27

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

VALUE ADDED COURSE

ON

"SLOPE STABILITY ANALYSIS USING GEOSTUDIO"

Resource Person:

P. Suresh Praveen Kumar, Assistant Professor, Dept. of CE, KSRMCE

Course Coordinator:

K. Niveditha, Assistant Professor, Dept. of CE, KSRMCE

Duration:

03/06/2023 to 15/06/2023

K.S.R.M. COLLEGE OF ENGINEERING
(UGC-AUTONOMOUS)
Kadapa, Andhra Pradesh, India– 516 003
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Lr./KSRMCE/CE/2022-23/ Date:26-05-2023

To
The Principal,
KSRMCE,
Kadapa.

Sub: Permission to Conduct Value Added Course on "Slope Stability Analysis using GeoStudio" from 03/06/2023 to 15/06/2023–Req- Reg.

Respected Sir,

The Department of Civil Engineering is planning to offer a Value Added Course on "Slope stability Analysis using GeoStudio" to B. Tech. students. The course will be conducted from 03/06/2023 to 15/06/2023. In this regard, I kindly request you to grant permission to conduct the value added course.

Thanking you,

Forwarded to principal sir

Yours faithfully

K. Niveditha

(Asst. Professor, CED)

Permitted
V.S.S. murthy

K.S.R.M. COLLEGE OF ENGINEERING

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Kadapa, Andhra Pradesh, India– 516 003

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Cr./KSRMCE/CE/2022-23/ Date: 27/05/2023

Circular

The Department of Civil Engineering is offering a Value Added Course on "Slope Stability Analysis using GeoStudio" from 03/06/2023 to 15/06/2023 to B.Tech students. In this regard, interested students are requested to register their names for the Value Added Course with following registration link.

https://docs.google.com/forms/d/e/1FAIpQLSegEbmqIHrlp0wkgZ_OMd_zMsoaTYd_XC65XDdmZ9rcxD4d-w/viewform

For further information contact Course Coordinator.

Course Coordinator:
K. Niveditha,
Asst. Professor,
Dept. of Civil Engineering,
KSRMCE.

HOD

Dept. of Civil Engineering

Cc to:

IQAC-KSRMCE

Registration for VAC on "Slope Stability Analysis using GeoStudio" From **03/06/2023 to 15/06/2023**

niveditha@ksrmce.ac.in (not shared) Switch account

* Required

Roll Number *

Your answer

Name of the Student *

Your answer

B.Tech Semester *

- ◯ I SEM
- ◯ II SEM
- ◯ III SEM
- ◯ IV SEM
- ◯ V SEM
- ◯ VI SEM
- ◯ VII SEM
- ◯ VIII SEM

Branch *

- ◯ CIVIL
- ◯ EEE
- ◯ MECHANICA
- ◯ LECE
- ◯ CSE
- ◯ AI&ML

Email ID *

Your answer

Submit

Clear form

Never submit passwords through Google Forms.

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DEPARTMENT OF CIVIL ENGINEERING

List of students registered for Value Added Course On "Slope Stability Analysis using GeoStudio" from 03/06/2023 to 15/06/2023

Sl. No.	Roll Number	Name of the student	Semester	Branch
1	209Y1A0103	Avula Kiran Kumar	VI	Civil
2	209Y1A0104	Avula Venkatasubbamma	VI	Civil
3	209Y1A0105	Balla Gurusuchitr	VI	Civil
4	209Y1A0107	Basireddy Bharath Simha Reddy	VI	Civil
5	209Y1A0115	Chelluboina Sravani	VI	Civil
6	209Y1A0118	Dharmavaram Aditya Sreeram	VI	Civil
7	209Y1A0121	Gondi Aravind	VI	Civil
8	209Y1A0122	Janagani Ganesh	VI	Civil
9	209Y1A0126	Kancherla Sree Revathi	VI	Civil
10	209Y1A0136	Kovuru Srivalli	VI	Civil
11	209Y1A0141	Malle Venkata Tharun	VI	Civil
12	209Y1A0189	Urlagaddala Poojitha	VI	Civil
13	209Y1A0191	Velpula Anusha	VI	Civil
14	209Y1A0194	Yarrapu Reddy Anusha Lakshmi	VI	Civil
15	219Y5A0104	Banda Anitha	VI	Civil
16	219Y5A0107	Bhukya Suresh Naik	VI	Civil
17	219Y5A0128	Karamthod Sai Kumar Naik	VI	Civil
18	219Y5A0132	Kore Sasirekha	VI	Civil
19	219Y5A0134	Kunchapu Subhash	VI	Civil
20	219Y5A0135	Kuruba Lavanya	VI	Civil
21	219Y5A0142	Malishetty Guru Lakshmi	VI	Civil
22	219Y5A0143	Mallu Teja	VI	Civil
23	219Y5A0148	Nannuru Shankar	VI	Civil
24	219Y5A0149	Nare Malleswaridevi	VI	Civil
25	219Y5A0152	Pasupuleti Sai Charan	VI	Civil
26	219Y5A0153	Pathan Rahamathullah Khan	VI	Civil
27	219Y5A0156	Poreddy Sunanda	VI	Civil
28	219Y5A0166	Shaik Nasar	VI	Civil

Coordinator

HOD

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

Syllabus of Value Added Course

Course Name: Slope Stability Analysis using GeoStudio

Course Objectives:

1. Develop a solid foundation in the fundamentals of slope stability analysis and its importance in geotechnical engineering.
2. Acquire the skills to perform slope stability analysis using both Limit Equilibrium methods and numerical methods.
3. Understand the significance of slip surface geometry, material properties, and field/lab evaluations in slope stability assessments.
4. Enhance critical thinking skills by analyzing case studies and real-world examples of slope stability issues.

Course Outcomes: Upon completing the course students will be able to:

1. Demonstrate a clear understanding of different types of slopes, their classifications, and the factors influencing their stability.
2. Utilize GeoStudio software effectively to create slope models, input material properties, define boundary conditions, and perform stability analyses.
3. Identify potential causes of slope failures, considering geological, geotechnical, and external factors that contribute to instability.
4. Analyze and evaluate material strength properties of different soils using both laboratory testing and field investigations.
5. Interpret the results of slope stability analyses, including factors of safety and failure modes, and make informed engineering judgments.

UNIT-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

UNIT-II

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

UNIT-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

UNIT-IV

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

Text Books/Reference 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

Reference Links:

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

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SCHEDULE

Department of Civil Engineering

Value Added Course

On

"Slope Stability Analysis using GeoStudio" from 03/06/2023 to 15/06/2023

Date	Timing	Resource Person	Topic to be covered
3/6/2023	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Fundamentals on slopes, Types of slopes
4/6/2023	9 AM to 6 PM	Sri. P. Suresh Praveen Kumar	Methods of analysis -Limit Equilibrium, Numerical Methods like Finite Element Methods, Finite Difference Methods
5/6/2023	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	boundary Element methods, Universal Distinct Element Methods, Langranian Methods. Causes of Failures
6/6/2023	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Different Limit equilibrium methods and its application to slopes
7/6/2023	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Introdcution about Geo Studio, Fundamentals on LE
8/6/2023	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Different Shapes of Slip surfaces, Geometry of slope
9/6/2023	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	various functions in Geo Studio
10/6/2023	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Material strength of different soils and evaluation of properties in lab and field
11/6/2023	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,
12/6/2023	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Examples on various site conditions – slope, Embankment, Layered Soil,
13/6/2023	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Examples on various site conditions – slope, Embankment, Layered Soil,
14/6/2023	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Examples on various site conditions – slope, Embankment, Layered Soil
15/6/2023	4 PM to 6 PM	Sri. P. Suresh Praveen Kumar	Examples on various site conditions – slope, Embankment, Layered Soil

Resource Person(s) Coordinator(s) HOD

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Value Added Course

on

"Slope Stability Analysis using GeoStudio"

Recourse person

Smt. P. Suresh Praveen Kumar

Assistant Professor,

Department of Civil Engineering

Coordinator

Smt. K. Niveditha

Assistant Professor,

Department of Civil Engineering

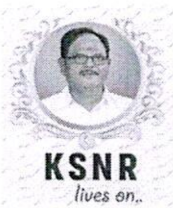
Date

03-06-2023

15-06-2023

04.00 PM - 06.00 PM

CE 216 CADD LAB



Report of
Value Added Course on "Slope stability Analysis using GeoStudio"
From 03/06/2023 to 15/06/2023

Target Group	:	**B. Tech. Students**
Details of Participants	:	**28 Students**
Co-coordinator(s)	:	**Smt. K. Niveditha**
Resource Person(s)	:	**Sri P. Suresh Praveen Kumar**
Organizing Department	:	**Civil Engineering**
Venue	:	**CADD Lab, Civil Department**

Description:

The Department of Civil Engineering conducted a Value Added Course on "Slope stability Analysis using GeoStudio" from 3rd June 2023 to 15th June 2023. The course was instructed by Sri P. Suresh Praveen Kumar, Assistant Professor, Civil Engineering and coordinated by Smt. K. Niveditha, Assistant Professor, Department Civil Engineering, KSRMCE.

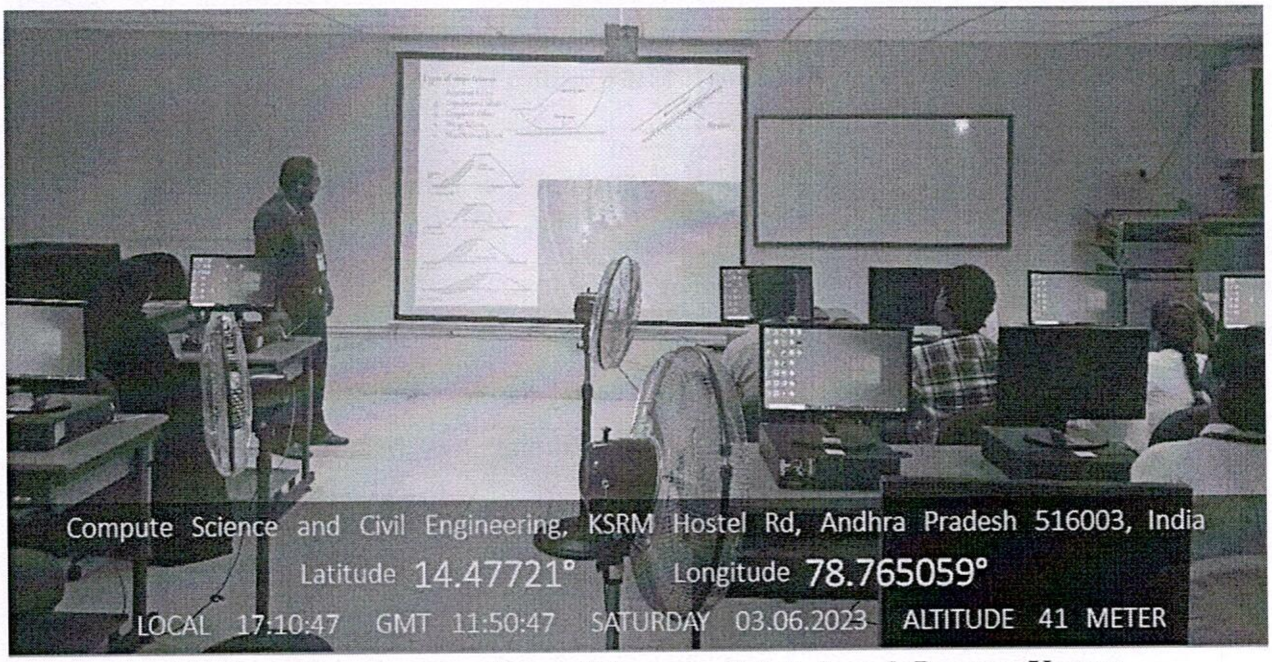
The certificate course on "Slope Stability Analysis using GeoStudio" provided participants with comprehensive knowledge and practical skills in analyzing the stability of slopes using the GeoStudio software suite. The course aimed to equip participants with the ability to assess and mitigate potential slope instability issues in engineering and geotechnical projects.

The primary objectives of the course were as follows:

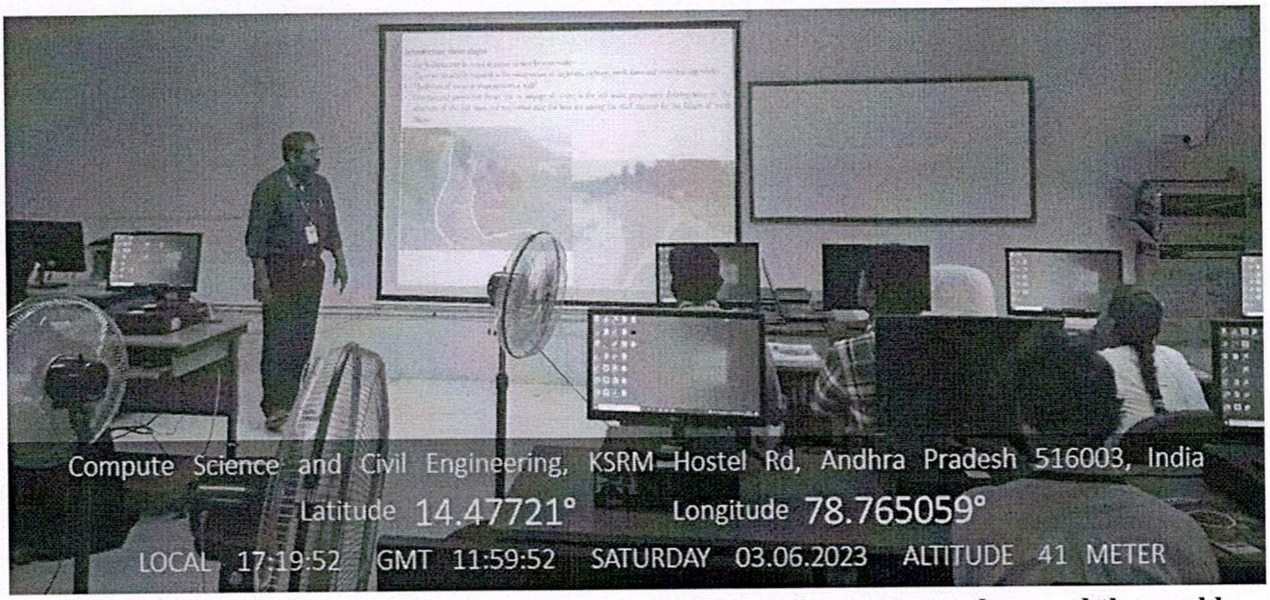
Develop a strong foundation in slope stability concepts and factors influencing stability. Introduce participants to various analysis methods, including Limit Equilibrium methods and numerical techniques like Finite Element Methods. Provide hands-on experience in utilizing GeoStudio software for slope stability analysis. Enhance participants' ability to interpret analysis results and recommend appropriate mitigation strategies. Foster critical thinking and problem-solving skills through real-world case studies.

