SLOPE STABILITY (LIMIT EQUILIBRIUM) ANALYSIS (28)

I Main Topics

A Role of slope stability analysis in 4-step procedure

B General procedure for slope stability (limit equilibrium) analyses

C Factor of safety

D Three main types of limit equilibrium analyses

E Method of slices

F Effect of flow parallel to a slope on water pressure

II Role of slope stability analysis in 4-step procedure

A Purpose: an evaluation to aid in assessing whether and where a slope is stable or unstable, and to aid in assessing the associated risk

B Should account for field characterization of the geology and hydrology

C Numerical calculations alone do not constitute an adequate stability analysis

D Focus should be on the effect of various conditions that promote slope failure and not on blind adherence to the numerical results

III General procedure for numerical slope stability analyses

A Short version

1 Postulate slip mechanism (failure criterion and failure geometry)

2 Calculate total shearing resistance (strength or moment) by method of statics

3 Calculate total driving stress (or moment) by method of statics

4 Find lowest factor of safety by iteration if failure surface is not known

III General procedure for numerical slope stability analyses

B Long version

1 Determine geometry of potential slide mass, potential failure surface(s), and identify other possible key factors

2 Decide on appropriate type of stability analysis and failure criteria

3 Calculate the static vertical force due to the weight of the block

III General procedure for numerical slope stability analyses

B Long version

4 Determine the static components of force perpendicular (normal) to the potential slip surface and the driving force parallel to the potential slip surface. Calculate the driving moment if need be.

5 If the slide material is saturated, calculate the pore pressure and then calculate the effective normal stress acting on the potential slip surface (divide the appropriate force by the area of the potential slip surface).

6 Consider the effect of flowing groundwater

III General procedure for numerical slope stability analyses

7 Calculate the resisting stress using the effective normal stress

8 Calculate the resisting force by multiplying the resisting stress by the area of the potential rupture surface (or calculate the resisting moment by multiplying the appropriate shear strength by the appropriate lever arm)

9 Calculate the factor of safety by dividing the resisting force (moment) by the driving force (moment)

10 Test sensitivity of results (consider different failure surfaces, strengths, dynamic effects, etc.)

III Factor of safety (F.S.)

A Gauge to how much the shear strength model parameters must be reduced to bring slope into limiting equilibrium (verge of failure) along a given slip surface

B $F.S. = \dfrac{\sum \text{Resisting forces}}{\sum \text{Shear driving forces}}$ or $F.S. = \dfrac{\sum \text{Resisting moments}}{\sum \text{Driving moments}}$

C Moment = Force x lever arm

III Factor of safety (F.S.)

D Key Points

1 The factor of safety is not a measure of stability at a point; it is a number that represents averaging
2 The factor of safety cannot be measured in the field
3 The factor of safety is model-dependent
4 A factor of safety substantially greater than unity is desirable owing to uncertainty and variability

IV Factor of safety

E Words of caution from authorities

1. "The analysis of a rock slope in terms of a factor of safety is a subordinate activity to achieving a clear understanding of the controlling geology and water-pressure configuration." Morgenstern and Sangrey (SR 176, p. 165-166)
2. "The author has found their indiscriminate use misleading and sometimes unsafe... The computed minimum [factor of safety] is often unrealistic or geometrically impossible, diverting attention from the real answer." Sowers (1979, p. 579)
3. "Most mathematical models and computational abilities are more precise than the ability to determine reliable values for the properties and parameters needed for their application." (Rahn, 1996, p. 187)

III Factor of safety (F.S.)

