189Y1A01B4	T. Gayathri	19
45	189Y1A01B5	T.Dasthagiri	16
46	189Y1A01B7	Uncha Pavan Kalyan	15
47	189Y1A01C2	V.Hemanth Kumar Reddy	12
48	189Y1A01C3	Vennapusa Ganga Swetha	16
49	189Y1A01C4	Vusuvandla Rajesh	15
50	189Y1A01C6	Yelikanti Naga Hema Pranitha Sree	17
51	189Y1A01C8	Y.Sivanatha Reddy	13
52	199Y5A0102	Akula Malik	18
53	199Y5A0104	A Somasekhar	6
54	199Y5A0105	A.Venu Gopal Reddy	12
55	199Y5A0107	B. Vijay Kumar Reddy	16
56	199Y5A0109	Bukke Mahesh Naik	11
57	199Y5A0111	Chinna Swami Gari Rohith	12

58	199Y5A0117	Dudekula Dastagiri	18
59	199Y5A0122	G.Venkatesh	17
60	199Y5A0125	Judam Venkateshwarlu	7
61	199Y5A0127	Kashetty Venkateswarlu	15
62	199Y5A0128	Kunukuntla Viswanath	13
63	199Y5A0138	Nagulugari Reddaiah	6
64	199Y5A0140	Nandyala Vinod Kumar	10
65	199Y5A0141	N Parameswara	17
66	199Y5A0143	Pandeeti Kasanna	14
67	199Y5A0148	P.Vamsi Kumar	12
68	199Y5A0149	Sambaturu Chandra Mouli	17
69	199Y5A0151	Sannidanam Venkata Sai Kiran	19
70	199Y5A0152	Shaik.Mohammadarief	14
71	199Y5A0153	Shaik Mohammad Saleem	8
72	199Y5A0155	Sravani Sirigiri	15
73	199Y5A0156	S. Abhishek Kumar Reddy	13
74	199Y5A0159	Thoti Chandu	11
75	199Y5A0160	Udayagiri Siva Sai	13
76	209Y1D1205	Mohammad Abdul Wahab	13
77	209Y1D1208	Obugani Siva Sankar	14
78	209Y1D1212	Shaik Nasrin	16
79	209Y1D1213	S Fowjiya Tasleem	5
80	209Y1D1214	T.Sai Srinivas	15
81	209Y1D1216	Yarram Yashwanth	12

P. Rajendra Kumar
Coordinator

HoD

Head
Department of Civil Engineering
K.S.R.M. College of Engineering
(Autonomous)
KADAPA - 516 003. (A.P.)

15/20

K.S.R.M. COLLEGE OF ENGINEERING (AUTONOMOUS), KADAPA-516003
DEPARTMENT OF CIVIL ENGINEERING
CERTIFICATE COURSE ON
DESIGN OF SLOPES BY USING GEOSTUDIO
ASSESSMENT TEST

Name of the Student: C. Jithendra Reddy **Reg. Number:** 189Y1A0114

Time: 20 Min **(Objective Questions)** **Max. Marks: 20**

Note: Answer the following Questions and each question carries **one** mark.

1	What is the primary concern of geotechnical engineering?				[C] ✓
	A) Structural design	B) Environmental conservation	C) Soil and rock behavior	D) Traffic management	
2	What is the term for the study of the physical and mechanical properties of soils and rocks?				[C] ✓
	A) Seismology	B) Geophysics	C) Geomechanics	D) Hydrogeology	
3	Which type of soil has the smallest particle size and retains water most effectively?				[D] ✓
	A) Sand	B) Silt	C) Gravel	D) Clay	
4	What is the angle of repose for loose, dry sand typically measured at?				[B] ✓
	A) 15° to 20°	B) 30° to 45°	C) 60° to 75°	D) 90°	
5	What does the term "bearing capacity" refer to in geotechnical engineering?				[B] ✓
	A) The ability of soil to support plant life	B) The ability of soil to withstand heavy loads	C) The ability of soil to resist erosion	D) The ability of soil to filter contaminants	
6	What is the purpose of a geotechnical site investigation?				[B] ✗
	A) To determine the cost of construction	B) To assess the impact of traffic on the site	C) To collect data about soil and rock conditions	D) To calculate the building's height	
7	What is the primary function of retaining walls in geotechnical engineering?				[C] ✓
	A) To store water	B) To provide seating in parks	C) To stabilize slopes and prevent erosion	D) To generate electricity	
8	Which test is used to measure the moisture content of a soil sample?				[B] ✓
	A) Proctor compaction test	B) Atterberg limits test	C) Permeability test	D) Sieve analysis	
9	What is the main factor responsible for soil consolidation?				[C] ✗
	A) Water content	B) Air pressure	C) Temperature	D) Soil color	
10	Which type of foundation is typically used for tall buildings in geotechnical engineering?				[B] ✓
	A) Shallow foundation	B) Deep foundation	C) Pile foundation	D) Sloped foundation	
11	What is the purpose of a compaction test in geotechnical engineering?				[C] ✓
	A) To assess the shear strength of soil	B) To measure the water content of soil	C) To determine the density of soil	D) To calculate the depth of bedrock	
12	What type of force is primarily responsible for soil arching in an excavation?				[B] ✓
	A) Tensile force	B) Compressive	C) Shear force	D) Hydrostatic force	

		force			
13	In geotechnical engineering, what does the term "seepage" refer to?				
	A) The flow of groundwater through soil	B) The study of plant growth in soil	C) The analysis of air quality in soil	D) The measurement of soil density	[A] ✓
14	Which soil parameter is critical for determining the stability of a slope?				
	A) Soil color	B) Soil density	C) Soil permeability	D) Soil cohesion	[C] x
15	What is the typical unit for measuring soil shear strength in geotechnical engineering?				
	A) Kilopascals (kPa)	B) Meters per second (m/s)	C) Degrees Celsius (°C)	D) Cubic meters (m^3)	[A] ✓
16	What does the term "compaction" refer to in geotechnical engineering?				
	A) The process of increasing soil porosity	B) The process of reducing soil density	C) The process of planting vegetation	D) The process of measuring soil pH	[B] ✓
17	What type of analysis is conducted to assess the stability of a slope subjected to rainfall or irrigation?				
	A) Seismic analysis	B) Settlement analysis	C) Slope stability analysis	D) Percolation analysis	[C] ✓
18	Which type of foundation is typically used for small structures with shallow bedrock?				
	A) Spread foundation	B) Pile foundation	C) Mat foundation	D) Raft foundation	[B] x
19	What is the primary purpose of soil reinforcement techniques in geotechnical engineering?				
	A) To decrease the soil density	B) To increase the soil's water-holding capacity	C) To improve soil stability and load-bearing capacity	D) To decrease the soil's porosity	[C] ✓
20	Which test is commonly used to assess the compressibility and settlement characteristics of soils?				
	A) Proctor compaction test	B) Direct shear test	C) Standard penetration test	D) Consolidation test	[C] x

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CERTIFICATE COURSE ON
DESIGN OF SLOPES BY USING GEOSTUDIO
ASSESSMENT TEST

Name of the Student: B. Lokesh Kumar Reddy **Reg. Number:** 189Y1A0112

Time: 20 Min **(Objective Questions)** **Max. Marks: 20**

Note: Answer the following Questions and each question carries **one** mark.

1	What is the primary concern of geotechnical engineering?				[C]
	A) Structural design	B) Environmental conservation	C) Soil and rock behavior	D) Traffic management	
2	What is the term for the study of the physical and mechanical properties of soils and rocks?				[C]
	A) Seismology	B) Geophysics	C) Geomechanics	D) Hydrogeology	
3	Which type of soil has the smallest particle size and retains water most effectively?				[D]
	A) Sand	B) Silt	C) Gravel	D) Clay	
4	What is the angle of repose for loose, dry sand typically measured at?				[B]
	A) 15° to 20°	B) 30° to 45°	C) 60° to 75°	D) 90°	
5	What does the term "bearing capacity" refer to in geotechnical engineering?				[B]
	A) The ability of soil to support plant life	B) The ability of soil to withstand heavy loads	C) The ability of soil to resist erosion	D) The ability of soil to filter contaminants	
6	What is the purpose of a geotechnical site investigation?				[A]
	A) To determine the cost of construction	B) To assess the impact of traffic on the site	C) To collect data about soil and rock conditions	D) To calculate the building's height	
7	What is the primary function of retaining walls in geotechnical engineering?				[C]
	A) To store water	B) To provide seating in parks	C) To stabilize slopes and prevent erosion	D) To generate electricity	
8	Which test is used to measure the moisture content of a soil sample?				[B]
	A) Proctor compaction test	B) Atterberg limits test	C) Permeability test	D) Sieve analysis	
9	What is the main factor responsible for soil consolidation?				[A]
	A) Water content	B) Air pressure	C) Temperature	D) Soil color	
10	Which type of foundation is typically used for tall buildings in geotechnical engineering?				[B]
	A) Shallow foundation	B) Deep foundation	C) Pile foundation	D) Sloped foundation	
11	What is the purpose of a compaction test in geotechnical engineering?				[C]
	A) To assess the shear strength of soil	B) To measure the water content of soil	C) To determine the density of soil	D) To calculate the depth of bedrock	
12	What type of force is primarily responsible for soil arching in an excavation?				[B]
	A) Tensile force	B) Compressive	C) Shear force	D) Hydrostatic force	

		force			
13	In geotechnical engineering, what does the term "seepage" refer to?				
	A) The flow of groundwater through soil	B) The study of plant growth in soil	C) The analysis of air quality in soil	D) The measurement of soil density	[A]
14	Which soil parameter is critical for determining the stability of a slope?				
	A) Soil color	B) Soil density	C) Soil permeability	D) Soil cohesion	[D]
15	What is the typical unit for measuring soil shear strength in geotechnical engineering?				
	A) Kilopascals (kPa)	B) Meters per second (m/s)	C) Degrees Celsius (°C)	D) Cubic meters (m^3)	[A]
16	What does the term "compaction" refer to in geotechnical engineering?				
	A) The process of increasing soil porosity	B) The process of reducing soil density	C) The process of planting vegetation	D) The process of measuring soil pH	[B]
17	What type of analysis is conducted to assess the stability of a slope subjected to rainfall or irrigation?				
	A) Seismic analysis	B) Settlement analysis	C) Slope stability analysis	D) Percolation analysis	[C]
18	Which type of foundation is typically used for small structures with shallow bedrock?				
	A) Spread foundation	B) Pile foundation	C) Mat foundation	D) Raft foundation	[A]
19	What is the primary purpose of soil reinforcement techniques in geotechnical engineering?				
	A) To decrease the soil density	B) To increase the soil's water-holding capacity	C) To improve soil stability and load-bearing capacity	D) To decrease the soil's porosity	[B] T
20	Which test is commonly used to assess the compressibility and settlement characteristics of soils?				
	A) Proctor compaction test	B) Direct shear test	C) Standard penetration test	D) Consolidation test	[D]

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DESIGN OF SLOPES BY USING GEOSTUDIO
ASSESSMENT TEST

Name of the Student: B. Vamsi **Reg. Number:** 1899/A0111

Time: 20 Min **(Objective Questions)** **Max. Marks: 20**

Note: Answer the following Questions and each question carries **one** mark.