Photos

The pictures taken during the course are given below:



Explanation on modes of slope failures by Sri. P. Suresh Praveen Kumar



Explaining the elaborative literature on different slope failures occurred around the world.

Coordinator(s)

HoD

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Attendance sheet of Value Added Course on "Slope Stability Analysis using GeoStudio"

Sl. No.	Roll No.	Name	3/6/23	4/6/23	5/6/23	6/6/23	7/6/23	8/6/23	9/6/23	10/6/23	11/6/23	12/6/23	13/6/23	14/6/23	15/6/23
1	209Y1A0103	Avula Kiran Kumar	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
2	209Y1A0104	Avula Venkatasubbamma	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
3	209Y1A0105	Balla Gurusuchitr	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
4	209Y1A0107	Basireddy Bharath Simha Reddy	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
5	209Y1A0115	Chelluboina Sravani	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]
6	209Y1A0118	Dharmavaram Aditya Sreeram	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]
7	209Y1A0121	Gondi Aravind	[signature]	[signature]	[signature]	A	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]	[signature]

8	209Y1A0122	Janagani Ganesh	Ganesh	Ganesh	Ganesh	Ganesh	Ganesh	Ganesh	Ganesh	Ganesh	Ganesh	Ganesh	Ganesh	Ganesh	Ganesh
9	209Y1A0126	Kancherla Sree Revathi	Sree	Sree	Sree	Sree	Sree	Sree	Sree	Sree	Sree	Sree	Sree	Sree	Sree
10	209Y1A0136	Kovuru Srivalli	Srivalli	Srivalli	Srivalli	Srivalli	Srivalli	Srivalli	Srivalli	Srivalli	Srivalli	A	Srivalli	Srivalli	Srivalli
11	209Y1A0141	Malle Venkata Tharun	Tarun	Tarun	Tarun	Tarun	Tarun	Tharun	Tharun	Tharun	Tharun	Tharun	Tharun	Tharun	Tharun
12	209Y1A0189	Urlagaddala Poojitha	Poojitha	Poojitha	Poojitha	Poojitha	Poojitha	Poojitha	Poojitha	Poojitha	A	Poojitha	Poojitha	Poojitha	Poojitha
13	209Y1A0191	Velpula Anusha	Anusha	Anusha	Anusha	Anusha	Anusha	Anusha	Anusha	Anusha	Anusha	Anusha	Anusha	Anusha	Anusha
14	209Y1A0194	Yarrapu Reddy Anusha Lakshmi	A	Anu	Anu	Anu	Anu	Anu	Anu	Anu	Anu	Anu	Anu	Anu	Anu
15	219Y5A0104	Banda Anitha	B.Anitha	B.Anitha	B.Anitha	B.Anitha	B.Anitha	A	B.Anitha	B.Anitha	B.Anitha	B.Anitha	B.Anitha	B.Anitha	B.Anitha
16	219Y5A0107	Bhukya Suresh Naik	B.Suresh	B.Suresh	B.Suresh	B.Suresh	B.Suresh	B.Suresh	B.Suresh	B.Suresh	B.Suresh	B.Suresh	B.Suresh	B.Suresh	B.Suresh
17	219Y5A0128	Karamthod Sai Kumar Naik	K.Saikumar	K.Saikumar	K.Saikumar	K.Saikumar	K.Saikumar	K.Saikumar	K.Saikumar	K.Saikumar	K.Saikumar	K.Saikumar	K.Saikumar	K.Saikumar	K.Saikumar
18	219Y5A0132	Kore Sasirekha	Sasirekha	Sasirekha	Sasirekha	Sasirekha	Sasirekha	Sasirekha	Sasirekha	Sasirekha	Sasirekha	Sasirekha	Sasirekha	Sasirekha	Sasirekha
19	219Y5A0134	Kunchapu Subhash	K.Subhash	K.Subhash	K.Subhash	K.Subhash	K.Subhash	K.Subhash	K.Subhash	K.Subhash	A	K.Subhash	K.Subhash	K.Subhash	K.Subhash
20	219Y5A0135	Kuruba Lavanya	Lavanya	Lavanya	Lavanya	Lavanya	Lavanya	Lavanya	Lavanya	Lavanya	Lavanya	Lavanya	Lavanya	Lavanya	Lavanya
21	219Y5A0142	Malishetty Guru Lakshmi	Guru	Guru	Guru	Guru	Guru	Guru	Guru	Guru	Guru	Guru	A	Guru	Guru
22	219Y5A0143	Mallu Teja	Teja	Teja	Teja	Teja	Teja	Teja	Teja	Teja	Teja	Teja	Teja	Teja	Teja

23	219Y5A0148	Nannuru Shankar													
24	219Y5A0149	Nare Malleswaridevi													
25	219Y5A0152	Pasupuleti Sai Charan					A								
26	219Y5A0153	Pathan Rahamathullah Khan								A					
27	219Y5A0156	Poreddy Sunanda												A	
28	219Y5A0166	Shaik Nasar					A								

Coordinator(s)

HoD

Head
Department of Civil Engineering
K.S.R.M. College of Engineering
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Feedback form on Value Added Course "Slope Stability Analysis using GeoStudio" from **03/06/2023 to 15/06/2023**

niveditha @ksrmce.ac.in (not shared) Switch account

* Required

Roll Number *

Your answer

Name of the Student *

Your answer

The objectives of the Value Added Course were met*

- Excellent
- Good
- Satisfactory
- Poor

The content of the course was organized and easy to follow*

- ◯ Excellent
- ◯ Good
- ◯ Satisfactory
- ◯ Poor

The Resource Person was well prepared and able to answer any question *

- ◯ Excellent
- ◯ Good
- ◯ Satisfactory
- ◯ Poor

The exercises/role play were helpful and relevant *

- ◯ Excellent
- ◯ Good
- ◯ Satisfactory
- ◯ Poor

The Value Added Course satisfy my expectation as a value added Programme (Course Satisfaction) *

- Excellent
- Satisfactory
- Good
- Poor

Any other comments

Your answer

Submit

Clear form

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Feedback of Value Added Course on "Slope Stability Analysis using GeoStudio"

Sl. No.	Roll No.	Name	The objectives of the Value Added Course were met	The content of the course was organized and easy to follow	The Resource Person was well prepared and able to answer any question	The exercises/role play were helpful and relevant	The Value Added Course satisfy my expectation as a value added Programme
1	209Y1A0103	Avula Kiran Kumar	Excellent	Excellent	Excellent	Excellent	Excellent
2	209Y1A0104	Avula Venkatasubbamma	Excellent	Excellent	Excellent	Excellent	Excellent
3	209Y1A0105	Balla Gurusuchitr	Excellent	Good	Excellent	Excellent	Excellent
4	209Y1A0107	Basireddy Bharath Simha Reddy	Excellent	Excellent	Good	Excellent	Excellent
5	209Y1A0115	Chelluboina Sravani	Good	Excellent	Good	Excellent	Excellent
6	209Y1A0118	Dharmavaram Aditya Sreeram	Excellent	Good	Excellent	Satisfactory	Excellent
7	209Y1A0121	Gondi Aravind	Excellent	Excellent	Excellent	Excellent	Good
8	209Y1A0122	Janagani Ganesh	Excellent	Good	Excellent	Excellent	Excellent

9	209Y1A0126	Kancherla Sree Revathi	Excellent	Excellent	Excellent	Excellent	Excellent
10	209Y1A0136	Kovuru Srivalli	Excellent	Satisfactory	Good	Excellent	Excellent
11	209Y1A0141	Malle Venkata Tharun	Excellent	Excellent	Excellent	Excellent	Excellent
12	209Y1A0189	Urlagaddala Poojitha	Excellent	Excellent	Excellent	Good	Excellent
13	209Y1A0191	Velpula Anusha	Good	Good	Excellent	Satisfactory	Excellent
14	209Y1A0194	Yarrapu Reddy Anusha Lakshmi	Excellent	Excellent	Good	Good	Excellent
15	219Y5A0104	Banda Anitha	Excellent	Excellent	Excellent	Excellent	Excellent
16	219Y5A0107	Bhukya Suresh Naik	Excellent	Good	Excellent	Excellent	Excellent
17	219Y5A0128	Karamthod Sai Kumar Naik	Excellent	Excellent	Good	Good	Excellent
18	219Y5A0132	Kore Sasirekha	Good	Good	Excellent	Excellent	Good
19	219Y5A0134	Kunchapu Subhash	Excellent	Excellent	Good	Excellent	Good
20	219Y5A0135	Kuruba Lavanya	Excellent	Good	Excellent	Excellent	Good
21	219Y5A0142	Malishetty Guru Lakshmi	Excellent	Good	Excellent	Satisfactory	Excellent
22	219Y5A0143	Mallu Teja	Excellent	Good	Excellent	Excellent	Excellent
23	219Y5A0148	Nannuru Shankar	Excellent	Excellent	Excellent	Excellent	Excellent

24	219Y5A0149	Nare Malleswaridevi	Excellent	Excellent	Excellent	Excellent	Excellent
25	219Y5A0152	Pasupuleti Sai Charan	Excellent	Good	Good	Excellent	Excellent
26	219Y5A0153	Pathan Rahamathullah Khan	Excellent	Excellent	Excellent	Good	Good
27	219Y5A0156	Poreddy Sunanda	Excellent	Excellent	Satisfactory	Excellent	Excellent
28	219Y5A0166	Shaik Nasar	Excellent	Excellent	Excellent	Excellent	Excellent

Coordinator

HOD

Head
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K.S.R.M College of Engineering

(AUTONOMOUS)

KADAPA, ANDHRA PRADESH, INDIA-516003

DEPARTMENT OF CIVIL ENGINEERING

CERTIFICATE OF COURSE COMPLETION

This certificate is presented to

Gondi Aravind (Reg. No. 209Y1A0121), Student of KSRM College of Engineering (Autonomous) for successful completion of value added course on “Slope stability Analysis using GeoStudio” offered by Department of Civil Engineering, KSRMCE-Kadapa.

Course Duration: 38 Hours;
From: 03/06/2023 to 15/06/2023

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

Coordinator | **Head of the Department** | **Principal**

K.S.R.M College of Engineering

(AUTONOMOUS)

KADAPA, ANDHRA PRADESH, INDIA-516003

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DEPARTMENT OF CIVIL ENGINEERING

CERTIFICATE OF COURSE COMPLETION

This certificate is presented to

Kovuru Srivalli (Reg. No. 209Y1A0136), Student of KSRM College of Engineering (Autonomous) for successful completion of value added course on "Slope stability Analysis using GeoStudio" offered by Department of Civil Engineering, KSRMCE-Kadapa.

Course Duration: 38 Hours;
From: 03/06/2023 to 15/06/2023

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

V. S. S. Murthy

Coordinator | **Head of the Department** | **Principal**

K.S.R.M College of Engineering

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KADAPA, ANDHRA PRADESH, INDIA-516003

DEPARTMENT OF CIVIL ENGINEERING

CERTIFICATE OF COURSE COMPLETION

This certificate is presented to

Kore Sasirekha (Reg. No. 219Y5A0132), Student of KSRM College of Engineering (Autonomous) for successful completion of value added course on "Slope stability Analysis using GeoStudio" offered by Department of Civil Engineering, KSRMCE-Kadapa.

Course Duration: 38 Hours;
From: 03/06/2023 to 15/06/2023

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

Coordinator

Head of the Department

V. S. S. Murthy

Principal

K.S.R.M College of Engineering

(AUTONOMOUS)

KADAPA, ANDHRA PRADESH, INDIA-516003

DEPARTMENT OF CIVIL ENGINEERING

CERTIFICATE OF COURSE COMPLETION

This certificate is presented to

Mallu Teja (Reg. No. 219Y5A0143), Student of KSRM College of Engineering (Autonomous) for successful completion of value added course on "Slope stability Analysis using GeoStudio" offered by Department of Civil Engineering, KSRMCE-Kadapa.