F Interpretation of factor of safety (Sowers, 1979, p. 587)

Factor of Safety	Significance
Less than 1.0	Unsafe
1.0 - 1.2	Questionable safety
1.3 - 1.4	Satisfactory for cuts, fills; questionable for dams
1.5 - 1.75	Safe for dams

* This interpretation accounts for risk by considering the cost of failure

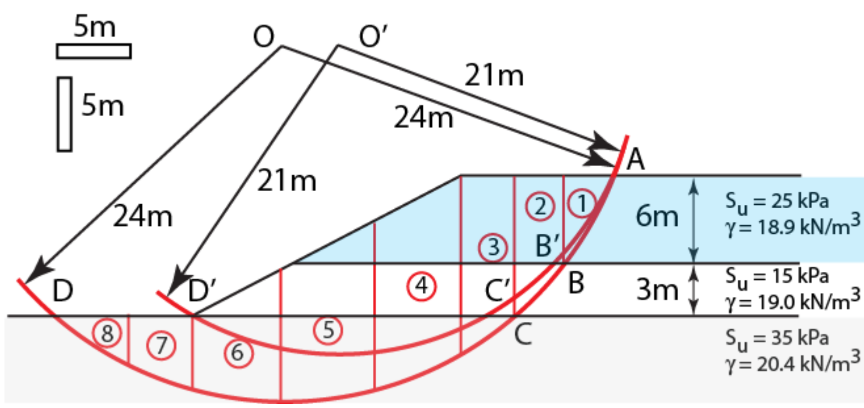
IV Three main types of limit equilibrium analyses

A Planar slip surface (uses resisting/driving forces)

B Circular slip surface (uses resisting/driving moments): Rahn, p. 183

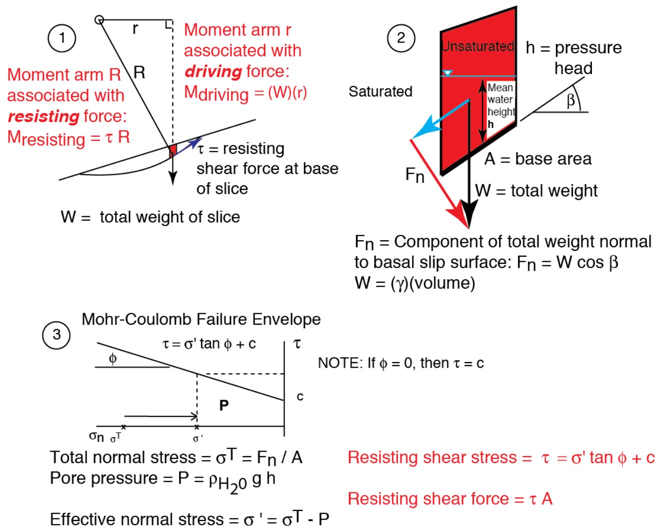
C Method of slices (uses resisting/driving moments): Rahn, p. 184-186.

V Method of slices
Example problem (from Rahn, 1996)



S_u = undrained shear strength; γ = unit weight (specific weight)

Method of slices

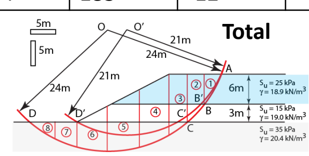


Method of slices (surface ABCD)

- Driving Moment

Slice	Unit thickness (m)	Width (m)	Height (m)	Specific weight (kN/m³)	Force (kN)	Lever arm (m)	Driving moment (kN•m)
1	1	3	3	18.9	170	20	3,400
2	1	3	7.5	18.9	425	17.5	7,442
3	1	3.5	10.5	19.1	703	14	9,842
4	1	6	12	19.4	1400	9	12,600
5	1	6	10	19.7	1182	3	3,546
6	1	6	7	20.1	844	-3	-2,532
7	1	4	4	20.4	326	-8	-2,608
8	1	6	1.5	20.4	183	-12	-2,196

Total 29,494

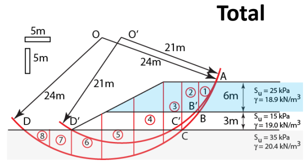


Method of slices (surface ABCD)

- Resisting Moment

Slice	Unit thickness (m)	Radius (m)	Subtended angle (°)	Subtended angle (radians)	Arc length (m)	Strength (kN/m^2)	Resisting moment (kN•m)
1	1	24	17.5	0.305432619	7.33	25	4398
2	1	24	10.5	0.183259571	4.40	15	1583
3	1	24	10.5	0.183259571	4.40	35	3695
4	1	24	15	0.261799388	6.28	35	5278
5	1	24	15	0.261799388	6.28	35	5278
6	1	24	14.5	0.253072742	6.07	35	5102
7	1	24	11.5	0.200712864	4.82	35	4046
8	1	24	15.5	0.270526034	6.49	35	5454
						Total	34,834