1	What is the primary concern of geotechnical engineering?				[C]
	A) Structural design	B) Environmental conservation	C) Soil and rock behavior	D) Traffic management	
2	What is the term for the study of the physical and mechanical properties of soils and rocks?				[C]
	A) Seismology	B) Geophysics	C) Geomechanics	D) Hydrogeology	
3	Which type of soil has the smallest particle size and retains water most effectively?				[C] X
	A) Sand	B) Silt	C) Gravel	D) Clay	
4	What is the angle of repose for loose, dry sand typically measured at?				[D] X
	A) 15° to 20°	B) 30° to 45°	C) 60° to 75°	D) 90°	
5	What does the term "bearing capacity" refer to in geotechnical engineering?				[B]
	A) The ability of soil to support plant life	B) The ability of soil to withstand heavy loads	C) The ability of soil to resist erosion	D) The ability of soil to filter contaminants	
6	What is the purpose of a geotechnical site investigation?				[C]
	A) To determine the cost of construction	B) To assess the impact of traffic on the site	C) To collect data about soil and rock conditions	D) To calculate the building's height	
7	What is the primary function of retaining walls in geotechnical engineering?				[B] X
	A) To store water	B) To provide seating in parks	C) To stabilize slopes and prevent erosion	D) To generate electricity	
8	Which test is used to measure the moisture content of a soil sample?				[D] X
	A) Proctor compaction test	B) Atterberg limits test	C) Permeability test	D) Sieve analysis	
9	What is the main factor responsible for soil consolidation?				[A]
	A) Water content	B) Air pressure	C) Temperature	D) Soil color	
10	Which type of foundation is typically used for tall buildings in geotechnical engineering?				[A] X
	A) Shallow foundation	B) Deep foundation	C) Pile foundation	D) Sloped foundation	
11	What is the purpose of a compaction test in geotechnical engineering?				[D] X
	A) To assess the shear strength of soil	B) To measure the water content of soil	C) To determine the density of soil	D) To calculate the depth of bedrock	
12	What type of force is primarily responsible for soil arching in an excavation?				[B]
	A) Tensile force	B) Compressive	C) Shear force	D) Hydrostatic force	

		force			
13	In geotechnical engineering, what does the term "seepage" refer to?				
	A) The flow of groundwater through soil	B) The study of plant growth in soil	C) The analysis of air quality in soil	D) The measurement of soil density	[A]
14	Which soil parameter is critical for determining the stability of a slope?				
	A) Soil color	B) Soil density	C) Soil permeability	D) Soil cohesion	[D]
15	What is the typical unit for measuring soil shear strength in geotechnical engineering?				
	A) Kilopascals (kPa)	B) Meters per second (m/s)	C) Degrees Celsius (°C)	D) Cubic meters (m^3)	[D]
16	What does the term "compaction" refer to in geotechnical engineering?				
	A) The process of increasing soil porosity	B) The process of reducing soil density	C) The process of planting vegetation	D) The process of measuring soil pH	[B]
17	What type of analysis is conducted to assess the stability of a slope subjected to rainfall or irrigation?				
	A) Seismic analysis	B) Settlement analysis	C) Slope stability analysis	D) Percolation analysis	[C]
18	Which type of foundation is typically used for small structures with shallow bedrock?				
	A) Spread foundation	B) Pile foundation	C) Mat foundation	D) Raft foundation	[A]
19	What is the primary purpose of soil reinforcement techniques in geotechnical engineering?				
	A) To decrease the soil density	B) To increase the soil's water-holding capacity	C) To improve soil stability and load-bearing capacity	D) To decrease the soil's porosity	[C]
20	Which test is commonly used to assess the compressibility and settlement characteristics of soils?				
	A) Proctor compaction test	B) Direct shear test	C) Standard penetration test	D) Consolidation test	[D]

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CERTIFICATE COURSE ON
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ASSESSMENT TEST

Name of the Student: P. Prathap **Reg. Number:** 179Y1A0171

Time: 20 Min **(Objective Questions)** **Max. Marks: 20**

Note: Answer the following Questions and each question carries **one** mark.

1	What is the primary concern of geotechnical engineering?				[C]
	A) Structural design	B) Environmental conservation	C) Soil and rock behavior	D) Traffic management	
2	What is the term for the study of the physical and mechanical properties of soils and rocks?				[C]
	A) Seismology	B) Geophysics	C) Geomechanics	D) Hydrogeology	
3	Which type of soil has the smallest particle size and retains water most effectively?				[D]
	A) Sand	B) Silt	C) Gravel	D) Clay	
4	What is the angle of repose for loose, dry sand typically measured at?				[B]
	A) 15° to 20°	B) 30° to 45°	C) 60° to 75°	D) 90°	
5	What does the term "bearing capacity" refer to in geotechnical engineering?				[B]
	A) The ability of soil to support plant life	B) The ability of soil to withstand heavy loads	C) The ability of soil to resist erosion	D) The ability of soil to filter contaminants	
6	What is the purpose of a geotechnical site investigation?				[C]
	A) To determine the cost of construction	B) To assess the impact of traffic on the site	C) To collect data about soil and rock conditions	D) To calculate the building's height	
7	What is the primary function of retaining walls in geotechnical engineering?				[C]
	A) To store water	B) To provide seating in parks	C) To stabilize slopes and prevent erosion	D) To generate electricity	
8	Which test is used to measure the moisture content of a soil sample?				[A] ✗
	A) Proctor compaction test	B) Atterberg limits test	C) Permeability test	D) Sieve analysis	
9	What is the main factor responsible for soil consolidation?				[B] ✗
	A) Water content	B) Air pressure	C) Temperature	D) Soil color	
10	Which type of foundation is typically used for tall buildings in geotechnical engineering?				[C] ✗
	A) Shallow foundation	B) Deep foundation	C) Pile foundation	D) Sloped foundation	
11	What is the purpose of a compaction test in geotechnical engineering?				[B] ✗
	A) To assess the shear strength of soil	B) To measure the water content of soil	C) To determine the density of soil	D) To calculate the depth of bedrock	
12	What type of force is primarily responsible for soil arching in an excavation?				[B]
	A) Tensile force	B) Compressive	C) Shear force	D) Hydrostatic force	

		force			
13	In geotechnical engineering, what does the term "seepage" refer to?				
	A) The flow of groundwater through soil	B) The study of plant growth in soil	C) The analysis of air quality in soil	D) The measurement of soil density	[A
14	Which soil parameter is critical for determining the stability of a slope?				
	A) Soil color	B) Soil density	C) Soil permeability	D) Soil cohesion	[B]
15	What is the typical unit for measuring soil shear strength in geotechnical engineering?				
	A) Kilopascals (kPa)	B) Meters per second (m/s)	C) Degrees Celsius (°C)	D) Cubic meters (m^3)	[A
16	What does the term "compaction" refer to in geotechnical engineering?				
	A) The process of increasing soil porosity	B) The process of reducing soil density	C) The process of planting vegetation	D) The process of measuring soil pH	[D
17	What type of analysis is conducted to assess the stability of a slope subjected to rainfall or irrigation?				
	A) Seismic analysis	B) Settlement analysis	C) Slope stability analysis	D) Percolation analysis	[C
18	Which type of foundation is typically used for small structures with shallow bedrock?				
	A) Spread foundation	B) Pile foundation	C) Mat foundation	D) Raft foundation	[A
19	What is the primary purpose of soil reinforcement techniques in geotechnical engineering?				
	A) To decrease the soil density	B) To increase the soil's water-holding capacity	C) To improve soil stability and load-bearing capacity	D) To decrease the soil's porosity	[C
20	Which test is commonly used to assess the compressibility and settlement characteristics of soils?				
	A) Proctor compaction test	B) Direct shear test	C) Standard penetration test	D) Consolidation test	[D

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K.S.R.M. COLLEGE OF ENGINEERING (AUTONOMOUS), KADAPA-516003
DEPARTMENT OF CIVIL ENGINEERING
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Name of the Student: G. Hyder Ali Khan **Reg. Number:** 179Y1A0128

Time: 20 Min **(Objective Questions)** **Max. Marks: 20**

Note: Answer the following Questions and each question carries **one** mark.