Course Duration: 38 Hours;
From: 03/06/2023 to 15/06/2023

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

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K.S.R.M. COLLEGE OF ENGINEERING (AUTONOMOUS), KADAPA-516003
DEPARTMENT OF CIVIL ENGINEERING
VALUE ADDED COURSE ON
SLOPE STABILITY ANALYSIS USING GEOSTUDIO
MARKS AWARD LIST

S.No	Roll Number	Name of the Student	Marks Obtained
1	209Y1A0103	Avula Kiran Kumar	19
2	209Y1A0104	Avula Venkatasubbamma	15
3	209Y1A0105	Balla Gurusuchitr	15
4	209Y1A0107	Basireddy Bharath Simha Reddy	15
5	209Y1A0115	Chelluboina Sravani	15
6	209Y1A0118	Dharmavaram Aditya Sreeram	16
7	209Y1A0121	Gondi Aravind	18
8	209Y1A0122	Janagani Ganesh	7
9	209Y1A0126	Kancherla Sree Revathi	14
10	209Y1A0136	Kovuru Srivalli	19
11	209Y1A0141	Malle Venkata Tharun	15
12	209Y1A0189	Urlagaddala Poojitha	16
13	209Y1A0191	Velpula Anusha	13
14	209Y1A0194	Yarrapu Reddy Anusha Lakshmi	18
15	219Y5A0104	Banda Anitha	19
16	219Y5A0107	Bhukya Suresh Naik	18
17	219Y5A0128	Karamthod Sai Kumar Naik	16
18	219Y5A0132	Kore Sasirekha	18
19	219Y5A0134	Kunchapu Subhash	16
20	219Y5A0135	Kuruba Lavanya	18
21	219Y5A0142	Malishetty Guru Lakshmi	14
22	219Y5A0143	Mallu Teja	14
23	219Y5A0148	Nannuru Shankar	13
24	219Y5A0149	Nare Malleswaridevi	17
25	219Y5A0152	Pasupuleti Sai Charan	15
26	219Y5A0153	Pathan Rahamathullah Khan	18
27	219Y5A0156	Poreddy Sunanda	16
28	219Y5A0166	Shaik Nasar	17

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
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ASSESSMENT TEST

Roll Number: 209Y1A0104 **Name of the Student:** A. Venkatasubbamma.

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

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

1	What is the primary purpose of slope stability analysis?				[b] ✓
	a) To calculate the volume of soil in a slope	b) To assess the potential for slope failure	c) To determine the height of a slope	d) To analyze the groundwater levels in a slope	
2	Which software suite is commonly used for slope stability analysis?				[C] ✓
	a) Microsoft Office Suite	b) AutoCAD	c) GeoStudio	d) Adobe Creative Suite	
3	What are the two main categories of methods used for slope stability analysis?				[b] ✓
	a) Geometric methods and graphical methods	b) Analytical methods and numerical methods	c) Manual methods and computer methods	d) Simple methods and complex methods	
4	Which method involves dividing a slope into slices and analyzing equilibrium conditions for each slice?				[A] ✓
	a) Bishop's method	b) Finite Element Method	c) Finite Difference Method	d) Taylor's method	
5	What is the primary purpose of using GeoStudio software in slope stability analysis?				[C] ✓
	a) Creating artistic renderings of slopes	b) Calculating the financial cost of slope failure	c) Analyzing the stability of slopes	d) Designing aesthetically pleasing slopes	
6	What is the term used to describe the ratio of resisting forces to driving forces in slope stability analysis?				[A] ✓
	a) Safety factor	b) Risk index	c) Stability coefficient	d) Failure ratio	
7	What is the significance of slip surface geometry in slope stability analysis?				[B] ✓
	a) It determines the color of the slope on the analysis chart.	b) It affects the stability of the slope and potential failure mechanisms.	c) It indicates the age of the slope.	d) It determines the economic value of the slope.	
8	Which unit of the course covers the analysis of various slip surface geometries?				[B] ✗
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	
9	Which method involves subdividing a slope into grid elements and solving for equilibrium at each node?				[B] ✓
	a) Limit Equilibrium	b) Finite Element Method	c) Finite Difference Method	d) Langrangian method	

	method				
10	What is a common cause of slope failures?				
	a) Excessive stability	b) Too much soil moisture	c) Inadequate loading	d) Weak geological formations	[A] X
11	In slope stability analysis, what does "FS" stand for?				
	a) Failure Solution	b) Factor of Safety	c) Finite Slice	d) Failure Scenario	[C] X
12	What is the primary objective of sensitivity analysis in slope stability analysis?				
	a) To determine the cost of the analysis	b) To analyze the effect of different factors on stability	c) To create a visually appealing slope stability chart	d) To calculate the safety factor	[B] ✓
13	Which unit of the course focuses on practical applications and case studies?				
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	[A] X
14	Which material properties are evaluated in lab and field for slope stability analysis?				
	a) Temperature and pressure	b) Density and color	c) Material strength	d) Electrical conductivity	[C] ✓
15	In slope stability analysis, what is the term used for an artificial slope made of compacted soil?				
	a) Embankment	b) Landslide	c) Cliff	d) Plateau	[A] ✓
16	What is a crucial skill acquired in the course for solving practical engineering problems?				
	a) Playing musical instruments	b) Painting landscapes	c) Critical thinking and problem-solving	d) Public speaking	[A] X
17	What is the purpose of designing mitigation strategies in slope stability analysis?				
	a) To maximize the risk of failure	b) To worsen the slope stability	c) To enhance slope instability	d) To improve slope stability and prevent failures	[D] ✓
18	Which section of the course introduces participants to various Limit Equilibrium methods?				
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	[B] ✓
19	What type of analysis is performed to evaluate the effects of varying input parameters on slope stability?				
	a) Stability analysis	b) Sensitivity analysis	c) Failure analysis	d) Geometric analysis	[B] ✓
20	What is the ultimate goal of slope stability analysis in engineering?				
	a) To create the most unstable slope possible	b) To determine the most aesthetically pleasing slope	c) To achieve a safety factor of zero	d) To ensure the safety of structures and prevent slope failures	[D] ✓

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Roll Number: 209Y1A0103 **Name of the Student:** A. Kiran Kumar

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

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

1	What is the primary purpose of slope stability analysis?				[B] ✓
	a) To calculate the volume of soil in a slope	b) To assess the potential for slope failure	c) To determine the height of a slope	d) To analyze the groundwater levels in a slope	
2	Which software suite is commonly used for slope stability analysis?				[C] ✓
	a) Microsoft Office Suite	b) AutoCAD	c) GeoStudio	d) Adobe Creative Suite	
3	What are the two main categories of methods used for slope stability analysis?				[B] ✓
	a) Geometric methods and graphical methods	b) Analytical methods and numerical methods	c) Manual methods and computer methods	d) Simple methods and complex methods	
4	Which method involves dividing a slope into slices and analyzing equilibrium conditions for each slice?				[A] ✓
	a) Bishop's method	b) Finite Element Method	c) Finite Difference Method	d) Taylor's method	
5	What is the primary purpose of using GeoStudio software in slope stability analysis?				[A] ✗
	a) Creating artistic renderings of slopes	b) Calculating the financial cost of slope failure	c) Analyzing the stability of slopes	d) Designing aesthetically pleasing slopes	
6	What is the term used to describe the ratio of resisting forces to driving forces in slope stability analysis?				[A] ✓
	a) Safety factor	b) Risk index	c) Stability coefficient	d) Failure ratio	
7	What is the significance of slip surface geometry in slope stability analysis?				[B] ✓
	a) It determines the color of the slope on the analysis chart.	b) It affects the stability of the slope and potential failure mechanisms.	c) It indicates the age of the slope.	d) It determines the economic value of the slope.	
8	Which unit of the course covers the analysis of various slip surface geometries?				[C] ✓
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	
9	Which method involves subdividing a slope into grid elements and solving for equilibrium at each node?				[B] ✓
	a) Limit Equilibrium	b) Finite Element Method	c) Finite Difference Method	d) Langrangian method	

	method				
10	What is a common cause of slope failures?				
	a) Excessive stability	b) Too much soil moisture	c) Inadequate loading	d) Weak geological formations	[D]
11	In slope stability analysis, what does "FS" stand for?				
	a) Failure Solution	b) Factor of Safety	c) Finite Slice	d) Failure Scenario	[B]
12	What is the primary objective of sensitivity analysis in slope stability analysis?				
	a) To determine the cost of the analysis	b) To analyze the effect of different factors on stability	c) To create a visually appealing slope stability chart	d) To calculate the safety factor	[B]
13	Which unit of the course focuses on practical applications and case studies?				[D]
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	
14	Which material properties are evaluated in lab and field for slope stability analysis?				
	a) Temperature and pressure	b) Density and color	c) Material strength	d) Electrical conductivity	[C]
15	In slope stability analysis, what is the term used for an artificial slope made of compacted soil?				[A]
	a) Embankment	b) Landslide	c) Cliff	d) Plateau	
16	What is a crucial skill acquired in the course for solving practical engineering problems?				
	a) Playing musical instruments	b) Painting landscapes	c) Critical thinking and problem-solving	d) Public speaking	[C]
17	What is the purpose of designing mitigation strategies in slope stability analysis?				
	a) To maximize the risk of failure	b) To worsen the slope stability	c) To enhance slope instability	d) To improve slope stability and prevent failures	[D]
18	Which section of the course introduces participants to various Limit Equilibrium methods?				[B]
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	
19	What type of analysis is performed to evaluate the effects of varying input parameters on slope stability?				
	a) Stability analysis	b) Sensitivity analysis	c) Failure analysis	d) Geometric analysis	[B]
20	What is the ultimate goal of slope stability analysis in engineering?				
	a) To create the most unstable slope possible	b) To determine the most aesthetically pleasing slope	c) To achieve a safety factor of zero	d) To ensure the safety of structures and prevent slope failures	[D]

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Roll Number: 20981A0105 **Name of the Student:** B. Gurusuchitra

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

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

1	What is the primary purpose of slope stability analysis?				[B] ✓
	a) To calculate the volume of soil in a slope	b) To assess the potential for slope failure	c) To determine the height of a slope	d) To analyze the groundwater levels in a slope	
2	Which software suite is commonly used for slope stability analysis?				[C] ✓
	a) Microsoft Office Suite	b) AutoCAD	c) GeoStudio	d) Adobe Creative Suite	
3	What are the two main categories of methods used for slope stability analysis?				[B] ✓
	a) Geometric methods and graphical methods	b) Analytical methods and numerical methods	c) Manual methods and computer methods	d) Simple methods and complex methods	
4	Which method involves dividing a slope into slices and analyzing equilibrium conditions for each slice?				[A] ✓
	a) Bishop's method	b) Finite Element Method	c) Finite Difference Method	d) Taylor's method	
5	What is the primary purpose of using GeoStudio software in slope stability analysis?				[C] ✓
	a) Creating artistic renderings of slopes	b) Calculating the financial cost of slope failure	c) Analyzing the stability of slopes	d) Designing aesthetically pleasing slopes	
6	What is the term used to describe the ratio of resisting forces to driving forces in slope stability analysis?				[B] ✗
	a) Safety factor	b) Risk index	c) Stability coefficient	d) Failure ratio	
7	What is the significance of slip surface geometry in slope stability analysis?				[B] ✓
	a) It determines the color of the slope on the analysis chart.	b) It affects the stability of the slope and potential failure mechanisms.	c) It indicates the age of the slope.	d) It determines the economic value of the slope.	
8	Which unit of the course covers the analysis of various slip surface geometries?				[B] ✗
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	
9	Which method involves subdividing a slope into grid elements and solving for equilibrium at each node?				[B] ✓
	a) Limit Equilibrium	b) Finite Element Method	c) Finite Difference Method	d) Langrangian method	

	method				
10	What is a common cause of slope failures?				
	a) Excessive stability	b) Too much soil moisture	c) Inadequate loading	d) Weak geological formations	[B] X
11	In slope stability analysis, what does "FS" stand for?				
	a) Failure Solution	b) Factor of Safety	c) Finite Slice	d) Failure Scenario	[B]
12	What is the primary objective of sensitivity analysis in slope stability analysis?				
	a) To determine the cost of the analysis	b) To analyze the effect of different factors on stability	c) To create a visually appealing slope stability chart	d) To calculate the safety factor	[B]
13	Which unit of the course focuses on practical applications and case studies?				
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	[D]
14	Which material properties are evaluated in lab and field for slope stability analysis?				
	a) Temperature and pressure	b) Density and color	c) Material strength	d) Electrical conductivity	[B] X
15	In slope stability analysis, what is the term used for an artificial slope made of compacted soil?				
	a) Embankment	b) Landslide	c) Cliff	d) Plateau	[A]
16	What is a crucial skill acquired in the course for solving practical engineering problems?				
	a) Playing musical instruments	b) Painting landscapes	c) Critical thinking and problem-solving	d) Public speaking	[c]
17	What is the purpose of designing mitigation strategies in slope stability analysis?				
	a) To maximize the risk of failure	b) To worsen the slope stability	c) To enhance slope instability	d) To improve slope stability and prevent failures	[D]
18	Which section of the course introduces participants to various Limit Equilibrium methods?				
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	[C] X
19	What type of analysis is performed to evaluate the effects of varying input parameters on slope stability?				
	a) Stability analysis	b) Sensitivity analysis	c) Failure analysis	d) Geometric analysis	[B]
20	What is the ultimate goal of slope stability analysis in engineering?				
	a) To create the most unstable slope possible	b) To determine the most aesthetically pleasing slope	c) To achieve a safety factor of zero	d) To ensure the safety of structures and prevent slope failures	[D]

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Roll Number: 209Y1A0107 **Name of the Student:** B. Bhavath Simhareddy

