OLD HOMEWORKS - Slope Stability Questions

G1. A landslide has occurred along a slip surface parallel to the ground surface which was inclined at 15^o to the horizontal. The slip surface is at a vertical depth of 4 m, and the length of the slip measured along the slope is 200 m. Water in the soil may be assumed to extend to the ground surface and to be flowing parallel to it. The bulk unit weight of the soil is 18.5 kN/m^3 .

(a) Working from first principles, calculate the value of ϕ' if c' is assumed as zero.

(b) What would have been the factor of safety if the soil had, in addition, $c' = 5$ kPa?

G2. A 30-degree slope is to be cut in sand having an angle of friction of 33^o and a unit weight of 17.5 kN/m^3. There is no water table in the sand, but at a depth of 16 m below the horizontal ground surface there is a soft clay layer with an undrained shear strength of 14 kPa. The toe of the slope will lie 12 m below the ground surface.

(a) Calculate the factor of safety of the slope against the possibility of a translational slide along the top of the clay.

(b) If the clay had a saturated unit weight of 16.5 kN/m^3, and the positions of the sand and clay in the above problem were interchanged, calculate the factor of safety of the slope using stability charts.

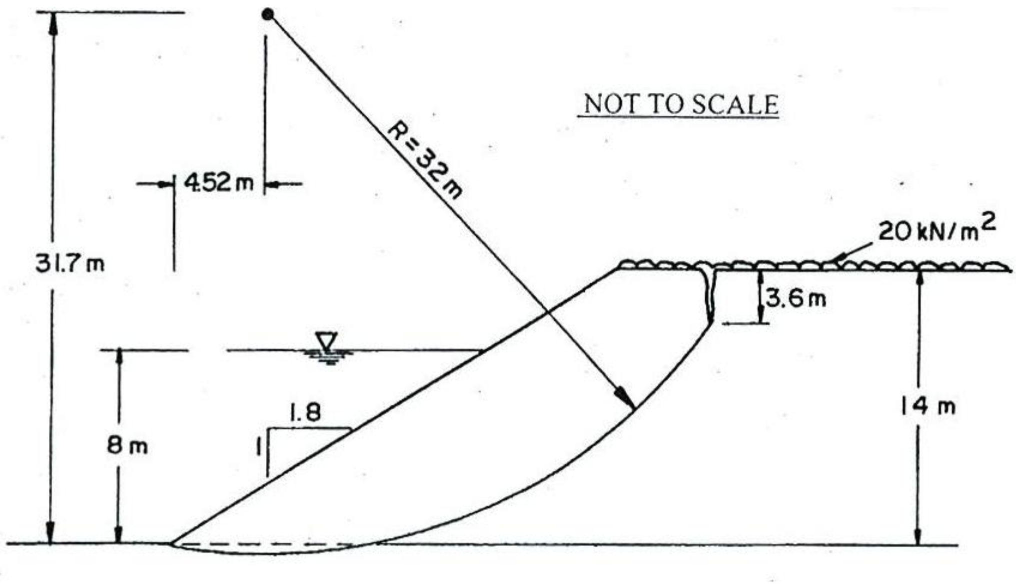
G3. A 14 m deep canal is to be cut through a saturated clay having an undrained shear strength of 40 kPa and bulk unit weight of 18 kN/m^3. By considering the slip circle shown, and assuming tension cracks up to a depth 3.6 m below the ground surface, calculate the short-term stability of the slope under the following conditions:

(a) Canal and tension cracks dry; no surcharge.

(b) Water of depth 8 m in the canal; tension cracks filled with rain water; no surcharge.

(c) A surcharge of 20 kN/m^2 applied uniformly at the ground surface in addition to condition (b), assuming this not to affect the depth of tension cracks.