1	What is the primary concern of geotechnical engineering?				[C] ✓
	A) Structural design	B) Environmental conservation	C) Soil and rock behavior	D) Traffic management	
2	What is the term for the study of the physical and mechanical properties of soils and rocks?				[A] ✗
	A) Seismology	B) Geophysics	C) Geomechanics	D) Hydrogeology	
3	Which type of soil has the smallest particle size and retains water most effectively?				[D] ✓
	A) Sand	B) Silt	C) Gravel	D) Clay	
4	What is the angle of repose for loose, dry sand typically measured at?				[A] ✗
	A) 15° to 20°	B) 30° to 45°	C) 60° to 75°	D) 90°	
5	What does the term "bearing capacity" refer to in geotechnical engineering?				[B] ✓
	A) The ability of soil to support plant life	B) The ability of soil to withstand heavy loads	C) The ability of soil to resist erosion	D) The ability of soil to filter contaminants	
6	What is the purpose of a geotechnical site investigation?				[C] ✓
	A) To determine the cost of construction	B) To assess the impact of traffic on the site	C) To collect data about soil and rock conditions	D) To calculate the building's height	
7	What is the primary function of retaining walls in geotechnical engineering?				[A] ✗
	A) To store water	B) To provide seating in parks	C) To stabilize slopes and prevent erosion	D) To generate electricity	
8	Which test is used to measure the moisture content of a soil sample?				[A] ✗
	A) Proctor compaction test	B) Atterberg limits test	C) Permeability test	D) Sieve analysis	
9	What is the main factor responsible for soil consolidation?				[A] ✓
	A) Water content	B) Air pressure	C) Temperature	D) Soil color	
10	Which type of foundation is typically used for tall buildings in geotechnical engineering?				[B] ✓
	A) Shallow foundation	B) Deep foundation	C) Pile foundation	D) Sloped foundation	
11	What is the purpose of a compaction test in geotechnical engineering?				[C] ✓
	A) To assess the shear strength of soil	B) To measure the water content of soil	C) To determine the density of soil	D) To calculate the depth of bedrock	
12	What type of force is primarily responsible for soil arching in an excavation?				[B] ✓
	A) Tensile force	B) Compressive	C) Shear force	D) Hydrostatic force	

		force			
13	In geotechnical engineering, what does the term "seepage" refer to?				[A]
	A) The flow of groundwater through soil	B) The study of plant growth in soil	C) The analysis of air quality in soil	D) The measurement of soil density	
14	Which soil parameter is critical for determining the stability of a slope?				[D]
	A) Soil color	B) Soil density	C) Soil permeability	D) Soil cohesion	
15	What is the typical unit for measuring soil shear strength in geotechnical engineering?				[A]
	A) Kilopascals (kPa)	B) Meters per second (m/s)	C) Degrees Celsius (°C)	D) Cubic meters (m^3)	
16	What does the term "compaction" refer to in geotechnical engineering?				[B]
	A) The process of increasing soil porosity	B) The process of reducing soil density	C) The process of planting vegetation	D) The process of measuring soil pH	
17	What type of analysis is conducted to assess the stability of a slope subjected to rainfall or irrigation?				[C]
	A) Seismic analysis	B) Settlement analysis	C) Slope stability analysis	D) Percolation analysis	
18	Which type of foundation is typically used for small structures with shallow bedrock?				[A]
	A) Spread foundation	B) Pile foundation	C) Mat foundation	D) Raft foundation	
19	What is the primary purpose of soil reinforcement techniques in geotechnical engineering?				[C]
	A) To decrease the soil density	B) To increase the soil's water-holding capacity	C) To improve soil stability and load-bearing capacity	D) To decrease the soil's porosity	
20	Which test is commonly used to assess the compressibility and settlement characteristics of soils?				[D]
	A) Proctor compaction test	B) Direct shear test	C) Standard penetration test	D) Consolidation test	

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.

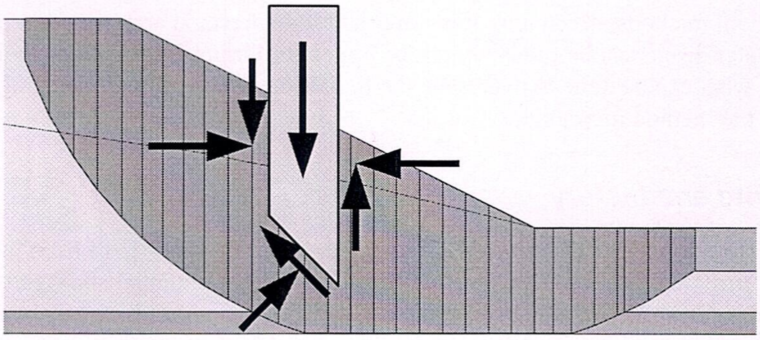

Figure 2-1 Slice discretization and slice forces in a sliding mass

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.

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 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.

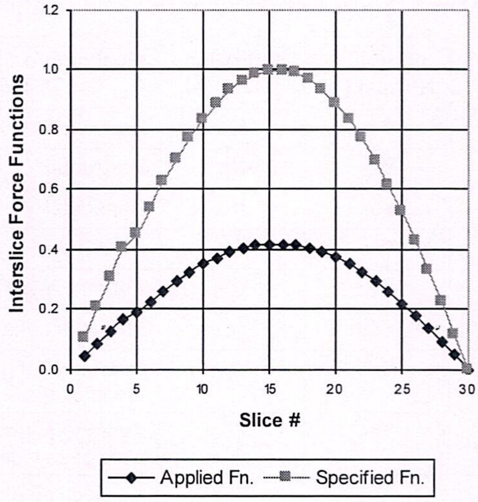

Figure 2-2 Half-sine interslice force function

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:

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

The terms in the equations are:

c'	=	effective cohesion
φ'	=	effective angle of friction
u	=	pore-water pressure
N	=	slice base normal force
W	=	slice weight
D	=	concentrated point load
β, R, x, f, d, ω	=	geometric parameters
α	=	inclination of slice base

(There are additional terms in the factor of safety equations, but they are not required for the discussion on limit equilibrium fundamentals; the complete equations are presented in the theory chapter.)

One of the key variables in both equations is *N*, the normal at the base of each slice. This equation is obtained by the summation of vertical forces, thus vertical force equilibrium is consequently satisfied. In equation form, the base normal is defined as:

$$N = \frac{W + (X_R - X_L) - \dfrac{(c'\beta \sin\alpha + u\beta \sin\alpha \tan\phi')}{F}}{\cos\alpha + \dfrac{\sin\alpha \tan\phi'}{F}}$$

F is F_m when N is substituted into the moment factor of safety equation and F is F_f when N is substituted into the force factor of safety equation. The literature on slope stability analysis often refers to the denominator of this equation as m_α.

A very important point to make here is that the slice base normal is dependent on the interslice shear forces X_R and X_L on either side of a slice. The slice base normal is consequently different for the various methods, depending on how each method deals with the interslice shear forces.

The GLE formulation computes F_m and F_f for a range of lambda (λ) values. With these computed values, a plot similar to Figure 2-3 can be drawn which shows how F_m and F_f vary with lambda (λ).

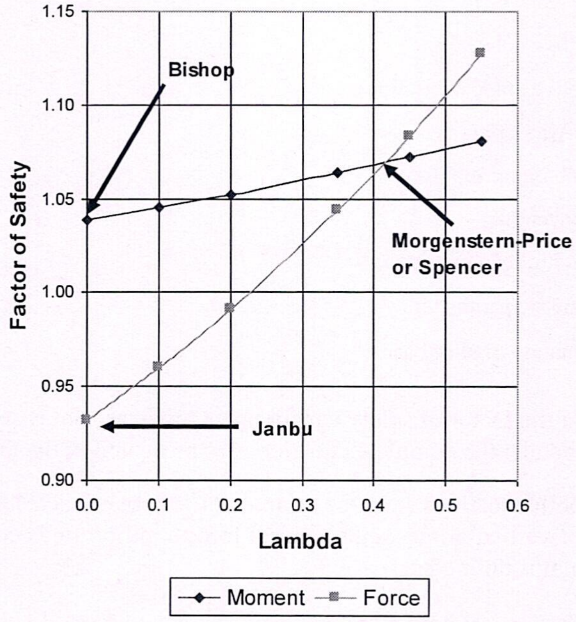

Figure 2-3 A factor of safety versus lambda (λ) plot

As listed in Table 2-1 and Table 2-2, Bishop's Simplified method ignores interslice shear forces and satisfies only moment equilibrium. In the GLE terminology, neglecting interslice shear forces means λ is zero. As a result, the Bishop's Simplified factor of safety falls on the moment curve in Figure 2-3 where lambda is zero. Janbu's Simplified method also ignores interslice shear forces and only satisfies force equilibrium. The Janbu's Simplified factor of safety consequently falls on the force curve in Figure 2-3 where λ is zero. The Spencer and Morgenstern-Price (M-P) factors of safety are determined at the point where the two curves cross in Figure 2-3. At this point, the factor of safety satisfies both moment and force equilibrium. Whether the crossover point is the Spencer or M-P factor of safety depends on the interslice force function. Spencer only considered a constant *X/E* ratio for all slices. The M-P method can utilize any general appropriate function. The Corp of Engineers and Lowe-Karafiath factors of safety fall on the force curve in Figure 2-3. The position on the force curve depends on the procedure used to establish the inclinations of the interslice resultant. The inclination of the interslice resultant is arc tan(λ) when *f(x)* is a constant 1.0 as in the Spencer method.

The GLE formulation is very useful for explaining the differences between the various methods and for determining how the interslice force functions influence the computed factor of safety, as discussed in more detail below.

There is one characteristic in the two factor of safety equations and the base normal equation that have a profound consequence. In the end there is only one factor of safety for the overall slope. F_m and F_f are the same when both moment and force equilibrium are satisfied. This same value appears in the equation for the normal at the slice base. This means the factor of safety is the same for each and every slice. As we will see later, this has a significant effect on the resulting computed stress distributions within the sliding mass and along the slip surface.

Another important point about the GLE formulation is that it is not restricted by the shape of the slip surface. The Bishop's Simplified method was initially developed for circular slip surfaces, but the assumptions inherent in the Bishop's Simplified method can be applied to any noncircular slip surface. In fact, with the GLE formulation, all methods listed in Table 2-1 can be applied to any kinematicly admissible slip surface shape.

2.5 *Interslice force functions*

How the interslice shear forces are handled and computed is a fundamental point with most of the methods listed in Table 2-1. The Spencer method, for example, uses a constant function which infers that the ratio of shear to normal is a constant between all slices. You do not need to select the function; it is fixed to be a constant function in the software when the Spencer method is selected.

Only the Morgenstern-Price allows for user-specified interslice functions. Some of the functions available are the constant, half-sine, clipped-sine, trapezoidal and data-point specified. The most commonly used functions are the constant and half-sine functions. A Morgenstern-Price analysis with a constant function is the same as a Spencer analysis.

SLOPE/W by default uses the half-sine function for the M-P method. The half-sine function tends to concentrate the interslice shear forces towards the middle of the sliding mass and diminishes the interslice shear in the crest and toe areas. Defaulting to the half-sine function for these methods is based primarily on experience and intuition and not on any theoretical considerations. Other functions can be selected if deemed necessary.