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

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

1	What is the primary purpose of slope stability analysis?				[B]	✓
	a) To calculate the volume of soil in a slope	b) To assess the potential for slope failure	c) To determine the height of a slope	d) To analyze the groundwater levels in a slope		
2	Which software suite is commonly used for slope stability analysis?				[D]	✗
	a) Microsoft Office Suite	b) AutoCAD	c) GeoStudio	d) Adobe Creative Suite		
3	What are the two main categories of methods used for slope stability analysis?				[B]	✓
	a) Geometric methods and graphical methods	b) Analytical methods and numerical methods	c) Manual methods and computer methods	d) Simple methods and complex methods		
4	Which method involves dividing a slope into slices and analyzing equilibrium conditions for each slice?				[A]	✓
	a) Bishop's method	b) Finite Element Method	c) Finite Difference Method	d) Taylor's method		
5	What is the primary purpose of using GeoStudio software in slope stability analysis?				[C]	✓
	a) Creating artistic renderings of slopes	b) Calculating the financial cost of slope failure	c) Analyzing the stability of slopes	d) Designing aesthetically pleasing slopes		
6	What is the term used to describe the ratio of resisting forces to driving forces in slope stability analysis?				[A]	✓
	a) Safety factor	b) Risk index	c) Stability coefficient	d) Failure ratio		
7	What is the significance of slip surface geometry in slope stability analysis?				[B]	✓
	a) It determines the color of the slope on the analysis chart.	b) It affects the stability of the slope and potential failure mechanisms.	c) It indicates the age of the slope.	d) It determines the economic value of the slope.		
8	Which unit of the course covers the analysis of various slip surface geometries?				[C]	✓
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV		
9	Which method involves subdividing a slope into grid elements and solving for equilibrium at each node?				[C]	✗
	a) Limit Equilibrium	b) Finite Element Method	c) Finite Difference Method	d) Langrangian method		

	method				
10	What is a common cause of slope failures?				[D]
	a) Excessive stability	b) Too much soil moisture	c) Inadequate loading	d) Weak geological formations	
11	In slope stability analysis, what does "FS" stand for?				[B]
	a) Failure Solution	b) Factor of Safety	c) Finite Slice	d) Failure Scenario	
12	What is the primary objective of sensitivity analysis in slope stability analysis?				[B]
	a) To determine the cost of the analysis	b) To analyze the effect of different factors on stability	c) To create a visually appealing slope stability chart	d) To calculate the safety factor	
13	Which unit of the course focuses on practical applications and case studies?				[C]
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	
14	Which material properties are evaluated in lab and field for slope stability analysis?				[C]
	a) Temperature and pressure	b) Density and color	c) Material strength	d) Electrical conductivity	
15	In slope stability analysis, what is the term used for an artificial slope made of compacted soil?				[C]
	a) Embankment	b) Landslide	c) Cliff	d) Plateau	
16	What is a crucial skill acquired in the course for solving practical engineering problems?				[D]
	a) Playing musical instruments	b) Painting landscapes	c) Critical thinking and problem-solving	d) Public speaking	
17	What is the purpose of designing mitigation strategies in slope stability analysis?				[A]
	a) To maximize the risk of failure	b) To worsen the slope stability	c) To enhance slope instability	d) To improve slope stability and prevent failures	
18	Which section of the course introduces participants to various Limit Equilibrium methods?				[B]
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	
19	What type of analysis is performed to evaluate the effects of varying input parameters on slope stability?				[B]
	a) Stability analysis	b) Sensitivity analysis	c) Failure analysis	d) Geometric analysis	
20	What is the ultimate goal of slope stability analysis in engineering?				[D]
	a) To create the most unstable slope possible	b) To determine the most aesthetically pleasing slope	c) To achieve a safety factor of zero	d) To ensure the safety of structures and prevent slope failures	

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Roll Number: 20941A0115 **Name of the Student:** Chelluboina sravani

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

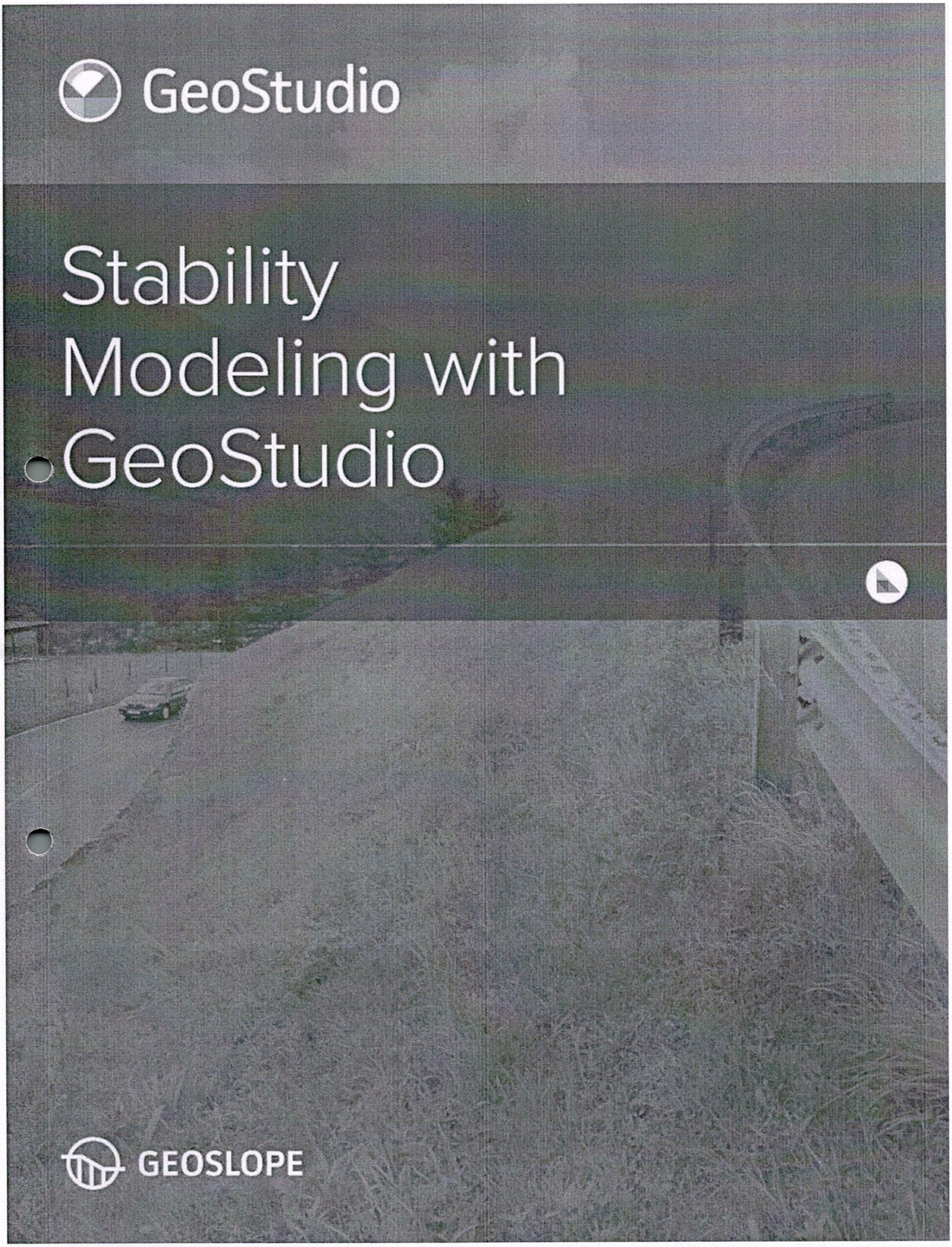
Note: Answer the following Questions and each question carries **one** mark.

1	What is the primary purpose of slope stability analysis?				[B] ✓
	a) To calculate the volume of soil in a slope	b) To assess the potential for slope failure	c) To determine the height of a slope	d) To analyze the groundwater levels in a slope	
2	Which software suite is commonly used for slope stability analysis?				[C] ✓
	a) Microsoft Office Suite	b) AutoCAD	c) GeoStudio	d) Adobe Creative Suite	
3	What are the two main categories of methods used for slope stability analysis?				[B] ✓
	a) Geometric methods and graphical methods	b) Analytical methods and numerical methods	c) Manual methods and computer methods	d) Simple methods and complex methods	
4	Which method involves dividing a slope into slices and analyzing equilibrium conditions for each slice?				[A] ✓
	a) Bishop's method	b) Finite Element Method	c) Finite Difference Method	d) Taylor's method	
5	What is the primary purpose of using GeoStudio software in slope stability analysis?				[C] ✓
	a) Creating artistic renderings of slopes	b) Calculating the financial cost of slope failure	c) Analyzing the stability of slopes	d) Designing aesthetically pleasing slopes	
6	What is the term used to describe the ratio of resisting forces to driving forces in slope stability analysis?				[A] ✓
	a) Safety factor	b) Risk index	c) Stability coefficient	d) Failure ratio	
7	What is the significance of slip surface geometry in slope stability analysis?				[B] ✓
	a) It determines the color of the slope on the analysis chart.	b) It affects the stability of the slope and potential failure mechanisms.	c) It indicates the age of the slope.	d) It determines the economic value of the slope.	
8	Which unit of the course covers the analysis of various slip surface geometries?				[C] ✓
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	
9	Which method involves subdividing a slope into grid elements and solving for equilibrium at each node?				[B] ✓
	a) Limit Equilibrium	b) Finite Element Method	c) Finite Difference Method	d) Langrangian method	

	method				
10	What is a common cause of slope failures?				[C] ✗
	a) Excessive stability	b) Too much soil moisture	c) Inadequate loading	d) Weak geological formations	
11	In slope stability analysis, what does "FS" stand for?				[B] ✓
	a) Failure Solution	b) Factor of Safety	c) Finite Slice	d) Failure Scenario	
12	What is the primary objective of sensitivity analysis in slope stability analysis?				[C] ✗
	a) To determine the cost of the analysis	b) To analyze the effect of different factors on stability	c) To create a visually appealing slope stability chart	d) To calculate the safety factor	
13	Which unit of the course focuses on practical applications and case studies?				[C] ✗
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	
14	Which material properties are evaluated in lab and field for slope stability analysis?				[C] ✓
	a) Temperature and pressure	b) Density and color	c) Material strength	d) Electrical conductivity	
15	In slope stability analysis, what is the term used for an artificial slope made of compacted soil?				[A] ✓
	a) Embankment	b) Landslide	c) Cliff	d) Plateau	
16	What is a crucial skill acquired in the course for solving practical engineering problems?				[C] ✓
	a) Playing musical instruments	b) Painting landscapes	c) Critical thinking and problem-solving	d) Public speaking	
17	What is the purpose of designing mitigation strategies in slope stability analysis?				[C] ✗
	a) To maximize the risk of failure	b) To worsen the slope stability	c) To enhance slope instability	d) To improve slope stability and prevent failures	
18	Which section of the course introduces participants to various Limit Equilibrium methods?				[C] ✗
	a) Unit-I	b) Unit-II	c) Unit-III	d) Unit-IV	
19	What type of analysis is performed to evaluate the effects of varying input parameters on slope stability?				[B] ✓
	a) Stability analysis	b) Sensitivity analysis	c) Failure analysis	d) Geometric analysis	
20	What is the ultimate goal of slope stability analysis in engineering?				[D] ✓
	a) To create the most unstable slope possible	b) To determine the most aesthetically pleasing slope	c) To achieve a safety factor of zero	d) To ensure the safety of structures and prevent slope failures	

GeoStudio

Stability Modeling with GeoStudio



GEOSLOPE

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.

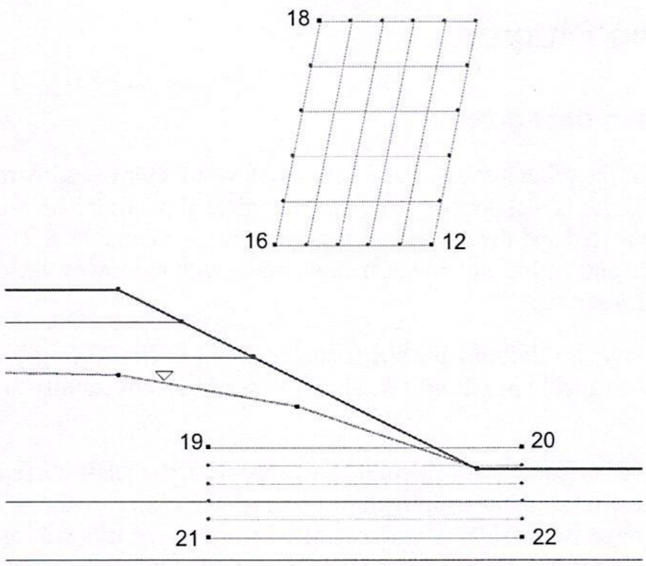


Figure 4-1 The grid and radius method of specifying trial slip surfaces

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.

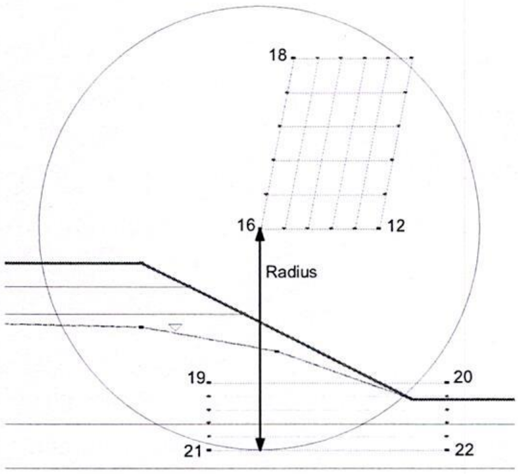


Figure 4-2 Imaginary trial slip surface

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.