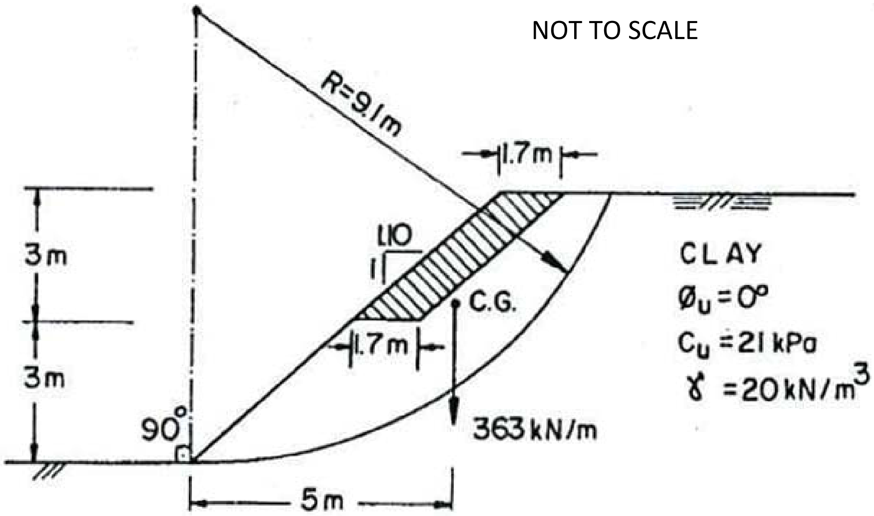
Calculate moments due to the weight of soil by dividing the sliding mass into six horizontal layers of suitable thickness.



G4. The figure below shows the details of a cutting to be made in a saturated clay with $\phi_u = 0$, $c_u = 21$ kN/m^2. For the given trial circle, calculate the short-term factor of safety against sliding for the following conditions:

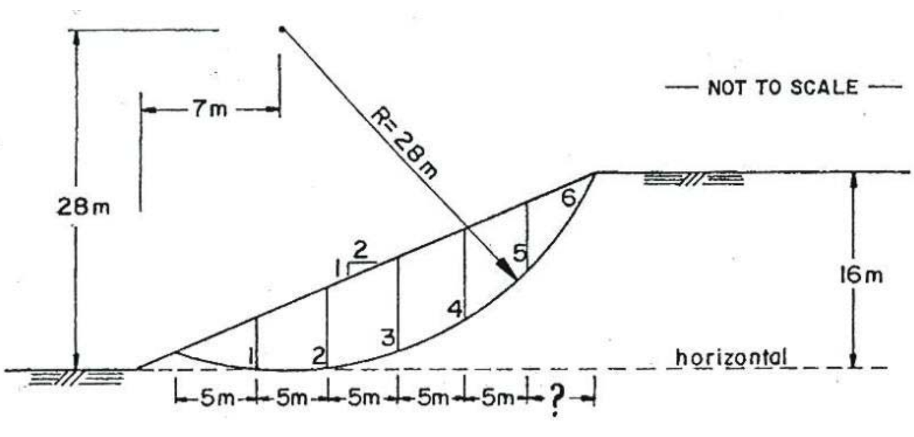
(a) Slope is cut at a uniform inclination of 1:1.10, and the weight of the sliding mass is 363 kN/m.

(b) Same as (a) but with the shaded portion removed.



G5. The figure below shows the section of the slope on the west side of the METU stadium, before it was paved. Piezometric head of water at the mid-point of the base of each slice has been measured as follows:

Slice No :	1	2	3	4	5	6
Head of water (m) :	0.5	2.3	3.1	3.0	1.4	0.0



The average of tests on undisturbed samples of soil taken at various points along the potential failure surface gave the following values for the soil properties:

$c' = 25$ kPa; $\phi' = 29^o$; $\gamma = 18.7$ kN/m^3.

Neglecting tension cracks, and assuming the centre of gravity of each slice to coincide with the mid-height, calculate the factor of safety, F_s, against failure by sliding along the surface shown, using

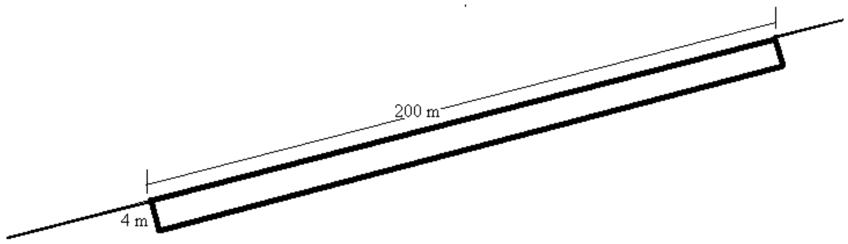
$$F_S = \frac{1}{\sum W \sin\alpha} \sum \left[c'l + (W\cos\alpha - ul)\tan\phi' \right]$$

where, for any slice, α = average angle between base and the horizontal ; W = weight; l = length of base; u = average pore pressure at base.