The Sarma method deals with the interslice shear-normal relationship somewhat differently. Most methods use a specified function or a specified direction to establish the relationship between the interslice shear and normal. The Sarma method uses a shear strength equation as noted in Table 2-2. This approach does not offer any particular advantages over the other approaches, for reasons that will become clear later in this chapter. In the end, this is just another mechanism to compute interslice shear forces from the normal forces, and is included primarily for completeness and to accommodate user preferences.

The influence and importance of the interslice forces is discussed in the next section.

2.6 *Slip surface shapes*

The importance of the interslice force function depends to a large extent on the amount of contortion the potential sliding mass must undergo to move. The function is not important for some kinds of movement while the function may significantly influence the factor of safety for other kinds of movement. The following examples illustrate this sensitivity.

Circular slip surface

Figure 2-4 presents a simple circular slip surface together with the associated FS vs λ plot. In this case the moment equilibrium is completely independent of the interslice shear forces, as indicated by the horizontal moment equilibrium curve. The force equilibrium, however, is dependent on the interslice shear forces.

The moment equilibrium is not influenced by the shear forces because the sliding mass as a free body can rotate without any slippage between the slices. However, substantial interslice slippage is necessary for the sliding mass to move laterally. As a consequence the horizontal force equilibrium is sensitive to interslice shear.

Since the moment equilibrium is completely independent of interslice shear, any assumption regarding an interslice force function is irrelevant. The interslice shear can be assumed to be zero, as in the Bishop's Simplified method, and still obtain an acceptable factor of safety, provided the method satisfies moment equilibrium. This is, of course, not true for a method based on satisfying only horizontal force equilibrium such as the Janbu's Simplified method. Ignoring the interslice shear when only horizontal force equilibrium is satisfied for a curved slip surface results in a factor of safety significantly different than when both force and moment equilibrium is satisfied.

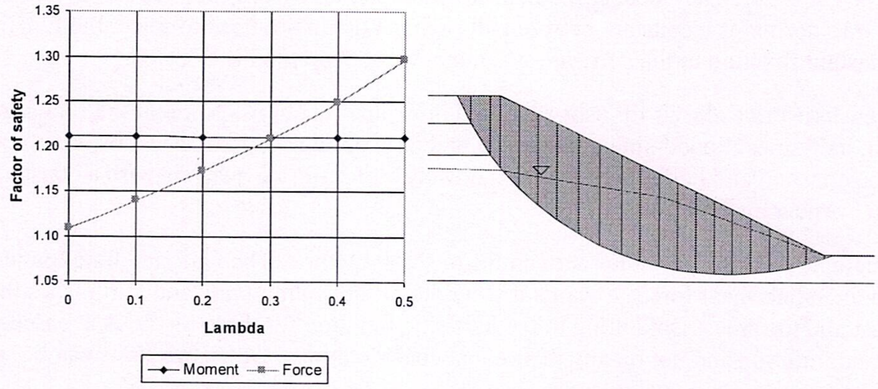

Figure 2-4 Conditions for a simple circular slip surface

The moment equilibrium curve is not always perfectly horizontal for circular slip surfaces. The moment curve in Figure 2-4 was obtained from a circular slip surface analysis and it is slightly inclined. Usually, however, the slope of the moment curve is nearly horizontal. This is why the Bishop and Morgenstern-Price factors of safety are often similar for circular slip surfaces.

Planar slip surface

Figure 2-5 illustrates a planar slip surface. The moment and force equilibrium curves now have reverse positions from those for a circular slip surface. Now force equilibrium is completely independent of interslice shear, while moment equilibrium is fairly sensitive to the interslice shear. The soil wedge on the planar slip surface can move without any slippage between the slices. Considerable slippage is, however, required for the wedge to rotate.

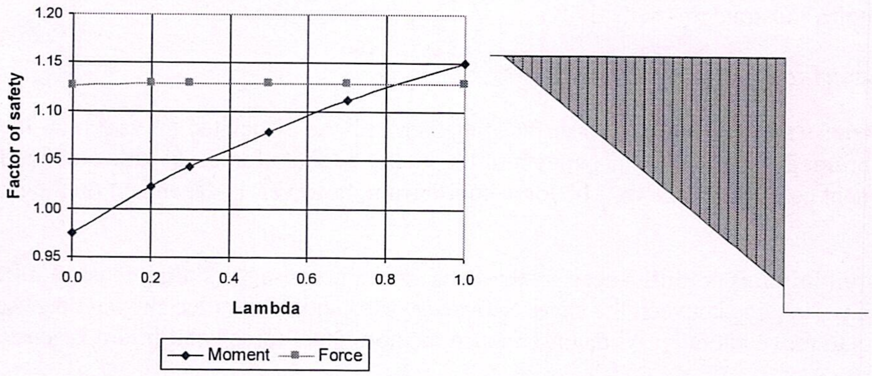

Figure 2-5 Situation for a planar slip surface

Composite slip surface

A composite slip surface is one where the slip surface is partly on the arc of a circle and partly on a planar surface, as illustrated in Figure 2-6. The planar portion in this example follows a weak layer, a common situation in many stratigraphic settings. In this case, both moment and force equilibrium are influenced by the interslice shear forces. Force equilibrium factors of safety increase, while moment equilibrium factors of safety decrease as the interslice shear forces increase (higher lambda values).

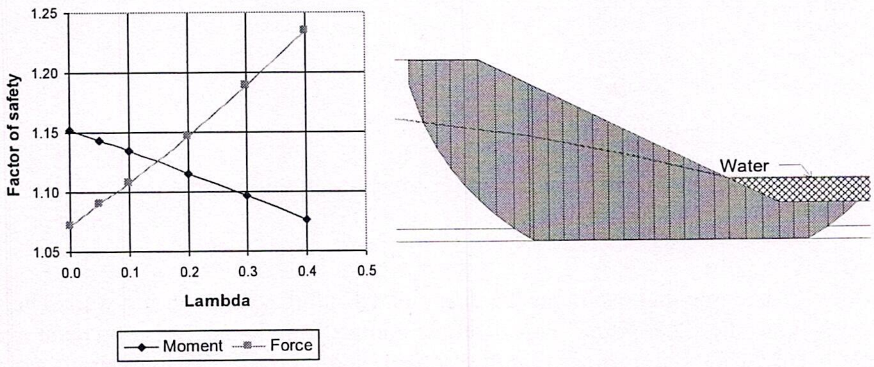

Figure 2-6 Situation for a typical composite slip surface

This illustrates that a Bishop's Simplified type of analysis does not always err on the safe side. A more rigorous formulation such as the Morgenstern-Price or Spencer method will give a lower factor of safety than a Bishop Simplified factor of safety. This is not necessarily true for all composite slip surfaces. For some composite slip surfaces, a mathematically more rigorous factor of safety may be higher than the Bishop's Simplified. It is not possible to generalize as to when a more simplified factor of safety will or will not err on the safe side.

Slippage between the slices needs to occur for both moment and force equilibrium for a slip surface of this shape and, consequently, the interslice shear is important for both types of equilibrium.

Block slip surface

Figure 2-7 shows a block-type slip surface. As with the previous composite slip surface, the moment and force equilibrium are both influenced by the interslice shear. The force equilibrium is more sensitive to the shear forces than the moment equilibrium, as indicated by the curve gradients in Figure 2-7. Once again it is easy to visualize that significant slippage is required between the slices for both horizontal translation and rotation, giving rise to the importance of the shear forces.

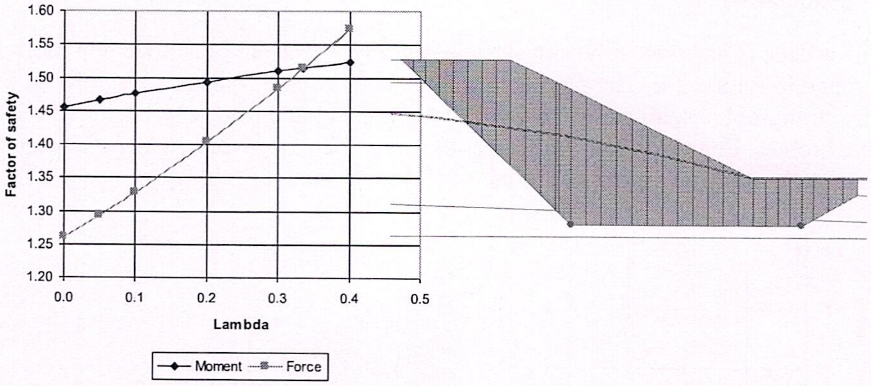

Figure 2-7 Typical situation for a block slip surface

Shoring wall

Figure 2-8 provides an example that examines the deep-seated stability of a shoring wall. The slip surface is beneath the lower tip of the sheet piling. This example comes from the analysis of a deep excavation in downtown Calgary. The *FS* vs λ plot shows that the moment and force equilibrium curves are similar in this case. They are both very sensitive to the interslice shear forces. Ignoring the interslice shear forces for this case results in a significant underestimation of the factor of safety. Without including the interslice shear forces, the factor of safety is less than 1.0 indicating an unstable situation. Including the shear forces increases the factor of safety to 1.22. The difference again is due to the contortion the potential failing mass would have to undergo to rotate or move laterally.

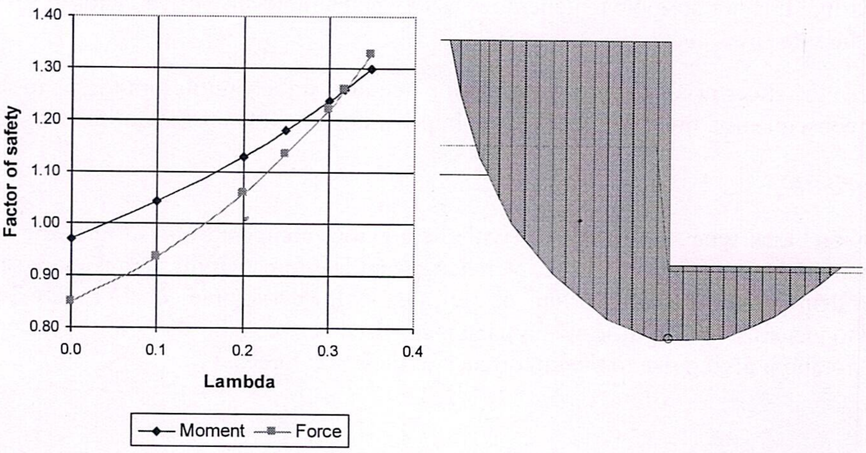

Figure 2-8 A deep stability analysis of a shoring wall

These examples show that the importance of the interslice force functions is strongly related to the shape of the potential slip surface, which in turn is related to the amount of contortion the sliding mass needs to undergo to rotate or move laterally.