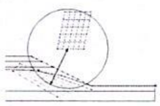


Figure 4-3 Specification of radius lines

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.

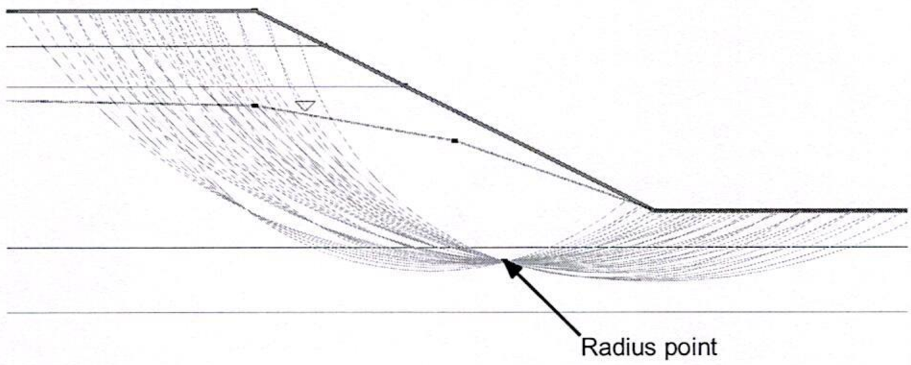


Figure 4-4 All slip surfaces through a point

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.

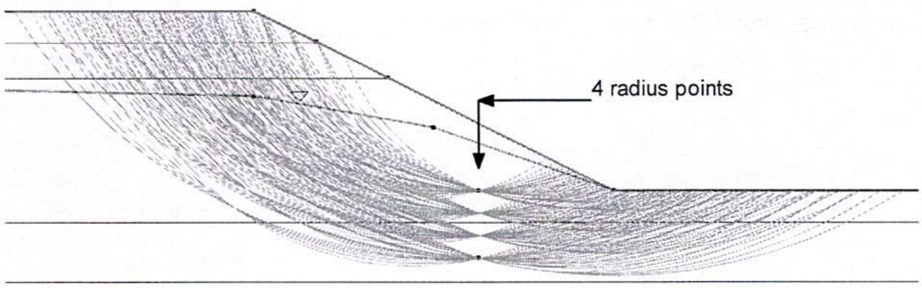


Figure 4-5 Slip surfaces though a series of radius points

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.

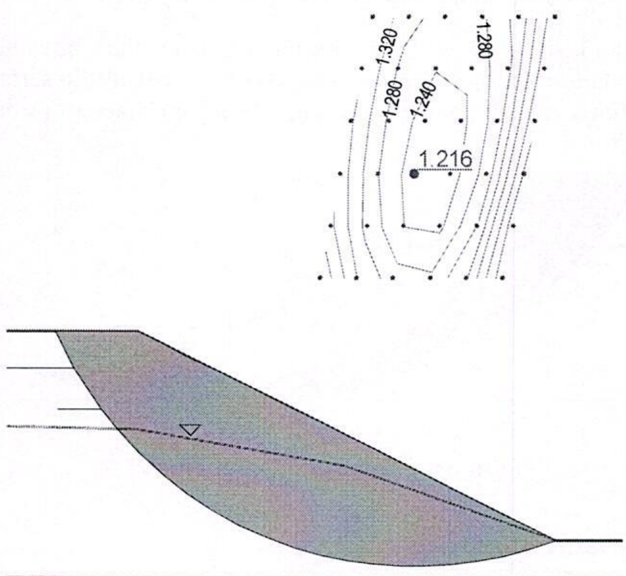


Figure 4-7 Factor of safety contours on grid of rotation centers

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.

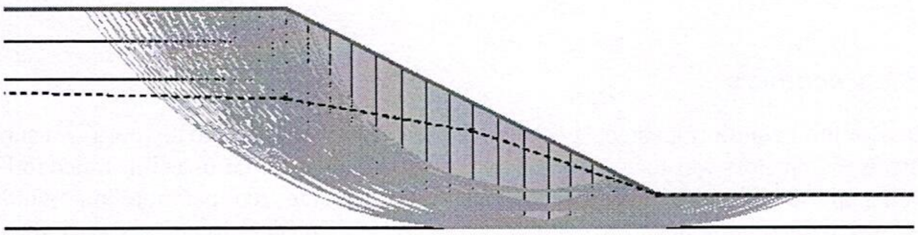


Figure 4-8 Display of multiple trial slip surfaces

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.

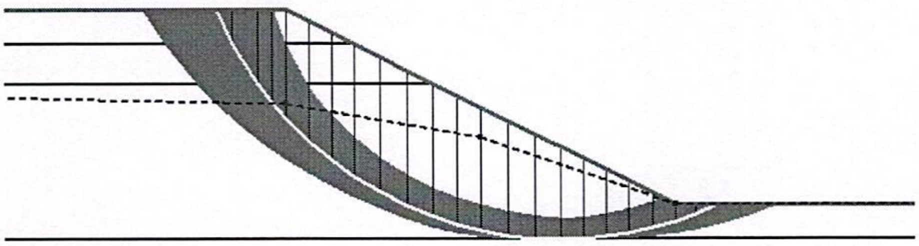


Figure 4-9 Display of safety map

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.

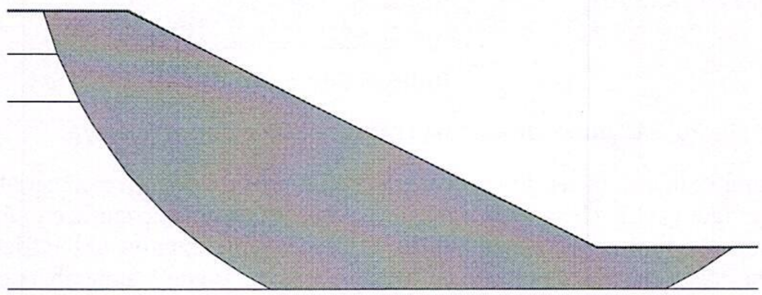


Figure 4-10 Composite slip surface controlled by impenetrable layer

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.

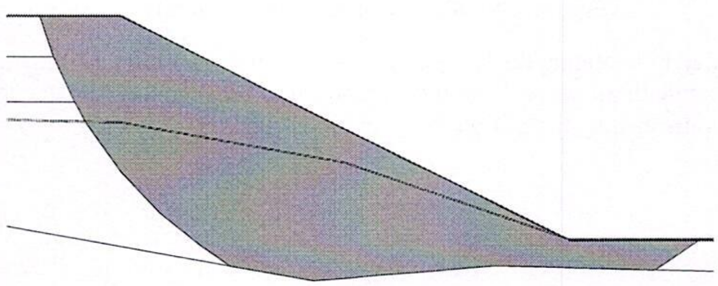


Figure 4-11 Irregular impenetrable layer

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.

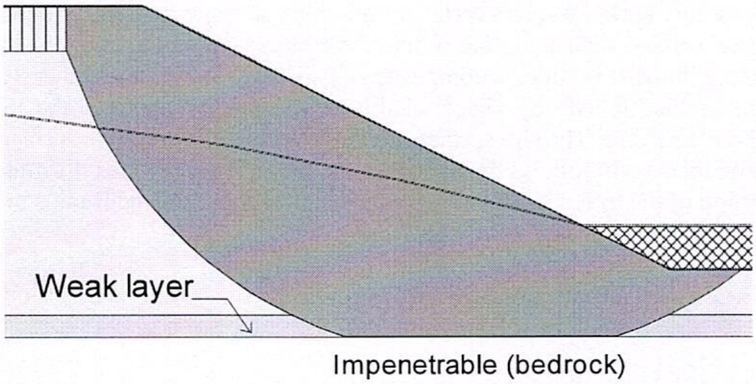


Figure 4-12 Impenetrable layer forces slip along weak layer

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.

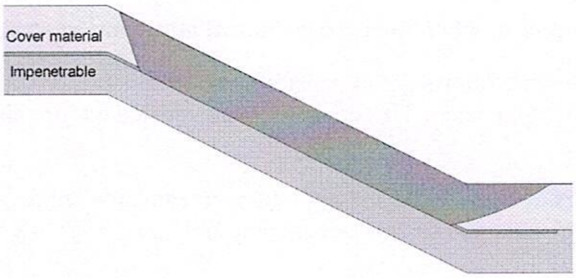


Figure 4-13 Sliding on a synthetic liner

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.

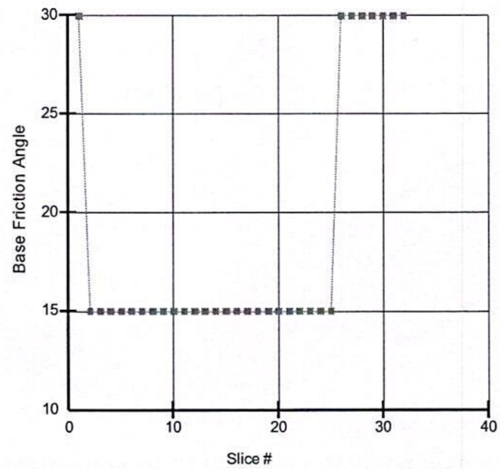


Figure 4-14 Variation of friction angle along slip surface

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.

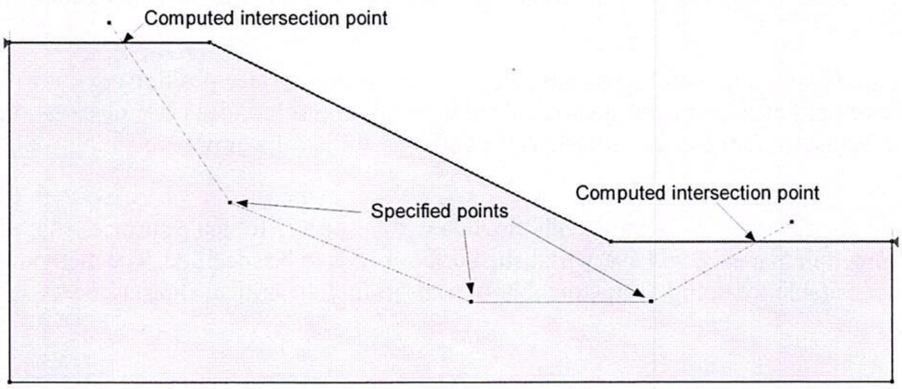


Figure 4-15 Fully specified slip surface

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.

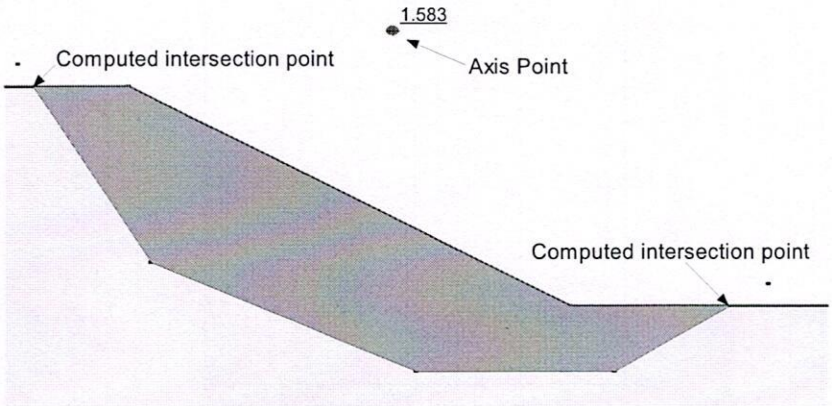


Figure 4-16 Axis point about which to compute moments

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.

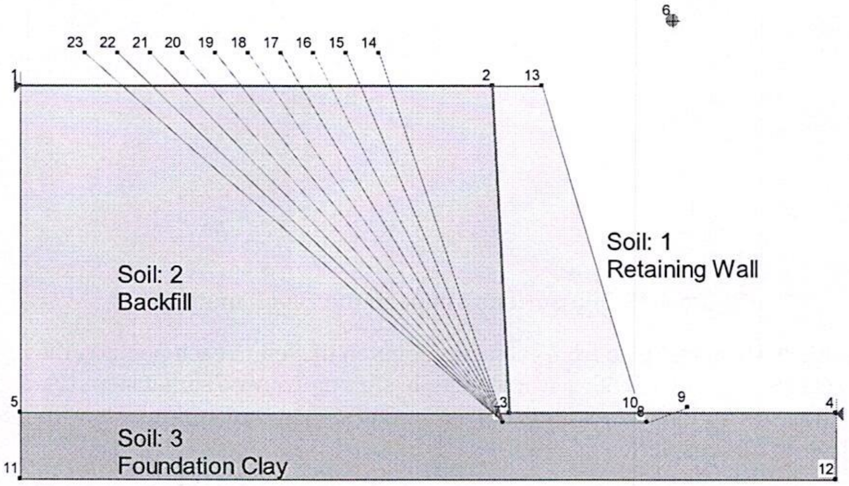


Figure 4-17 Sliding analysis of a gravity retaining wall

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.

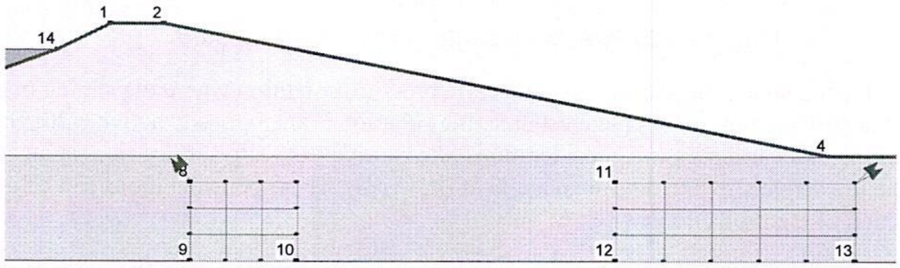


Figure 4-18 Grids in Block Specified method

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.