State whether a more rigorous method of analysis would result in a higher or lower value of F_s than that obtained here.

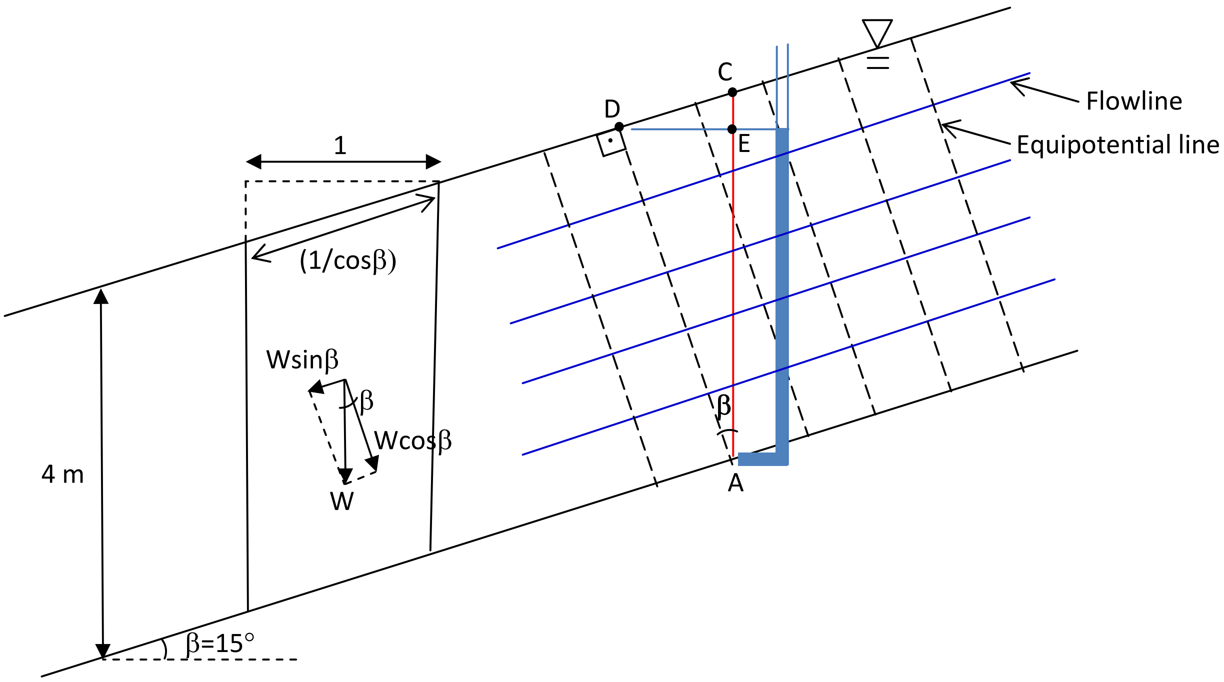
SOLUTIONS

G1)



Depth is small compared to length of sliding mass, so treat as infinite slope.

Consider a slice of unit width.



$$\frac{u}{\gamma_w} = |AE| = |AD|\cos\beta = (|AC|\cos\beta)\cos\beta = |AC|\cos^2\beta$$

$$u = \gamma_w(|AC|\cos^2\beta) = 9.8(4\times\cos^2\beta) = 39.2\cos^2\beta$$

a) $W = z\times1\times1\times\gamma = 4\times18.5 = 74$ kN/m (per meter because we consider 1 m into the page)

$$Total \quad normal \quad stress, \sigma = \frac{W\cos\beta}{Area} = \frac{W\cos\beta}{1/\cos\beta} = W\cos^2\beta = 74\cos^2 15° = 69.04 \quad kPa$$

$$Effective \quad normal \quad stress, \sigma' = \sigma - u = 74\cos^2\beta - 39.2\cos^2\beta = 34.8\cos^2 15° = 32.47 \quad kPa$$

$$Applied \quad shear \quad stress, \tau = \frac{W\sin\beta}{Area} = \frac{W\cos\beta}{1/\cos\beta} = W\sin\beta\cos\beta = 74\sin15°\cos15° = 18.5 \quad kPa$$

$$Available \quad shear \quad strength, \tau_f = c' + \sigma'\tan\phi' = 0 + 32.47\tan\phi'$$

$$At \quad failure, \tau = \tau_f \qquad 18.5 = 32.47\tan\phi' \qquad Therefore, \phi' = 29.67°$$