When the adopted interslice force function becomes critical in a stability analysis, the limit equilibrium method of slices is approaching the limits of its applicability. Alternative approaches such as described later may then be required.

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.

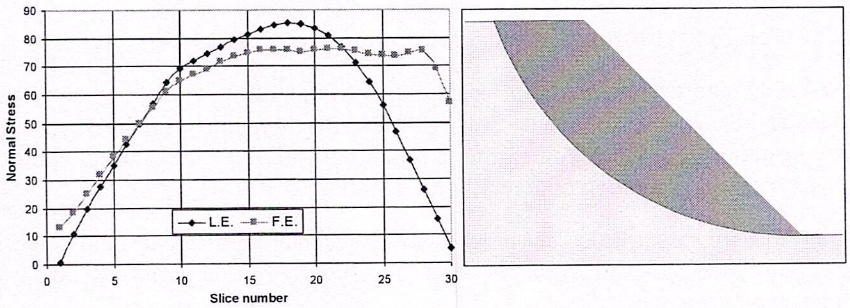

Figure 2-9 Normal stress distribution along a toe slip surface

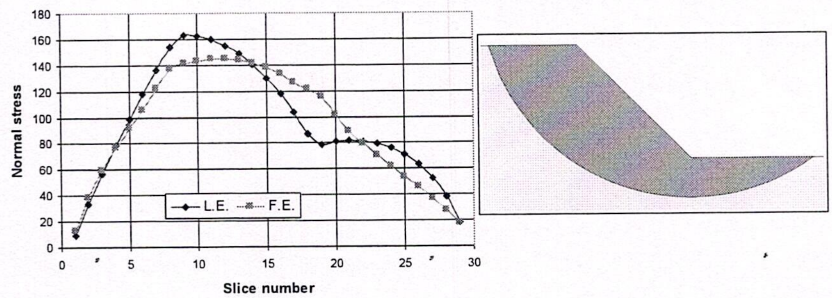

Figure 2-10 Normal stress distribution along a deep slip surface

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.

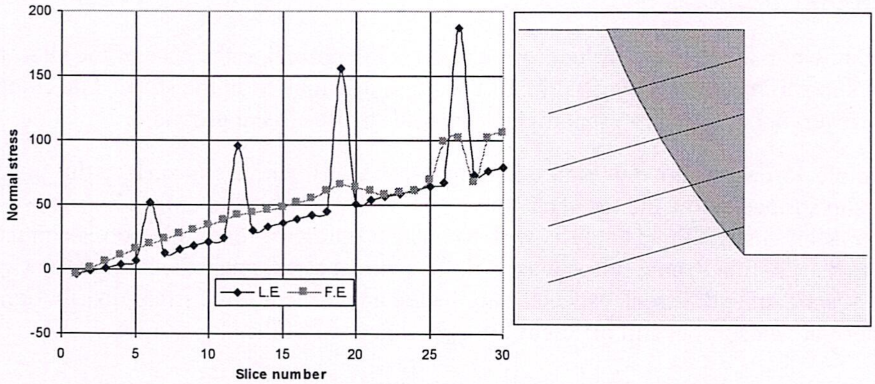

Figure 2-11 Normal stress distributions with reinforcement

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.

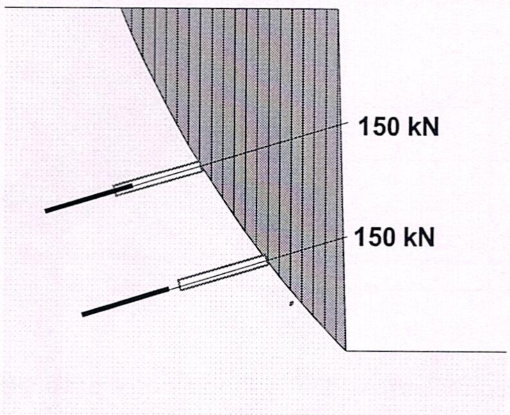

Figure 2-12 Tie-back wall example

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

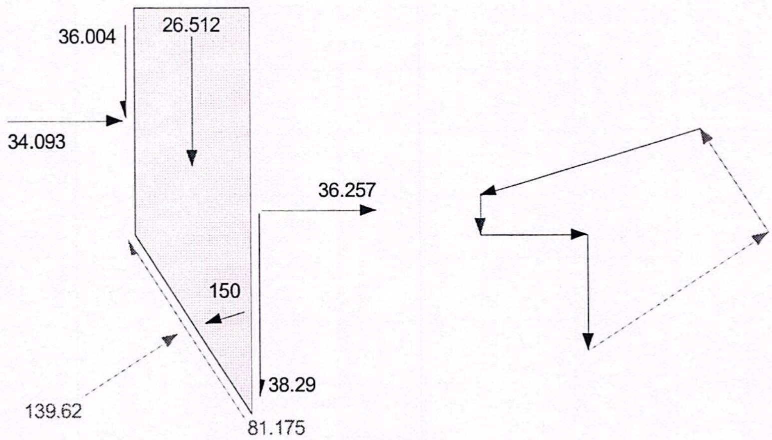

Figure 2-13 Free body and force polygon for upper anchor

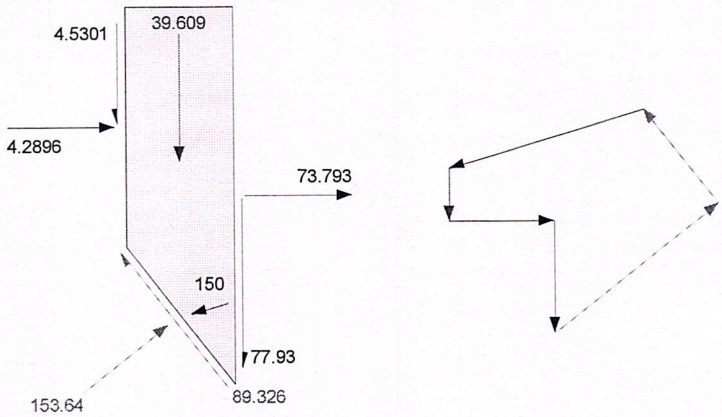

Figure 2-14 Free body and force polygon for lower anchor

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).

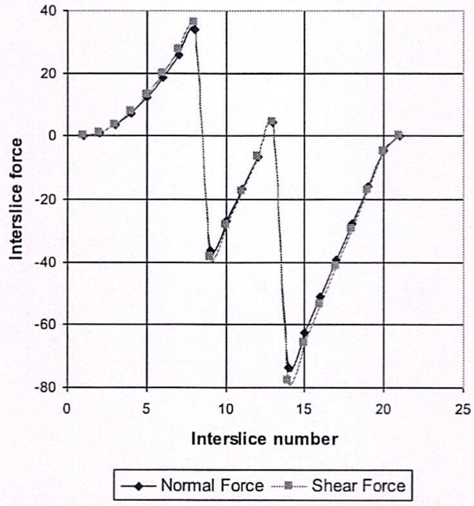

Figure 2-15 Interslice shear and normal forces with anchor loads applied at the slip surface

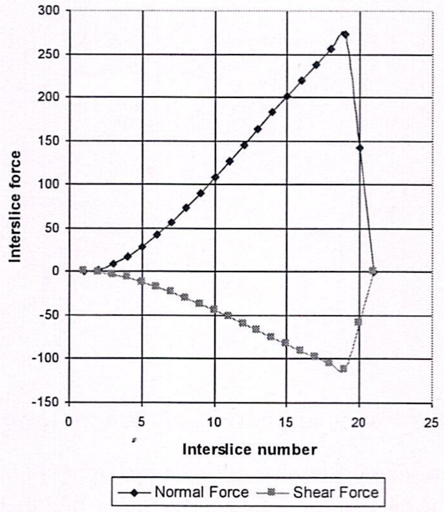

Figure 2-16 Interslice shear and normal forces with anchor loads applied at face of wall

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.

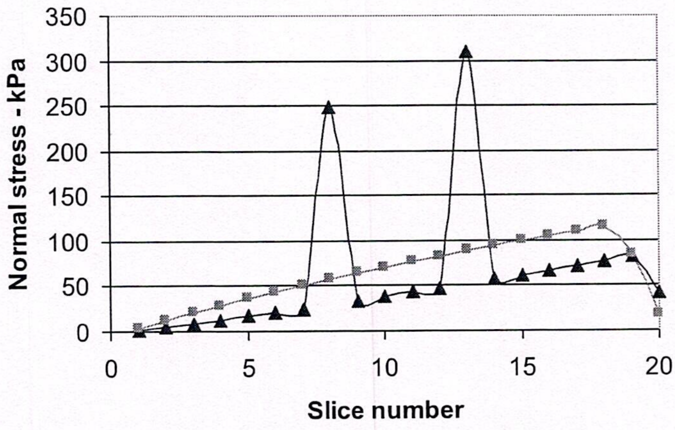

Figure 2-17 Comparison of normal stress distributions

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.

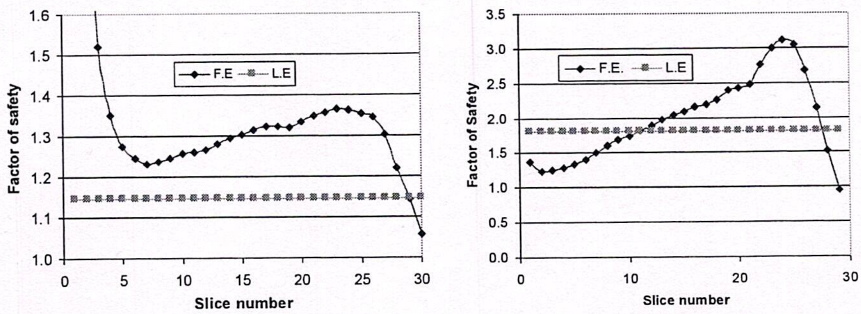

Figure 2-18 Local variation safety factors

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.