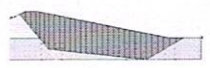


Figure 4-19 Slip surface shape in the Block method

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.

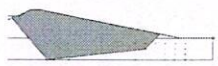


Figure 4-21 Trial slip surface with a sharp corner

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.

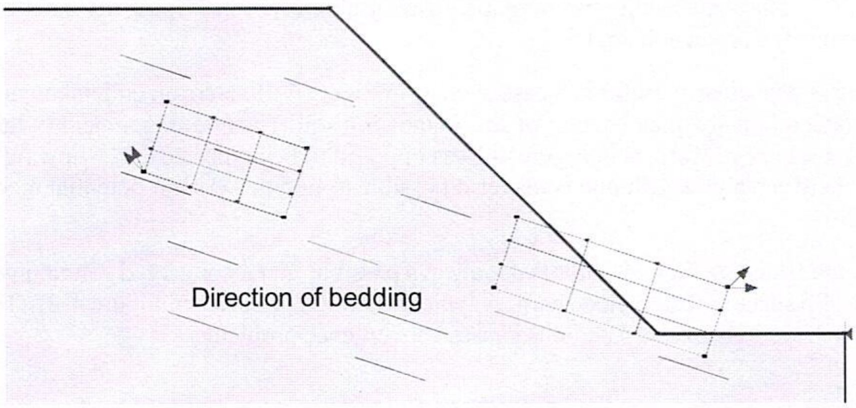


Figure 4-22 Slope with distinct bedding

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.

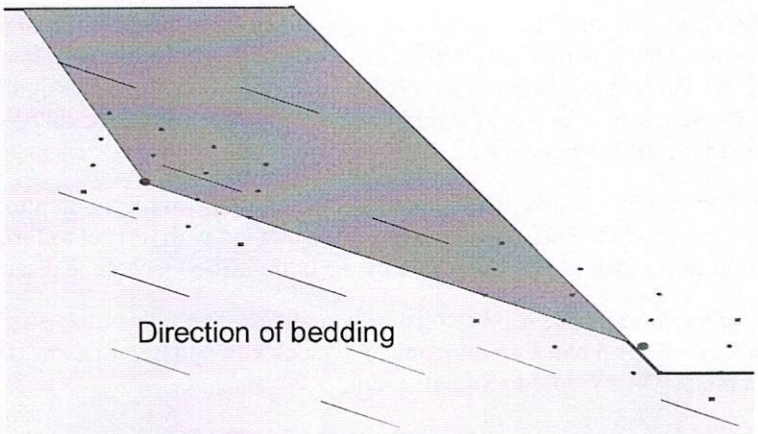


Figure 4-23 Trial slip surface follows the bedding

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).

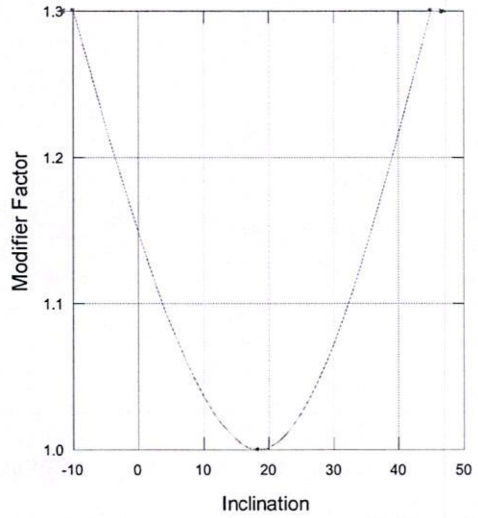


Figure 4-24 Anisotropic function

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.

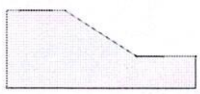


Figure 4-25 Entry and exit areas for forming trial slip surfaces

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.

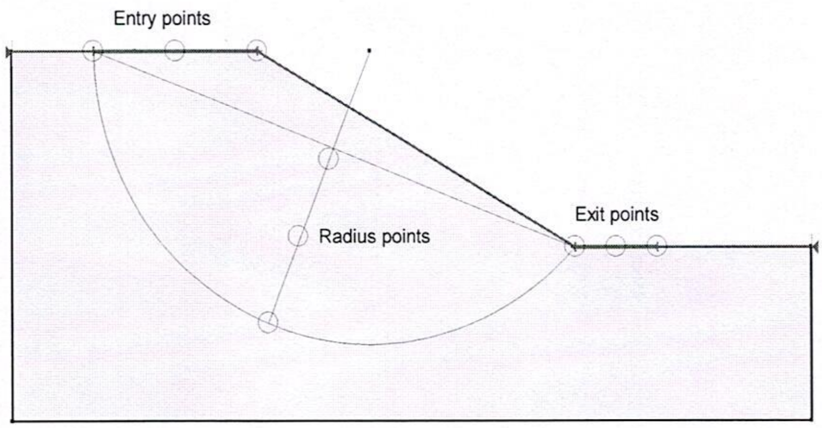


Figure 4-26 Schematic of the entry and exit slip surface

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.

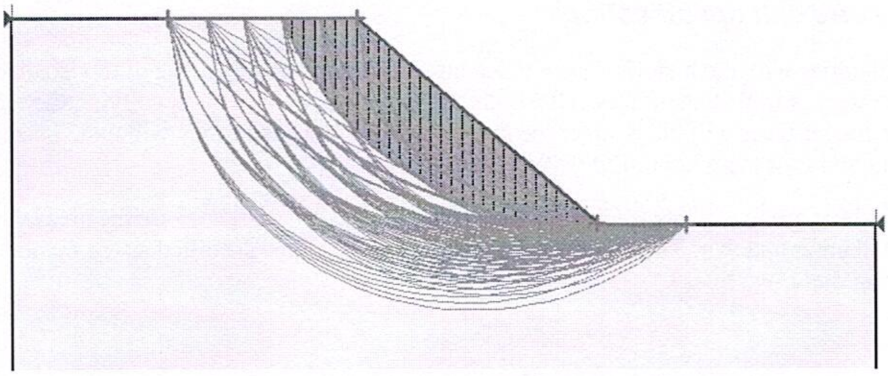


Figure 4-27 Display of all valid critical slip surfaces

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.

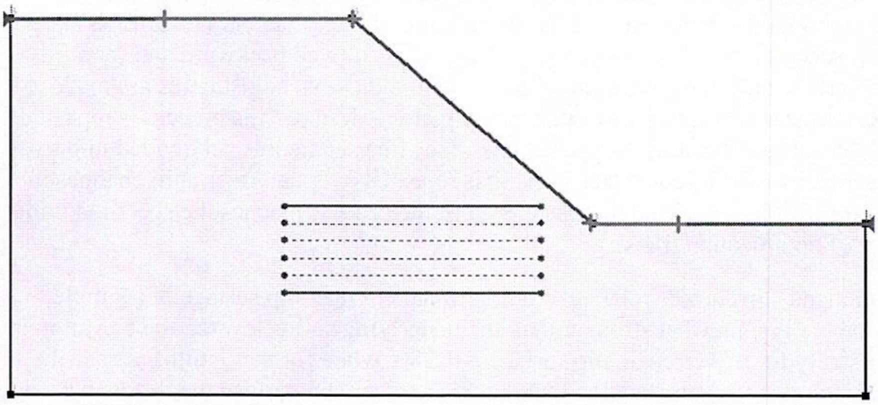


Figure 4-28 Entry and Exit slip surface with radius specification

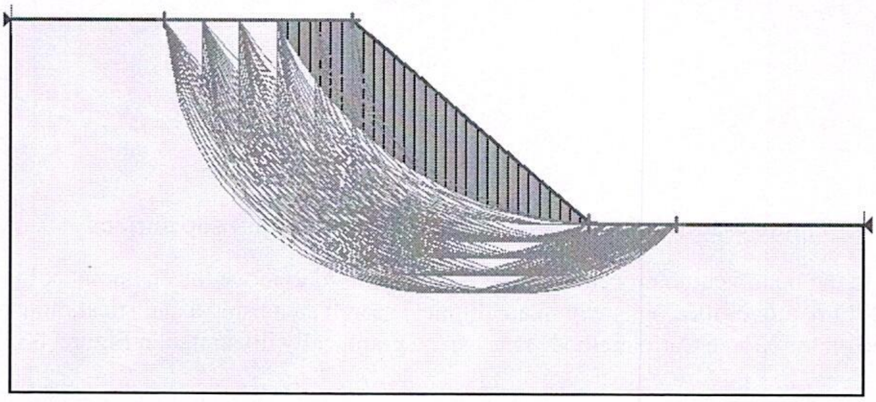


Figure 4-29 Display of all valid critical slip surfaces with radius specification

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.

The first step in the optimization process is to divide the slip surface into a number of straight line segments. The slip surface in essence becomes just like a Fully Specified slip surface. Next, the end points of the line segments are moved to probe the possibility of a lower safety factor. The process starts with the point where the slip surface enters ground surface. This point is moved backward and forward randomly along the ground surface until the lowest safety factor is found. Next, adjustments are made to the next point along the slip surface until again the lowest safety factor is found. This process is repeated for all the points along the slip surface. Next, the longest slip surface line segment is subdivided into two parts and a new point is inserted into the middle. This process is repeated over and over until changes in the computed safety factor are within a specified tolerance or until the process reaches the specified limits (e.g., the maximum number of optimization trials).

Figure 4-30 presents an optimized slip surface relative to a traditional circular slip surface of a simple slope. The material above the toe is somewhat stronger than the underlying soil below the toe elevation in this example. The factor of safety for this circular slip surface is 1.280, while for the optimized case the factor of safety is 1.240. Of interest is the observation that there is another slip surface that leads to a lower factor of safety than the one obtained for an assumed circular slip surface.

Figure 4-30 Traditional (Left) and Optimized (Right) slip surface

A key element in the optimization procedure is the technique used to move the end points of the line segments. SLOPE/W moves the points within an elliptical search area using a statistical random walk procedure based on the Monte Carlo method. This can be graphically illustrated in Figure 4-31.

Figure 4-31 Movement areas of points in the optimization procedure

As is readily evident, the optimization is an iterative procedure and consequently some limits and controls are required. These controls include defining a tolerance when comparing safety factor, the maximum number of optimization trials and the number of line segments. These controlling parameters are explained in the online help.

The solution in Figure 4-32 was discussed in the section on the Block method. The optimized solution is presented in Figure 4-33. The Block factor of safety is 1.744 while the Optimized factor of safety is 1.609.

Figure 4-32 Slip surface when using the Block method

Figure 4-33 Slip surface when Block method optimized

The above two examples discussed here illustrate that slip surfaces do exist that have a lower safety factor than the trial slips that can be created by assumed geometric parameters. This is the attraction of optimization technique. Moreover, the optimized shape, without sharp corners, is intuitively more realistic.

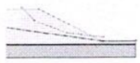
Figure 4-34 shows the difference of a fully specified slip and the slip surface after optimization for geometry with a thin weak layer. The fully specified slip surface does not follow the weak layer and results in a factor of safety of 1.2, but the optimized process was able to locate the weak layer and found a smaller factor of safety 0.96. The Optimization process is appealing in that the trial slip surface is based on soil properties to some extent. The technique will be biased towards weak layers or weak directions for anisotropic strengths.

Figure 4-34 Fully specified slip surface (Left) after optimization (Right)

The Optimization procedure is somewhat dependent on the starting slip surface position. The main reason for this is the available elliptical search area during the random walk procedure. Since the elliptical search area is based on the starting slip surface, it is not difficult to understand that the final optimized slip surface can be limited by a poor selection of the starting slip surface.

In the example that had a thin weak layer, depending on the starting position of the slip surface, the optimization process may not be able to locate the critical slip surface along the weak layer (Figure 4-35).

In SLOPE/W, the critical slip surface from a regular search is always used as the starting slip surface in the optimization process. In most cases, a smaller factor of safety can be obtained after the optimization.



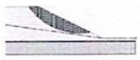


Figure 4-35 Fully specified slip surface (Left) after optimization (Right)

When a fully specified slip surface is used, any one of the points in the fully specified slip surface can be specified as "FIXED". The optimization process will not change the position of the "FIXED" point(s).

Please note that during the optimization stage, points within the elliptical search areas may move in all directions in an attempt to find a slip surface with lower factor of safety. Under normal conditions, the final optimized slip surface is "convex" in shape as shown in the preceeding figures. However, in some conditions with high external loads and large variations of material strength, the final optimzed slip surface may take a strange "concave" shape. The concave slip surface may give a lower factor of safety mathmatically, but the concave shape may not be physically admissible. In other words, you must judge the validity of an optimized solution not just based on the factor of safety but also based on the shape of the slip surface. SLOPE/W gives you the option to specify a maximum concave angles allowed for the upstream (driving side) and the downsteam (resisting side).

In a convex slip surface, the outside angle between two consecutive slices of the slip surface is larger than $180°$. By the same token, in a concave slip surface, the outside angle between two consecutive slices of the slip surface is smaller than $180°$.

4.8 *Effect of soil strength*

The fact that the position of the critical slip surface is dependent on the soil strength parameters is one of the most misunderstood and perplexing issues in slope stability analyzes. Coming to grips with this issue removes a lot of consternation associated with interpreting factor of safety calculations.

Purely frictional case

When the cohesion of a soil is specified as zero, the minimum factor of safety will always tend towards the infinite slope case where the factor of safety is,

$$F.S. = \frac{\tan\phi}{\tan\alpha}$$

where:

f = the soil friction angle

α = the inclination of the slope.