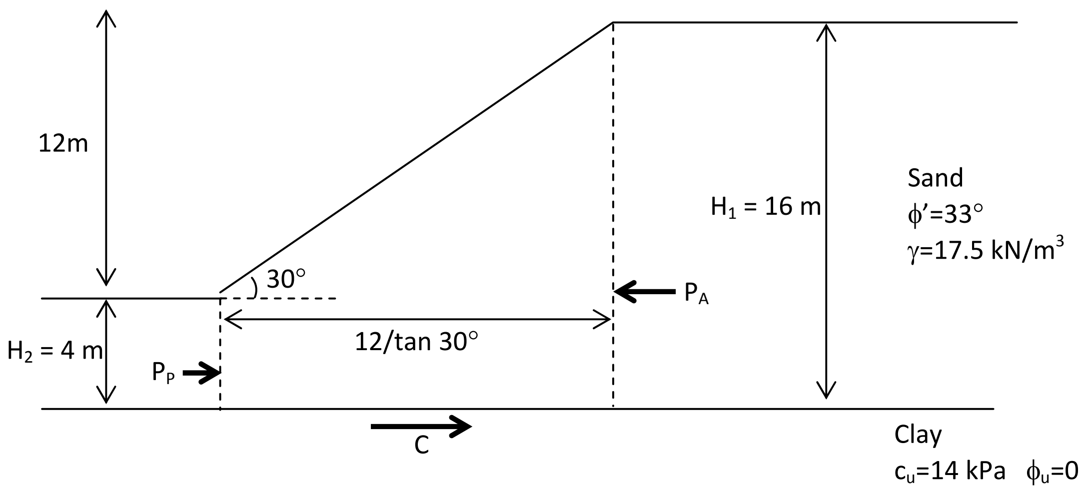
b) $If \quad c' = 5$ kPa, $\quad \tau_f = 5 + 32.47\tan(29.67) = 23.5 \quad kPa$

$\tau = 18.5 \quad kPa$

$$F.S. = \frac{\tau_f}{\tau} = \frac{23.5}{18.5} = 1.27$$

G2)

a.



$$K_a = \frac{1-\sin\phi'}{1+\sin\phi'} = 0.295 \qquad K_p = \frac{1+\sin\phi'}{1-\sin\phi'} = 3.392$$

$$F.S. = \frac{P_p + C}{P_a}$$

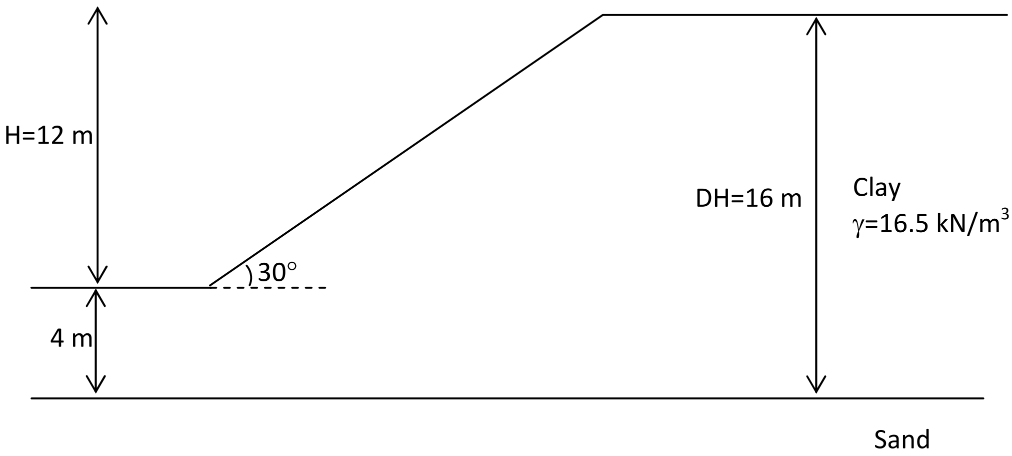
$$P_a = \frac{1}{2}K_a\gamma H_1^{\,2} = \frac{1}{2}(0.295)(17.5)(16^2) = 660.8kN/m$$

$$P_p = \frac{1}{2}K_p\gamma H_2^{\,2} = \frac{1}{2}(3.392)(17.5)(4^2) = 474.9kN/m$$

$$C = c_u(12/\tan 30°) = (14)(12/\tan 30°) = 291kN/m$$

$$F.S. = \frac{474.9+291}{660.8} = 1.16$$

b.