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.

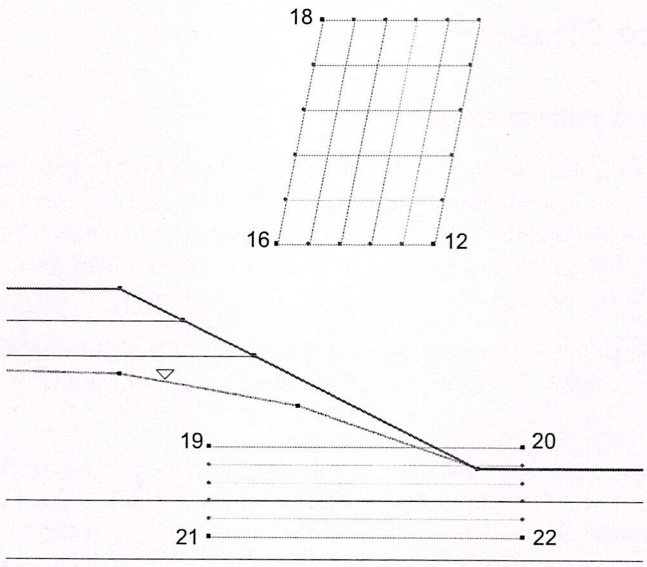

Figure 4-1 The grid and radius method of specifying trial slip surfaces

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.

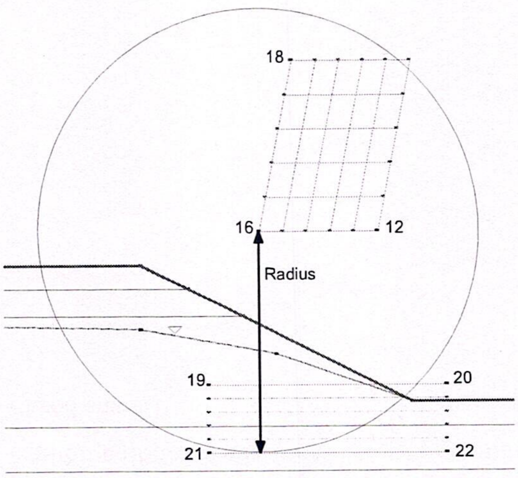

Figure 4-2 Imaginary trial slip surface

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.

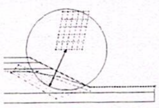

Figure 4-3 Specification of radius lines

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.

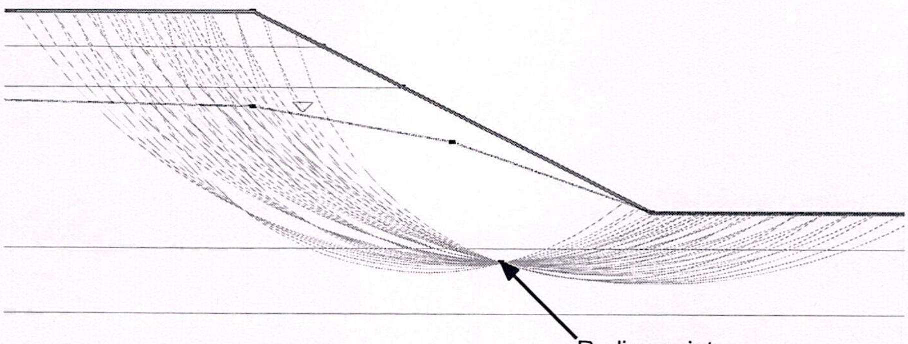

Figure 4-4 All slip surfaces through a point

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.

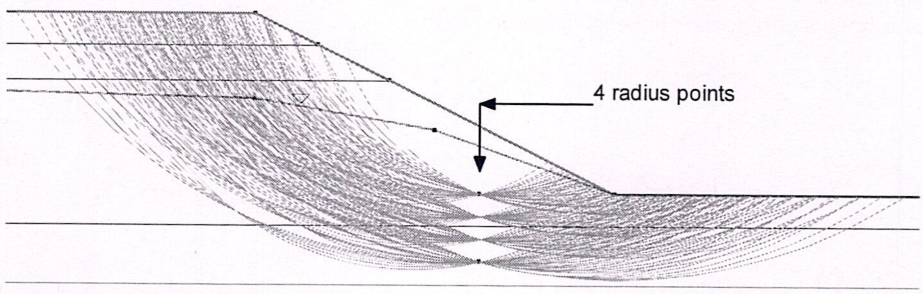

Figure 4-5 Slip surfaces though a series of radius points

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.

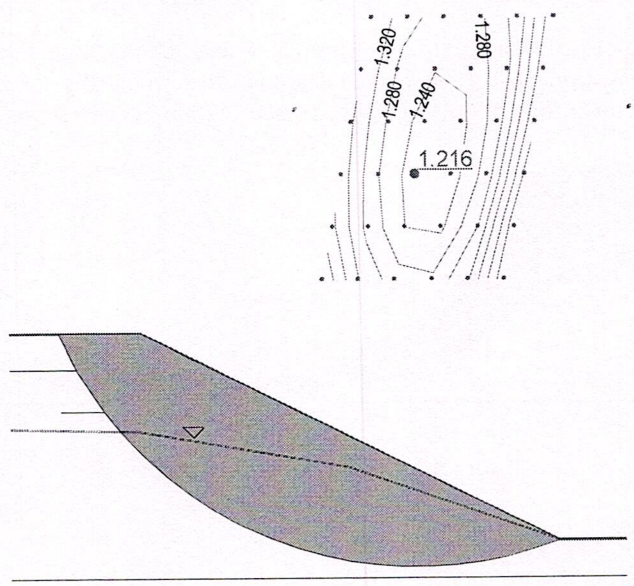

Figure 4-7 Factor of safety contours on grid of rotation centers

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.

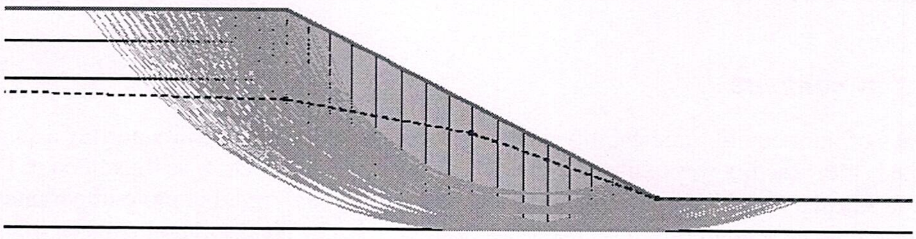

Figure 4-8 Display of multiple trial slip surfaces

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.

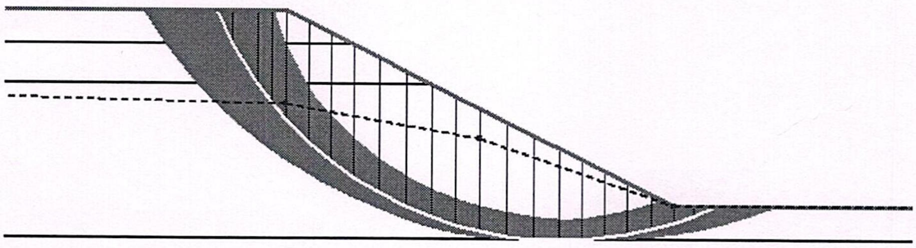

Figure 4-9 Display of safety map

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.

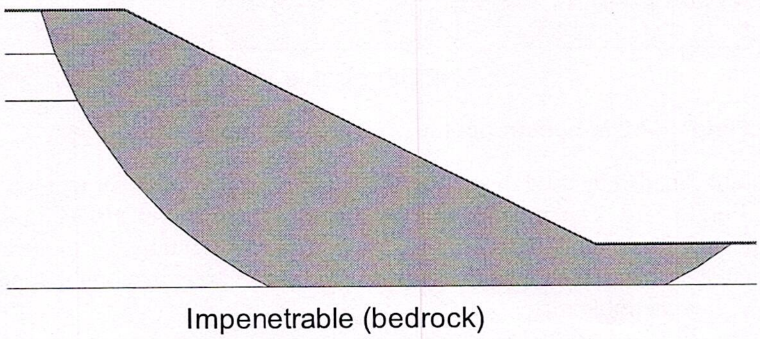

Figure 4-10 Composite slip surface controlled by impenetrable layer

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.

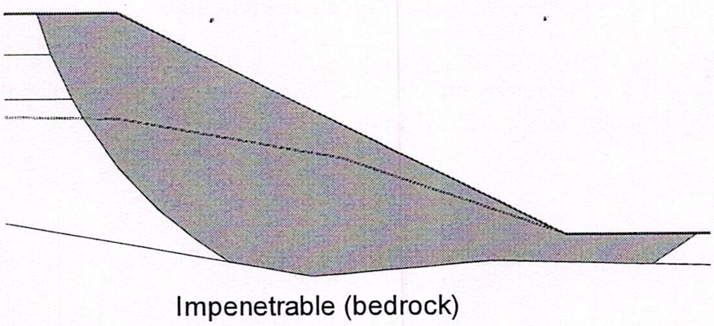

Figure 4-11 Irregular impenetrable layer

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.

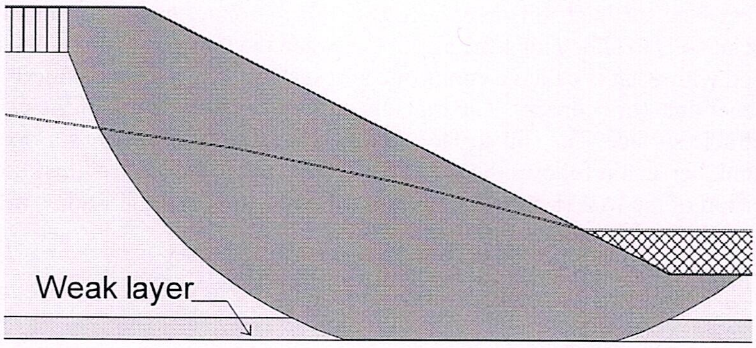

Figure 4-12 Impenetrable layer forces slip along weak layer

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.