Figure 4-36 shows a typical situation. The critical slip surface is parallel and immediately next to the slope face. The slope inclination is 26.57 degrees and the friction angle is 30 degrees. The computed factor of safety is 1.203, which is just over the infinite slope factor of safety of 1.15.

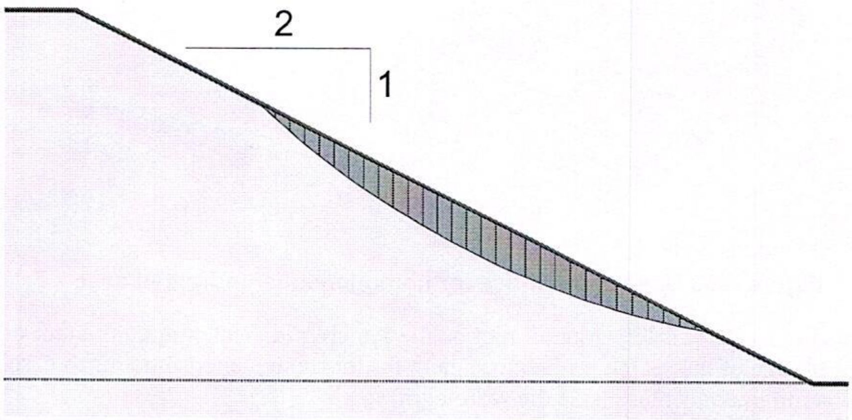


Figure 4-36 Shallow slip for purely frictional (c=0) case

The tendency to move towards the infinite slope case means the radius of the circle tends towards infinity. The minimum factor of safety is therefore usually on the edge of the grid of rotation centers. Figure 4-37 typifies this result. The minimum is right on the grid edge that represents the largest radius. Making the grid larger does not resolve the problem. The minimum occurs when the radius is at infinity, which cannot be geometrically specified. The Grid and Radius method appears to break down under these conditions, and the concept that the minimum factor of safety should be inside the grid is not achievable.

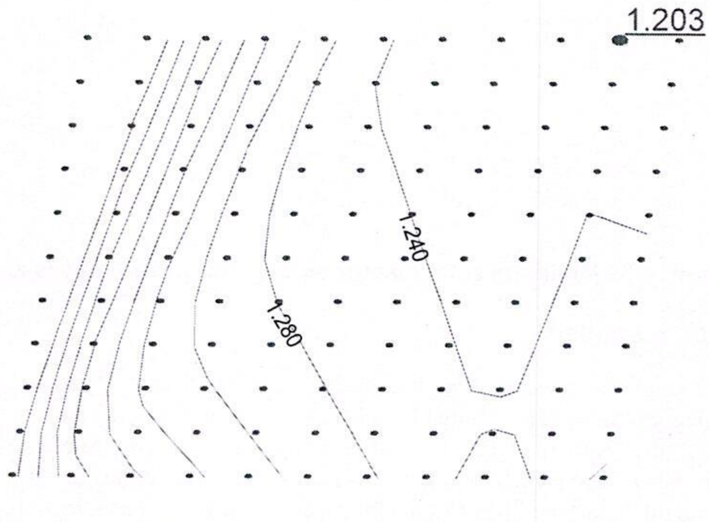


Figure 4-37 Minimum safety factor on edge of grid when c is zero

Undrained strength case

The opposite occurs when the soil strength is defined purely by a constant undrained strength; that is, ϕ is zero. In a case like this the critical slip surface will tend to go as deep as possible as shown in Figure 4-38. In this example the depth is controlled by the geometry. If the problem geometry was to be extended, the critical slip surface would go even deeper.

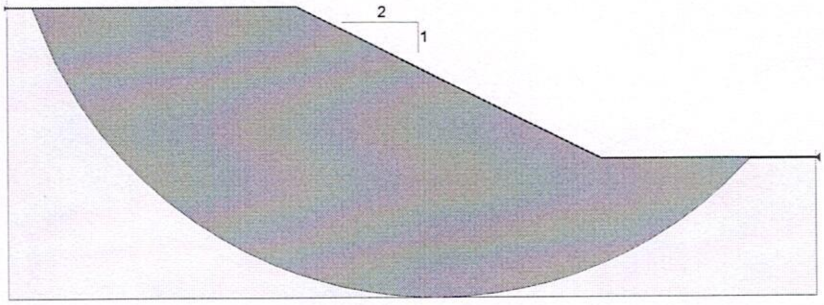


Figure 4-38 Deep slip surface for homogeneous undrained case

Figure 4-39 shows the factor of safety contour plot on the search grid. The minimum factor of safety is always on the lower edge of the search grid. Once again, for this homogenous undrained case it is not possible to define a minimum center inside the search grid.

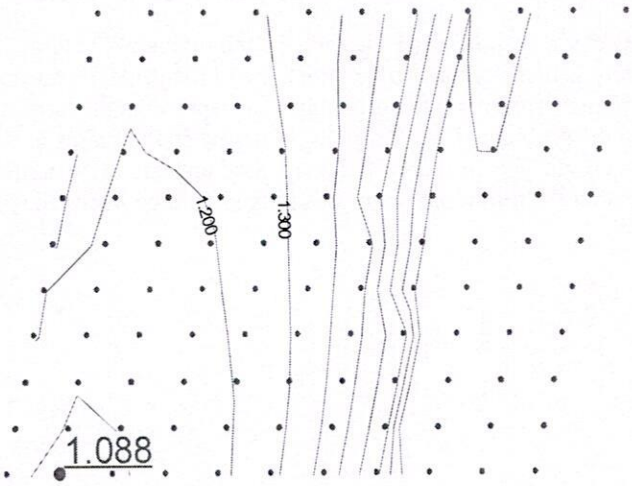


Figure 4-39 Minimum safety factor on edge of grid when ϕ is zero

Cause of unrealistic response

The reason for the unrealistic behavior in both the purely frictional case and the homogeneous undrained case is that the specified strengths are unrealistic. Seldom if ever, is the cohesion completely zero near the ground surface. Almost always there is a desiccated layer near the surface that has a higher strength or there a root-zone near the surface which manifests itself as an apparent cohesion. If the soil strength increases towards the ground surface, the critical slip surface will be at some depth in the slope.

The Shear Strength and Theory Chapter discuss how negative pore-water pressure (suction) increases the shear strength. This can be included in a SLOPE/W analysis by defining ϕ^b. If we make ϕ^b equal to 20 degrees, C equal to zero and ϕ equal to 30 degrees, then the position of the critical slip surface is as in Figure 4-40. Intuitively, this seems more realistic and is likely more consistent with field observations. Moreover, the minimum factor of safety is now inside the grid.

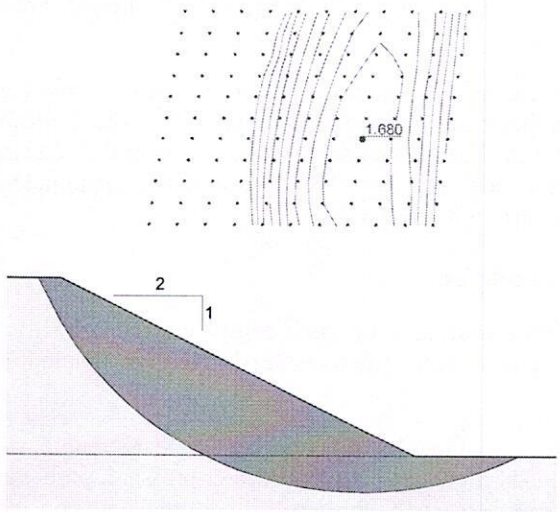


Figure 4-40 Critical slip surface when soil suction is considered

Figure 4-41 presents a plot of strength along the slip surface. Note the additional strength due to the suction and that the cohesion is zero everywhere.

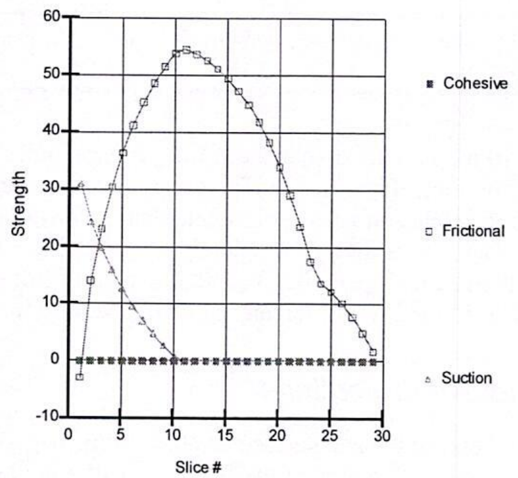


Figure 4-41 Strength components along the slip surface

The problem with the undrained case is that the undrained strength is the same everywhere. Once again, this is seldom, if ever, the case in the field. Usually there is some increase in strength with depth even for very soft soils. If the undrained strength is modeled more realistically with some increase with depth, the critical slip surface position no longer tends to go as deep as possible within the defined geometry. SLOPE/W has several soil models that can accommodate strength increase with depth.

Minimum depth

In SLOPE/W you can specify a minimum sliding mass depth. Say for example, that you specify a minimum depth of one meter. At least one slice within the potential sliding mass will then have a height greater or equal to the specified value. Any trial slips where all slice heights are less than the specified value are ignored.

The minimum depth parameter can be used to prevent SLOPE/W from analyzing very shallow slips. The slip surface with the minimum factor of safety will, however, still be the shallowest one analyzed and the lowest factor of safety will often still be on the edge of the rotation grid. As a result, this parameter does not really solve the underlying inherent problem. The minimum depth parameter should consequently only be used if the implications are fully understood.

Most realistic slip surface position

The most realistic position of the critical slip surface is computed when effective strength parameters are used and when the most realistic pore-water pressures are defined. This includes both positive and negative pore-water pressures.

Someone once said that the main issue in a stability analysis is shear strength, shear strength, shear strength. The main issue is actually more correctly pore-water pressure, pore-water pressure, pore-water pressure. Effective strength parameters can be fairly readily defined with considerable accuracy for most soils and rocks. This is, however, not always true for the pore-water pressure, particularly for the negative pore-water pressures. The difficulty with the negative pore-water pressures is that they vary with environmental conditions and consequentially vary with time. Therefore the stability can only be evaluated for a certain point in time.

> The most likely position of the critical slip surface will be computed when effective strength parameters are used together with realistic pore-water pressures.

Shallow slips near the ground surface actually do happen if the cohesion indeed goes to zero. This is why shallow slips often occur during periods of heavy rain. The precipitation causes the suction near the surface to go to zero and in turn the cohesion goes to zero, and then indeed shallow slips occur as would be predicted by SLOPE/W. Another case is that of completely dry sand. Placing completely dry sand from a point source will result in conical shaped pile of sand and the pile will grow by shallow slips on the surface exactly as predicted by SLOPE/W for a material with no cohesion.

4.9 Tension cracks and exit projections

The steepness of the entrance and exit of the slip surface can have some negative numerical consequences. At the crest, the normal at the base of the first slice will point away from the slice, indicating the presence of tension instead of compression. Generally, this is considered unrealistic, particularly for materials with little or no cohesion. Physically, it may suggest the presence of a tension crack. In the exit area, steep slip surface angles can sometimes cause numerical problems with the result that it is not possible to obtain a converged solution. Both of these difficulties can be controlled with specified angles.

Tension crack angle

In SLOPE/W, it is possible to specify a tension crack angle. What it means is that if the base of a slice in a trial slip exceeds the specified angle, SLOPE/W removes the slice from the analysis. This has the effect and appearance of a tension crack, as shown in Figure 4-42. In this case, the first slice on the left had a base inclination that exceeded the specified allowable; consequently the slice was ignored and replaced with a tension crack.

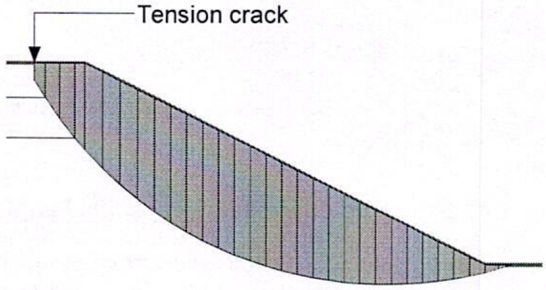


Figure 4-42 Tension crack based on specified inclination angle

Angles are specified in a counter-clockwise direction from the positive x-coordinate axis. In this example the tension crack angle was specified as 120 degrees. So any slice base inclination equal to or greater than 60 degrees from the horizontal is ignored.

The slip surface entrance point is analogous to an active earth pressure situation. Theoretically, the active earth pressure slip line is inclined at $(45 + \phi/2)$ degrees from the horizontal. While this is not strictly applicable, it is nonetheless a useful guide for specifying tension crack angles.

Constant tension crack depth

A constant tension crack depth can also be specified as part of the geometry, as discussed earlier.

Tension crack fluid pressures

Tension cracks can be assumed to be dry or filled with water. The extent to which the crack is full of water is expressed by a number between zero and 1.0. Zero means dry and 1.0 means completely full. If there is water in the tension crack, a hydrostatic force is applied to the side of the first element. The value of the lateral fluid force can always be verified by viewing the slice forces.

The idea of a significant fluid pressure in a tension crack is likely not very real. First of all, it is hard to imagine that a tension crack could hold water for any period of time. Secondly, the volume of water in a narrow tension crack is very small, so any slight lateral movement of the sliding mass would result in an immediately disappearance of the water and the associated lateral force. So considerable thought has to be given to whether a tension crack filled with water can actually exist and if it can exist, will the lateral hydraulic force remain when there is some as movement.