Using Taylor's stability chart

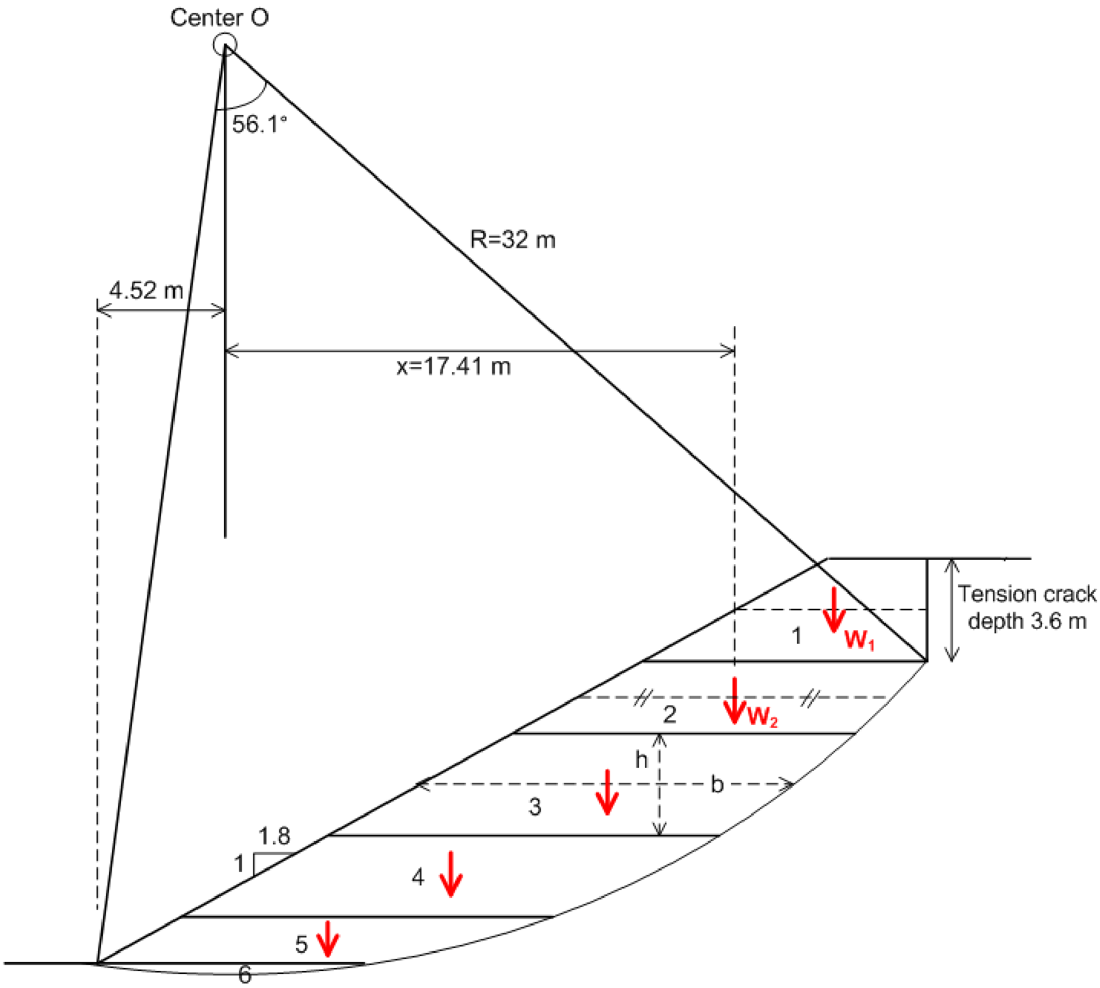
Depth Factor ; D=16/12=1.33

inclination, i = 30 degrees

Taylor's Stability Number from Figure, N = 0.158 (in stability number N equation, F is factor of safety) $F = \dfrac{c_u}{N\gamma H} = \dfrac{14}{(0.158)(16.5)(12)} = 0.45$ $\quad$ *Slope is UNSAFE*