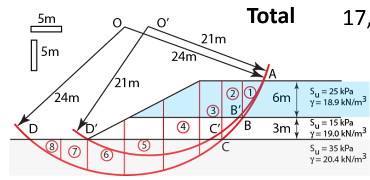
F.S. = 34,834/29,441 = 1.18



Method of slices (surface AB'C'D')

- Driving Moment

Slice	Unit thickness (m)	Width (m)	Height (m)	Specific weight (kN/m^3)	Force (kN)	Lever arm (m)	Driving moment (kN•m)
1	1	3	2.75	18.9	156	16	2495
2	1	3	7.5	18.9	425	15	6379
3	1	3.5	8.5	18.9	562	9	5060
4	1	6	8.5	19	969	5.5	5330
5	1	6	7	19	798	0	0
6	1	6	2.5	19.7	296	-5.5	-1625
						Total	17,638

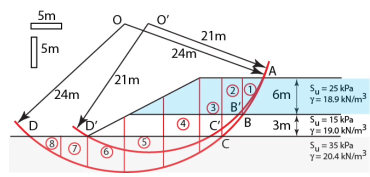


Method of slices (surface AB’C’D’)

- Resisting Moment

Slice	Unit thickness (m)	Radius (m)	Subtended angle (°)	Subtended angle (radians)	Arc length (m)	Strength (kN/m^2)	Resisting moment (kN•m)
1	1	21	18.5	0.32	6.78	25	3560
2	1	21	10.5	0.18	3.85	15	1212
3	1	21	13	0.23	4.76	35	3502
4	1	21	15.5	0.27	5.68	35	4176
5	1	21	17.5	0.31	6.41	35	4714
6	1	21	18	0.31	6.60	35	4849
						Total	22,013

F.S. = 22,013/17,638 = 1.25



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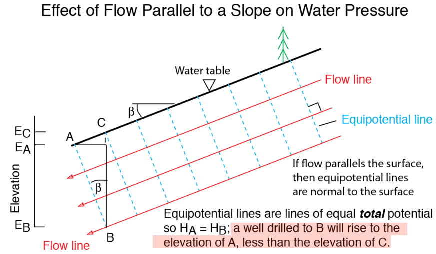
VI Effect of flow parallel to a slope on water pressure

- What is the pressure (P_B) at Pt. B?
- $P_B = (\rho_{H20})(g)\ h_{pressure(B)}$
- $h_{total} = h_{elevation} + h_{pressure}$
- $h_A = E_A + 0$
- $h_B = E_B + h_{pressure(B)}$
- Since $h_A = h_B$, $h_{pressure(B)} = E_A - E_B$
- By trigonometry of ΔABC

  $h_{pressure(B)} = E_A - E_B =$

  $= (E_C - E_B) \cos\beta \cos\beta$
- $P_B = (\rho_{H20})(g)\ (E_C - E_B) \cos\beta \cos\beta$
- This is the pressure that affects the effective stress at B.
- $h_{pressure(B)} < E_C - E_B$, so flow reduces the pressure at B

Effect of Flow Parallel to a Slope on Water Pressure



In example, the water table is along the ground surface
h = head

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References

- Rahn, P.H., 1996, Engineering geology: an environmental approach: Prentice Hall, Upper Saddle River, New Jersey, 657 p.
- Sowers, G.F., 1979, Introductory Soil Mechanics & Foundations: Geotechnical Engineering: Prentice Hall, Upper Saddle River, New Jersey, 640 p.
- Morgenstern, N.R., and Sangrey, D.A., 1978, Methods of stability analysis, in Schuster, R.L., and Krizek, R.J., eds., Landslides: Analysis and control: Washington, U.S. National Academy of Sciences, Transportation Research Board Special Report 176, p. 155-171.