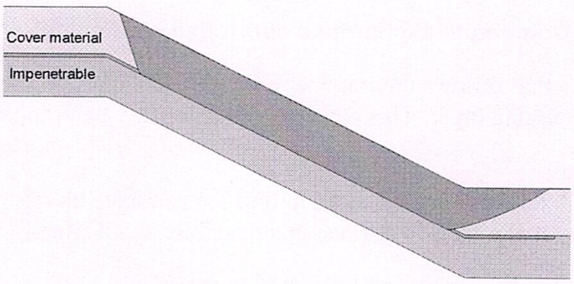

Figure 4-13 Sliding on a synthetic liner

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.

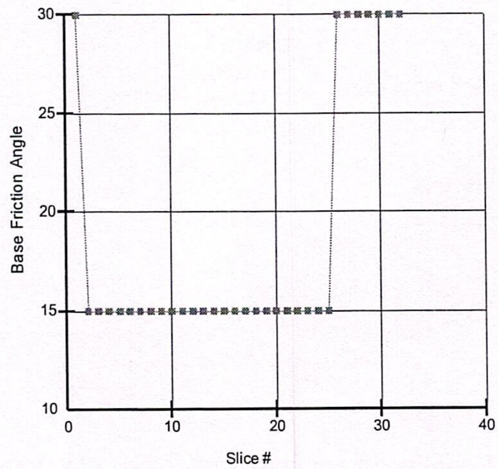

Figure 4-14 Variation of friction angle along slip surface

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.

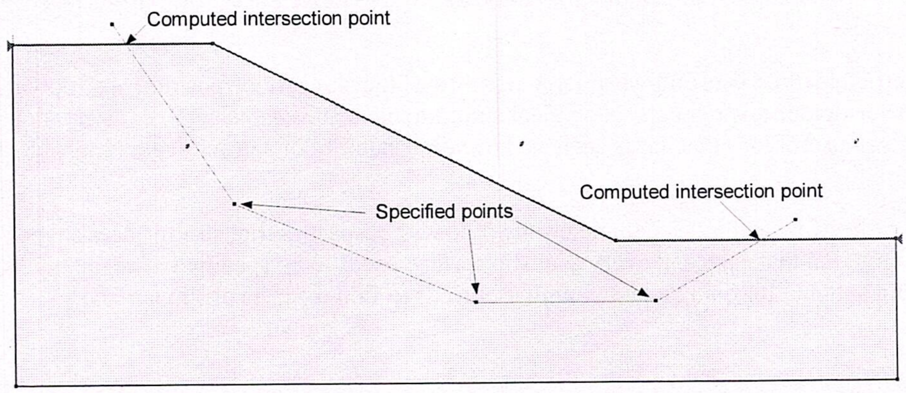

Figure 4-15 Fully specified slip surface

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.

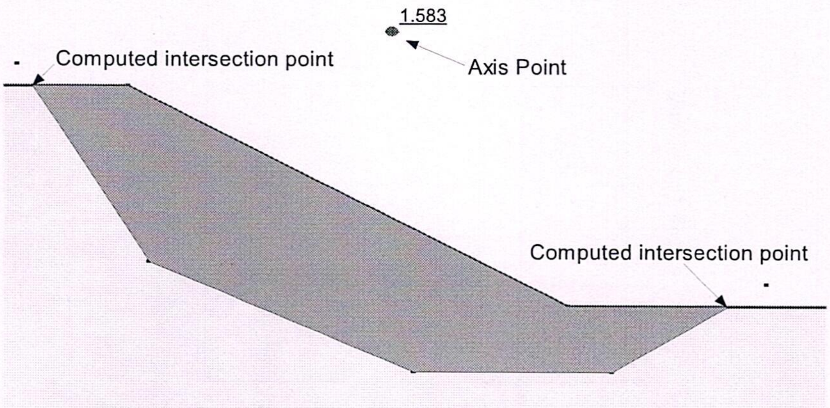

Figure 4-16 Axis point about which to compute moments

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.

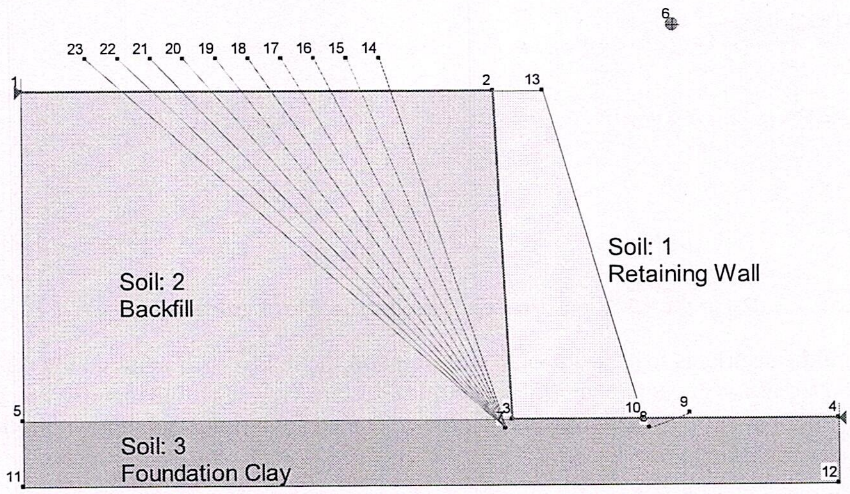

Figure 4-17 Sliding analysis of a gravity retaining wall

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.

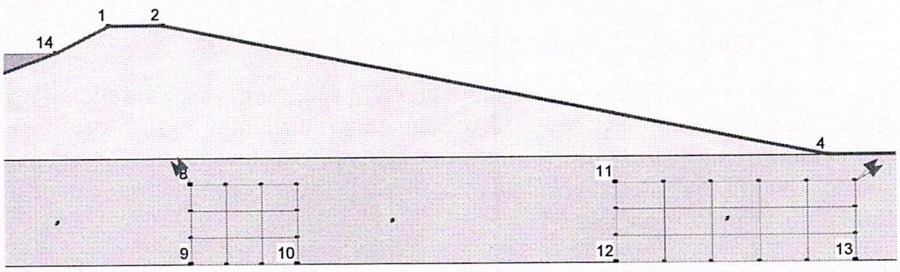

Figure 4-18 Grids in Block Specified method

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.

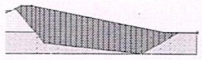

Figure 4-19 Slip surface shape in the Block method

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.

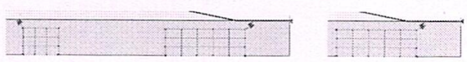

Figure 4-20 Projection angles in the Block method

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

3 x 3 which equals 3,456. Some caution is consequently advisable when specifying the size of the grid blocks and the number of projection angles.

The Block method is particularly useful in a case such as in Figure 4-19. Here an embankment with flat side slopes rests on a relatively thick stratum of soft foundation soil. The middle segment of the crucial slip surface tends to dip downward as in Figure 4-19 as opposed to being horizontal. Allowing the middle segments to vary between all the grid points makes it possible to find this critical potential mode of sliding.

A difficulty with the Block method is that it is not always possible find a converged solution when the corners along the slip surface become too sharp. A typical situation is shown in Figure 4-21. The break in the slip surface on the left is too sharp and this causes convergence problems.

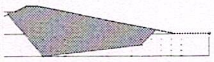

Figure 4-21 Trial slip surface with a sharp corner

The convergence difficulties with the Block method can result in a large number of trial slip surfaces with an undefined safety factor. This is particularly problematic when the grid blocks get close to each other. The Block method works the best and is the most suitable for cases where there is a significant distance between the two blocks. Stated another way, the middle segment line segment should be significantly longer than the two end projection segments.

Slip surfaces seldom, if ever, have sharp corners in reality, which is one of the assumptions made in the Block method. This reality points to another weakness of this method with respect to forming trial slip surfaces. This limitation can sometimes be overcome by the optimization technique discussed below.

Worth noting is that the two grid blocks can be collapsed to a line with points or to a single point. If the two left specified points in the grid block are the same, the block will collapse to a line. If all three points are the same, the grid block will collapse to a single point.

When generating slip surfaces with Block Search, it is quite easy to generate a lot of physically impossible slip surfaces.

Specific parallel form

There are situations where it is preferable to have all the middle line segments of the trial slip surface parallel. Take, for example, the case of a slope where the material is strongly bedded and the strength along the bedding is less than across the bedding. This is illustrated in Figure 4-22. The grid blocks are placed so that the bases are parallel to the bedding. By selecting the "No crossing" option, the middle segments of the trial slip surfaces will all be along the bedding.

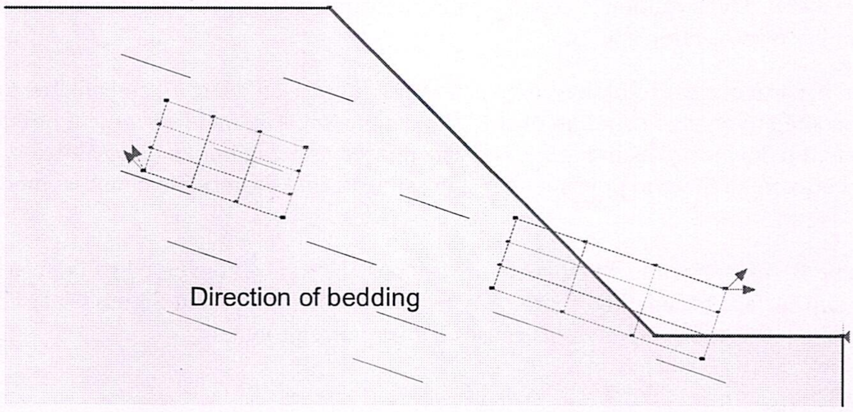

Figure 4-22 Slope with distinct bedding

A typical trial slip surface looks like the one in Figure 4-23.

> 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 block slip surafces. When missing, SLOPE/W estimates an axis point based on the geontry and the positions of the left and right blocks.