G3) a) $$F.S.=\frac{R\sum(C_u \cdot l)}{\sum(W \cdot x)}$$

In order to find the weight of the sliding mass and its moment about center O accurately, it is better to divide the mass into pieces and find weight and moment of each of the piece. You can divide into any geometrical shape, but horizontal or vertical slices are convenient to use.



Slice No	Thickness h(m)	Mean Width b(m)	Area, A (m^2) A=h*b	Weight (kN/m) W=A*γ	Moment arm about O, x (m)	Moment (kN.m/m) M=W*x
1	3.60	6.47	23.29	419.26	20.67	8666.02
2	2.40	10.74	25.78	463.97	17.41	8077.68
3	3.60	12.73	45.83	824.90	13.00	10723.75
4	2.80	13.32	37.30	671.33	7.54	5061.81
5	1.60	11.48	18.37	330.62	2.66	879.46
6	-	-	-		-	0

∑Wx=33408.73

$$\theta = 56.1° \qquad \sum l = (\theta/180) \cdot \pi \cdot R = (56.1/180) \cdot \pi \cdot 32 = 31.33 \text{ m}$$

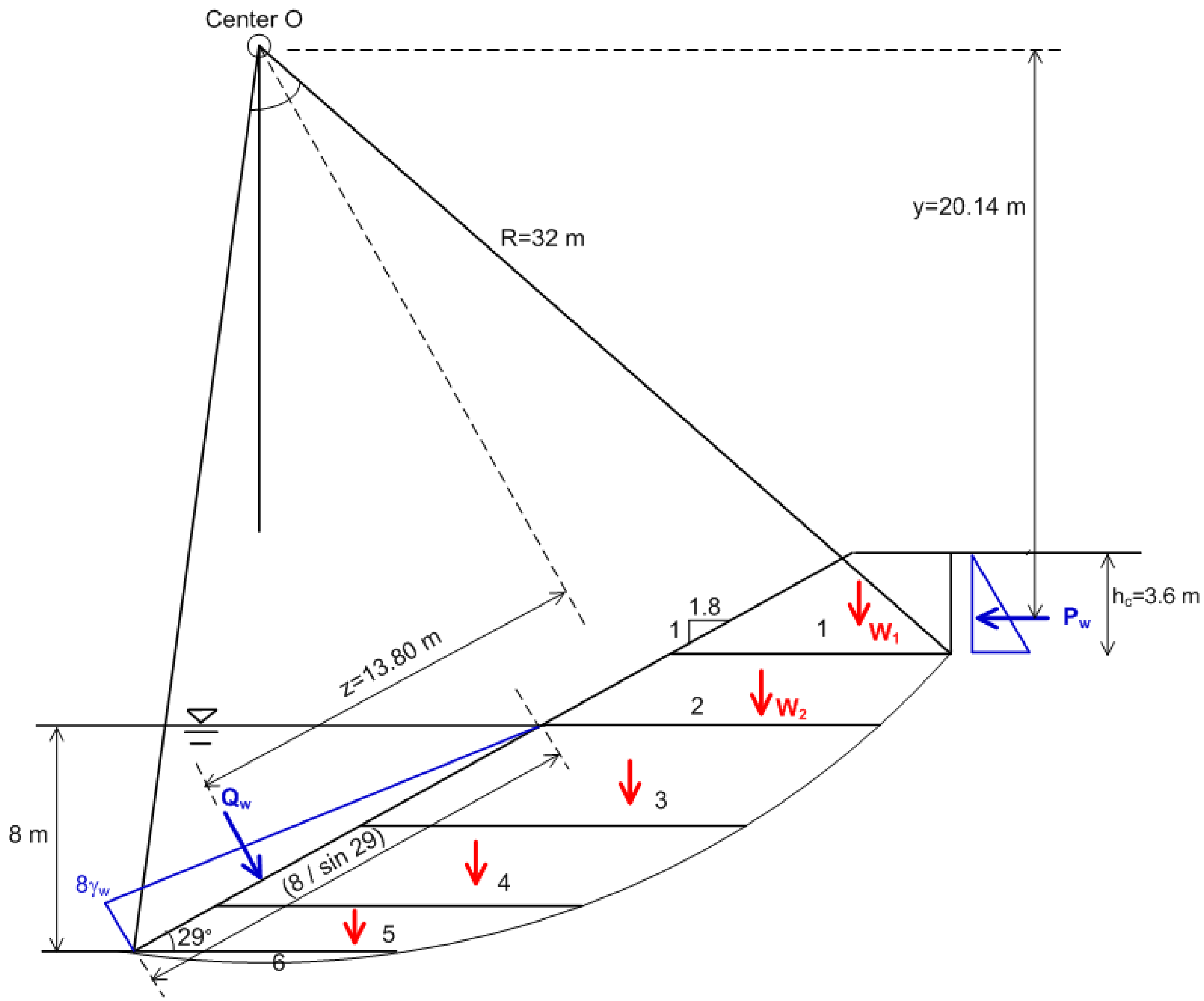
$$R \sum C_u \cdot l = (32)(40)(31.33) = 40102.40 \quad \text{kN} \cdot \text{m/m}$$