Toe projection

As noted earlier, steep exit angles can sometimes cause numerical difficulties. To overcome these difficulties, the steepness of the exit can be controlled with a specified angle, as illustrated in Figure 4-43. If the slice base has an inclination greater than the specified angle, SLOPE/W reforms the trial slip surface along a projection at the specified angle. Note how, in Figure 4-43, the curvature of the slip surface transforms into a straight line in the exit area.

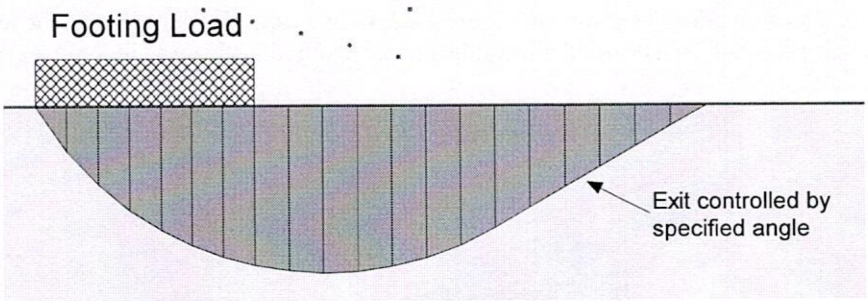


Figure 4-43 Exit angle controlled by specified angle

The toe area of a sliding mass is somewhat analogous to passive earth pressure conditions. In the example in Figure 4-43 the toe area is being pushed up and to the right just in a passive earth pressure case. Theoretically, the inclination of the passive slip line is at an angle of $(45 - \phi/2)$. This can be used as a guide when specifying this exit projection angle.

4.10 Physical admissibility

A consequence of the procedures used to generate trial slip surfaces, is that trial slip surfaces are sometimes formed that are not physically admissible; that is, they cannot exist in reality, or movement cannot possibly take place along the trial slip surface. Fortunately, in many cases it is not possible to obtain a solution for a physically inadmissible trial slip surface due to lack of convergence. Unfortunately, sometimes factors of safety are computed and displayed for cases where it is highly improbable that the potential sliding mass can slide or rotate as would be dictated by the trial slip surface.

This issue is complicated by the fact that there are no firm criteria to mathematically judge physical inadmissibility. SLOPE/W has some general rules that prevent some unreal cases like, for example, the inclination of the slip surface exit angle. If the slip surface exit is too steep, the results can become unrealistic and so the exit angle is arbitrarily limited to a maximum value. It is, however, not possible to develop similar rules for all potentially inadmissible cases. Consequently, it is necessary for the analyst to make this judgment. While performing limit equilibrium stability analyses, you should constantly mentally ask the question, can the critical trial slips actually exist in reality? If the answer is no, then the computed results should not be relied on in practice.

Some of the more common inadmissible situations are when the slip surface enters the ground at a steep angle and then exits at a steep angle with a relatively short lateral segment as illustrated in Figure 4-44. Described another way, the situation is problematic when the steep enter and exit segments are longer than the lateral segment of the slip surface. The problem is further complicated by very sharp breaks or corners on the trial slip surface. For the example in Figure 4-44 it is not possible to compute a Spencer or Morgenstern-Price factor of safety.

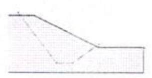


Figure 4-44 An example of a physically inadmissible slip surface

Another example of physical inadmissibility is when a very strong material overlies a very weak material. In the extreme case, if the weak material has essentially no strength, then the upper high strength material needs to sustain tensile stresses for the slope to remain stable. In reality, the soil cannot sustain tensile stresses. Mathematically, this manifests itself in lack of convergence. In other words, the model attempts to represent something that cannot exist in reality.

Sometimes it can be useful to assess the problem in a reverse direction. Instead of finding a factor of safety, the objective is to find the lowest strength of the weak material that will give a factor of safety equal to 1.0; that is, what is the lowest strength to maintain stability? Then the lowest strength required to maintain stability can be compared with the actual shear available. If the actual strength is less than what is required, then the slope will of course be unstable.

As a broad observation, convergence difficulties are often encountered when the model is beyond the point of limiting equilibrium or the sliding mode is physically inadmissible.

In the end, it is vital to remember that while SLOPE/W is a very powerful analytical tool, it is you who must provide the engineering judgment.

4.11 Invalid slip surfaces and factors of safety

A typical analysis may involve many trial slip surfaces; however, some of the slip surfaces may not have a valid solution. In such cases, a factor of safety with a value ranging from 983 - 999 is stored. It is important to realize that these values are not really factors of safety; they actually represent different error conditions of the particular trial slip surface.

The invalid slip surface may be due to convergence difficulties, in which a 999 is stored instead of the real factor of safety. Quite often, the invalid slip surface is also due to the position of the trial slip surface, the position of the grid center in a grid and radius, the pressure line definition, the direction of the sliding mass, the thickness of the sliding mass and overhanging ground surface etc. Although, the Verify feature in SLOPE/W attempts to identify these conditions before the actual computation, many of these conditions can only be detected during the computation inside the solver. In such cases, the solver outputs a factor of safety error code instead of the true factor of safety. SLOPE/W RESULT interprets the error conditions and displays a message concerning the error when you attempt to view the invalid slip surface using the Draw Slip Surfaces command.

The following summarizes the various error conditions:

983 – Slip Surface encounters missing stresses at the slice base center. This is not allowed in SLOPE/W. This happens when finite element stresses are used in the stability analysis and if the slip surface is sliding inside the interface elements defined with a "Slip surface" material model in SIGMA/W. The "Slip surface" material model does not compute any stresses. The work around is to limit the slip surface from sliding inside the interface elements, or to use an "Elastic-Plastic" material model for the interface elements instead of the "Slip surface" material model.

984 – Slip Surface encounters an air gap or vertical / overhanging bedrock region (Figure 4-45). This happens when adjacent regions are not connected properly or when a slip surface goimg through a vertical or overhanging bedrock. This causes the slip surface to be discontinous which is not allowed in SLOPE/W.

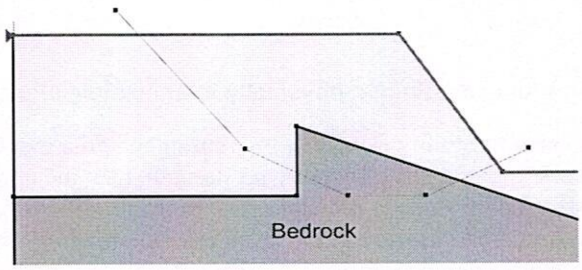


Figure 4-45 Slip surface intersecting an overhanging or vertical bedrock

985 – Overlapping Pressure lines exist. This happens when multiple pressure lines are defined at the same x-coordinate above the ground surface. This is not allowed in SLOPE/W.

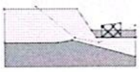


Figure 4-46 Slip surface intersecting a pressure line inside a zero strength material

987 - Slip surface inside a region with an internal pressure line (**Error! Reference source not found.**). T his happens when a pressure line is defined below the ground surface. A pressure line must be defined above the ground surface to have the loading handled properly. A pressure line defined below the ground surface is intuitively impossible and is therefore not allowed in SLOPE/W.

988 - Slip surface does not contain any material with strength. This is not allowed in SLOPE/W. This happens when the entire slip surface is inside material region with no material strength model defined.

990 - Slip surface does not intersect the ground surface line. This happens when there is problem in the trial slip surface. For example if a fully specified slip surface does not cut through the ground surface line. No slip surface can be generated.

991 - Slip surface center defined below the slip surface exit points. This results in a slice with base angle larger than 90 degrees. This is not allowed in SLOPE/W.

992 - Slip surface cannot be generated (Figure 4-47). This happens whenever there is a problem in generating a trial slip surface. There may be problems in finding the ground surface line or finding the slip surface intersecting points with the ground surface. This also happens with an overhanging slip surface or when a slip surface is trying to undercut itself. No factor of safety can be computed when a slip surface cannot be generated.

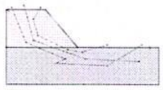


Figure 4-47 Slip surface cannot be generated

993 - Slip surface is too shallow (Figure 4-48). This happens when the thickness of all slices are smaller than the specified minimum slip surfaces thickness. In a purely frictional material, the critical slip surface tends to develop on the shallow ground surface where the normal force is small and the shear strength is low. Although this is theoretically correct and physically admissible, this shallow critical slip surface may not be of any interest to you. SLOPE/W allows you to set a minimum slip surface thickness so that any slip surface shallower than the specified limit will be considered invalid and will not included in the factor of safety calculation.

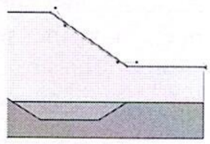


Figure 4-48 Slip surface with thickness less than specified minimum

994 - No intersecting point is obtained in the factor of safety versus lambda plot for the GLE formulation (Figure 4-49). This happens when there are convergence difficulties or when the specified lambda values are not sufficient for the factor of safety by moment and factor of safety by force to obtain an intersecting point on the factor of safety versus lambda plot.

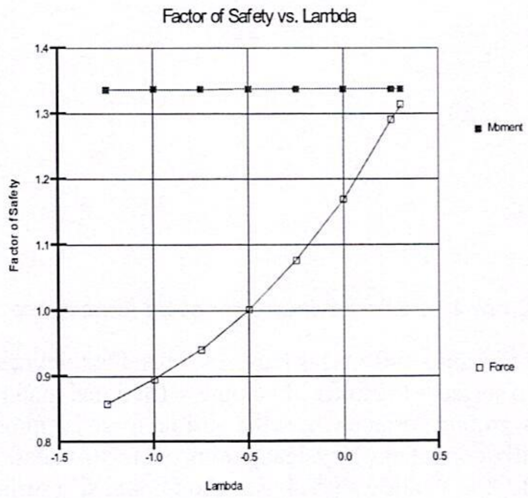


Figure 4-49 No intersecting point in a GLE formulation

995 - Slip surface could not be analyzed. This happens when all other conditions appear to be fine, but the solver encounters problems in the factor of safety computation. For example, the mobilized shear reistance is in the opposite direction due to a large negative normal force. This error message could also be related to extreme soil properties or large external forces relative to the sliding mass.

996 - Slip surface is not in the same direction as the specified direction of movement. This happens when the direction of movement is not set properly in SLOPE/W or in a complex geometry where a slip surface has an exit point higher than the entry point.

997 - Slip surface exit angle is too steep (M-alpha approaches zero). In limit equilibrium, the M-alpha value used in the computation of the normal force at the base of a slice is a function of the slice base angle and the material frictional angle. The normal force approaches infinity when M-alpha approaches zero. This is not allowed in SLOPE/W. This happens when a frictional mterial is used and when the exit angle of a slip surface is too steep (usually larger than 45°). Please refer to the "M-alpha value" discussion in the Theory chapter of the book for details.

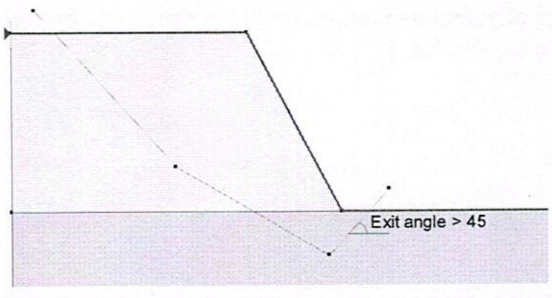


Figure 4-50 Slip surface with exit angle larger than 45 degrees

998 - Slip surface enter or exit beyond the slip surface limit. This happens when the slip surface extends beyond the specified slip surface limits (Figure 4-51). Both of the fully specified slip surfaces in the figure below have at least one exit or entry point beyond the slip surface limits.

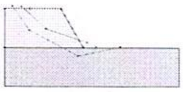


Figure 4-51 Slip surface enter and exit beyond the limits

999 - Slip surface does not have a converged solution. This happens when the solution for the slip surface does not converge. SLOPE/W uses an iterative procedure to solve the nonlinear factor of safety equation until the factor of safety converges within a specified tolerance. The convergence difficulties may be due to conditions with unreasonable soil strength properties, unreasonably large concentrated point loads or reinforcement loads, unreasonable seismic coefficient, unreasonable pore water pressure etc. By default, SLOPE/W uses a convergence tolerance of 0.01. While this tolerance is fine for most situations, you may like to relax this tolerance in order to obtain a solution when modeling extreme conditions.

For simplicity, the fully specified slip surface is used to illustrate the various problems with slip surfaces and geometry, however, the same situations would apply to other types of slip surface methods. In a slope stability analysis, it is quite common that some of the trial slip surfaces are invalid especially when using a grid and radius slip surface where the search grid is large and the search radius is long relative to the overall slope. It simply means that many trial slip surfaces are entering or exiting beyond the limits of the slope. Most likely, these invalid slip surfaces are of little interest to you and it is very unlikely that these invalid slip surfaces will be the most critical slip surfaces of the slope. You may choose to ignore these invalid slip surfaces, or you may like to better control the position of the search grid and radius to eliminate these invalid slip surfaces. The Entry and Exit slip surface method is much easier in controlling the position of the trial slip surfaces.

4.12 Concluding remarks

As noted in the introduction, finding the position of the critical slip surface requires considerable guidance from the analyst. SLOPE/W can compute the factors of safety for many trials very quickly, but in the end, it is up to the analyst to judge the results. Assuming that SLOPE/W can judge the results better than what you as the engineer can do is a perilous attitude. The SLOPE/W results must always be judged in context of what can exist in reality.