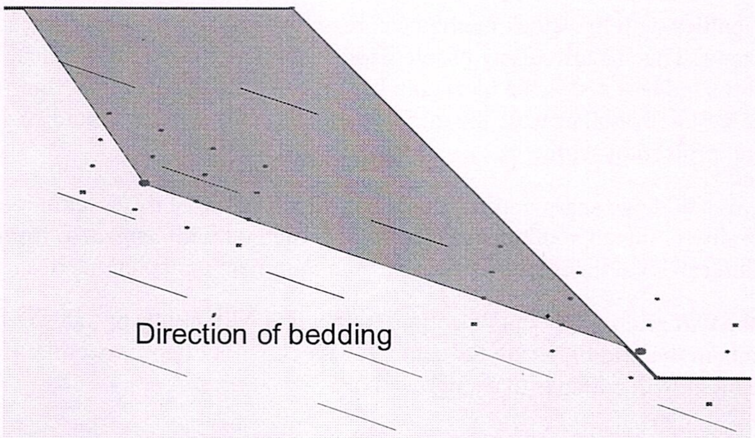

Figure 4-23 Trial slip surface follows the bedding

This approach can be combined with an anisotropic strength function to make the strength across bedding higher than along the bedding. The bedding is inclined at an angle of about 18 degrees. Let us specify the strength parameters along the bedding together with the anisotropic modifier function as in Figure 4-24. When the inclination of the slip surface is 18 degrees, the modifier is 1.0 and therefore the specified strength is used. Slip Surface inclinations other than 18 degrees will have a higher strength. The specified strength will be multiplied by a factor of 1.15, for example, if the slice base inclination is zero degrees (horizontal).

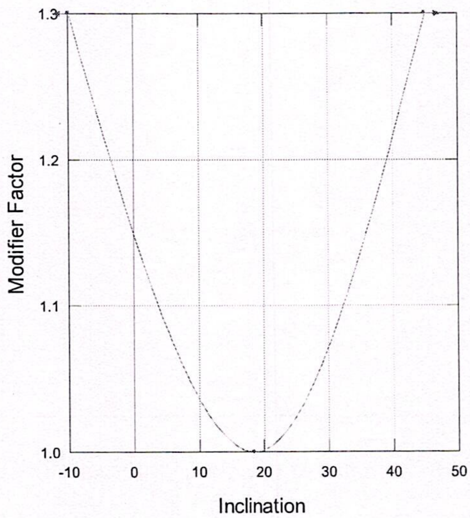

Figure 4-24 Anisotropic function

4.6 Entry and exit specification

One of the difficulties with the historic Grid and Radius method is that it is difficult to visualize the extents and/or range of trial slip surfaces. This limitation can be overcome by specifying the location where the trial slip surfaces will likely enter the ground surface and where they will exit. This technique is called the Entry and Exit method in SLOPE/W.

In Figure 4-25, there are two heavy (red) lines along the ground surface. These are the areas where the slip surfaces will enter and exit. The number of entries and exits can be specified as the number of increments along these two lines.

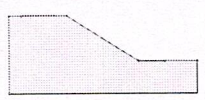

Figure 4-25 Entry and exit areas for forming trial slip surfaces

Behind the scenes, SLOPE/W connects a point along the entry area with a point along the exit area to form a line. At the mid-point of this connecting line, SLOPE/W creates a perpendicular line. Radius points along the perpendicular line are created to form the required third point of a circle (Figure 4-26). This radius point together with the entry and exit points are used to form the equation of a circle. SLOPE/W controls the locations of these radius points so that the circle will not be a straight line (infinite radius), and the entry angle of the slip circle on the crest will not be larger than 90 degrees (undercutting slip circle). The equation of a circle gives the center and radius of the circle, the trial slip surface is then handled in the same manner as the conventional Grid and Radius method and as a result, the Entry and Exit method is a variation of the Grid and Radius method. The number of radius increments is also a specified variable.

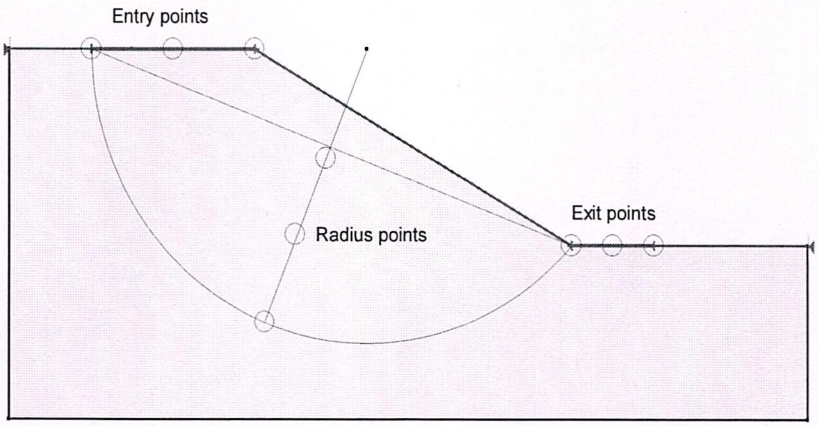

Figure 4-26 Schematic of the entry and exit slip surface

Figure 4-27 shows all the valid slip surfaces when the entry increments, the exit increments and the radius increments are set equal to 5. A total of 216 (6 x 6 x 6) slip surfaces are generated. The critical slip surface is the darker shaded area.

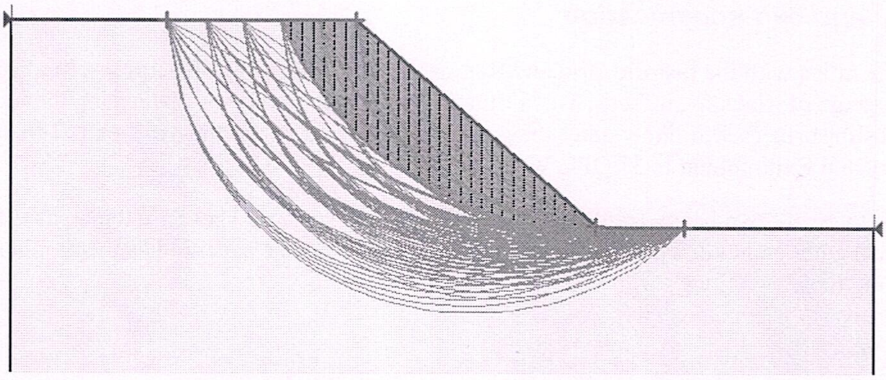

Figure 4-27 Display of all valid critical slip surfaces

In SLOPE/W, the generated slip surfaces from the Entry and Exit zones can be controlled with the 4 points radius specification in the same manner as the Gird and Radius method Figure 4-27 . The specified radius will force the generated slip surface to be tangent to the radius line Figure 4-27. In the case of a two point radius, all slip surfaces will pass through the specified radius zone. In the case of a single point radius, all slip surfaces will be forced to pass through the radius point.

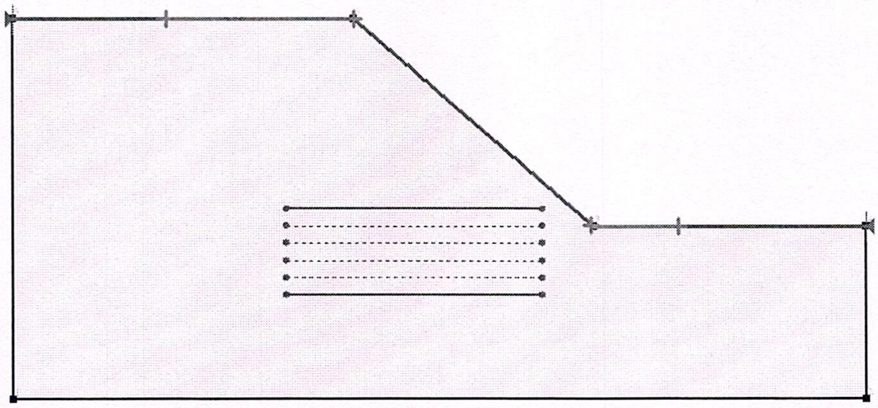

Figure 4-28 Entry and Exit slip surface with radius specification

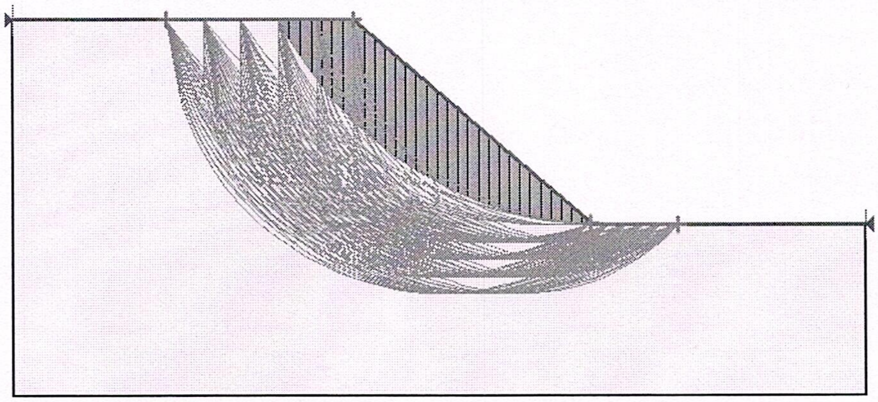

Figure 4-29 Display of all valid critical slip surfaces with radius specification

The radius specification in the Entry and Exit method can be useful in situations where the slip surfaces are controlled by beddings of weaker materials, or an impenetrable material layer (bedrock).

Note that although SLOPE/W posts no restriction to the location of the Entry and Exit zones, it is recommended that the Entry and Exit zones should be carefully defined on locations where the critical slip surface is expected to daylight. Defining a large Entry and Exit zones on the ground surface blindly may lead to many impossible slip surfaces and may miss the real critical slip surface.

4.7 Optimization

All the traditional methods of forming trial slip surfaces change the entire slip surface. Recent research has explored the possibility of incrementally altering only portions of the slip surface (Greco, 1996; Malkawi, Hassan and Sarma, 2001). A variation of the published techniques has been implemented in SLOPE/W. After finding the critical slip surface by one of the more traditional methods, the new segmental technique is applied to optimize the solution.