$$F.S. = \frac{R \sum (C_u \cdot l)}{\sum (W \cdot x)} = \frac{40102.40}{33408.73} = 1.20$$

b) Let;

P_w = Thrust of water in tension crack;
y = Moment Arm of P_w about O;

Q_w = Thrust of water on section AB of slope;
z = Moment Arm of Q_w about O.



$$P_w = \frac{1}{2}\gamma_w h_c^{\,2} = \frac{1}{2}(9.8)(3.6)^2 = 63.50 \text{ kN/m}, y = 20.14 \text{ m}$$

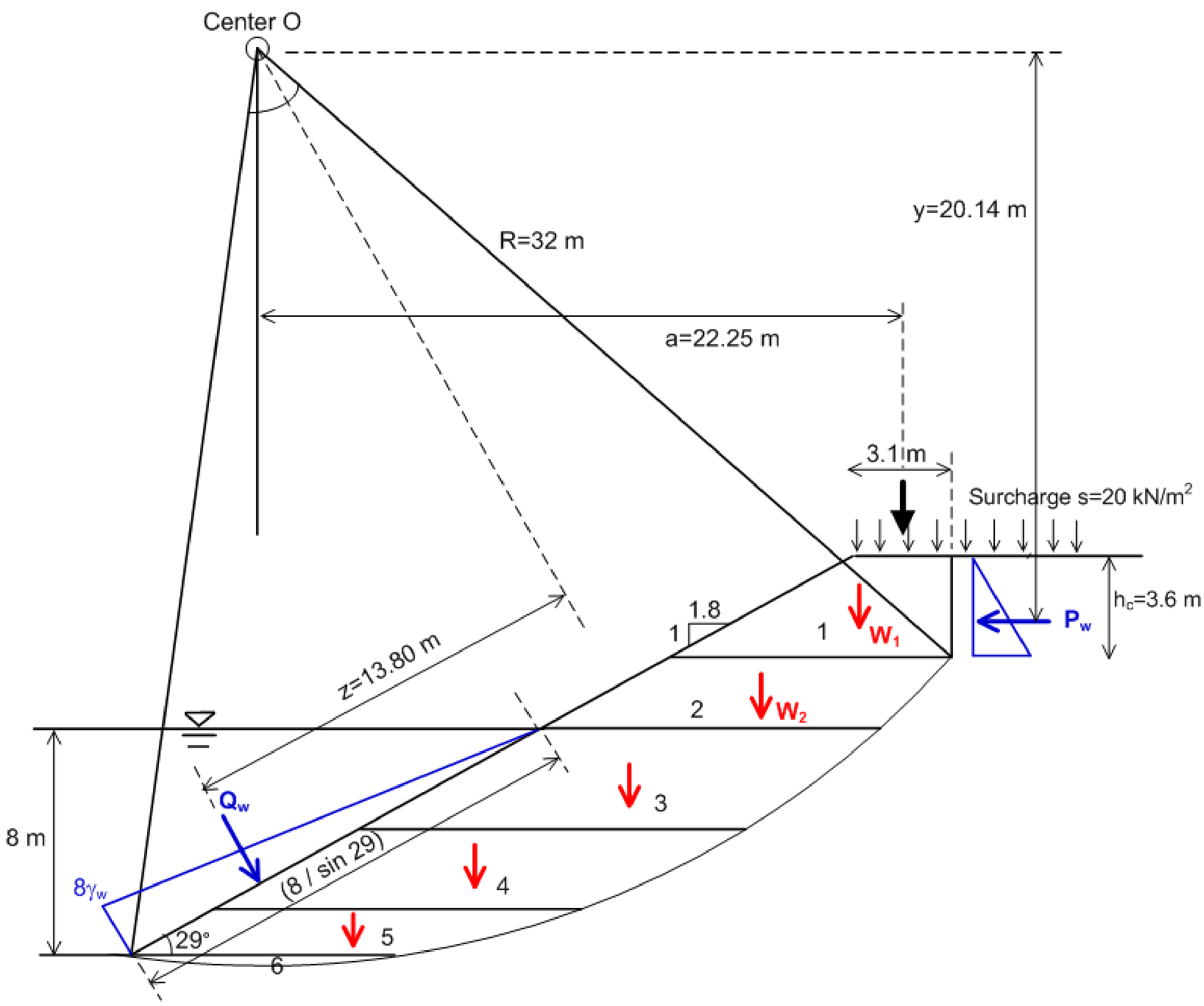
$$P_w * y = 1278.9 \quad \text{kN}\cdot\text{m/m}$$

$$Q_w = (8\gamma_w)\cdot(\frac{8}{\sin 29°})\cdot\frac{1}{2} = \frac{1}{2}\cdot\frac{(9.8)(8)^2}{\sin 29°} = 645.84 \text{ kN/m}, \; z = 13.80 \text{ m}$$

$$Q_w * z = 8912.59 \text{ kN}\cdot\text{m/m}$$

$$F.S. = \frac{R\sum(C_u \cdot l)}{\sum(W\cdot x) + P_w\cdot y - Q_w\cdot z} = \frac{40102.40}{33408.73 + 1278.9 - 8912.59} = 1.56$$

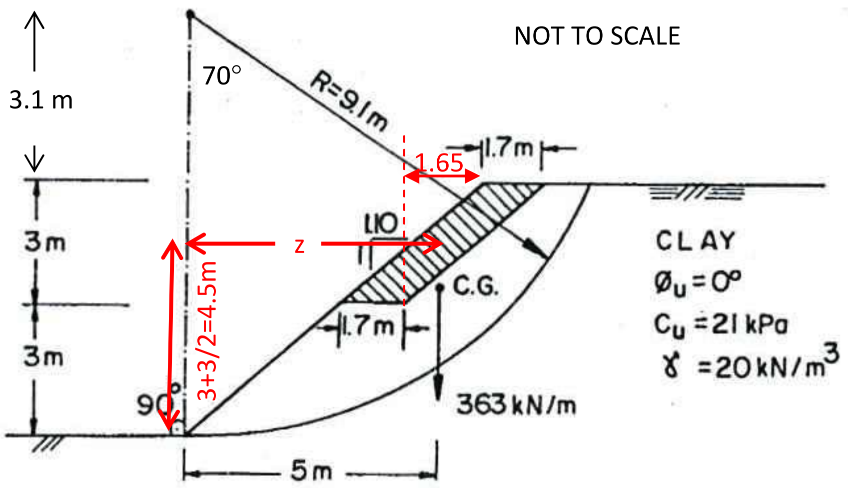
c)



$$\text{Additional disturbing moment}: \; s\cdot a = (20\cdot 3.1)\cdot(22.25) = 1379.5 \quad \text{kN.m/m}$$

$$F.S. = \frac{40102.40}{33408.73 + 1278.9 - 8912.59 + 1379.5} = 1.48$$

G4)



a) Disturbing moment,

$$M_d=(363)(5)=1815 \text{ kN.m/m}$$

Restoring moment,

$$M_r=C_u{*}R^2{*}\theta{*}(\pi/180)= (21)(9.1^2)(70)(\pi/180) = 2125 \text{ kN.m/m}$$

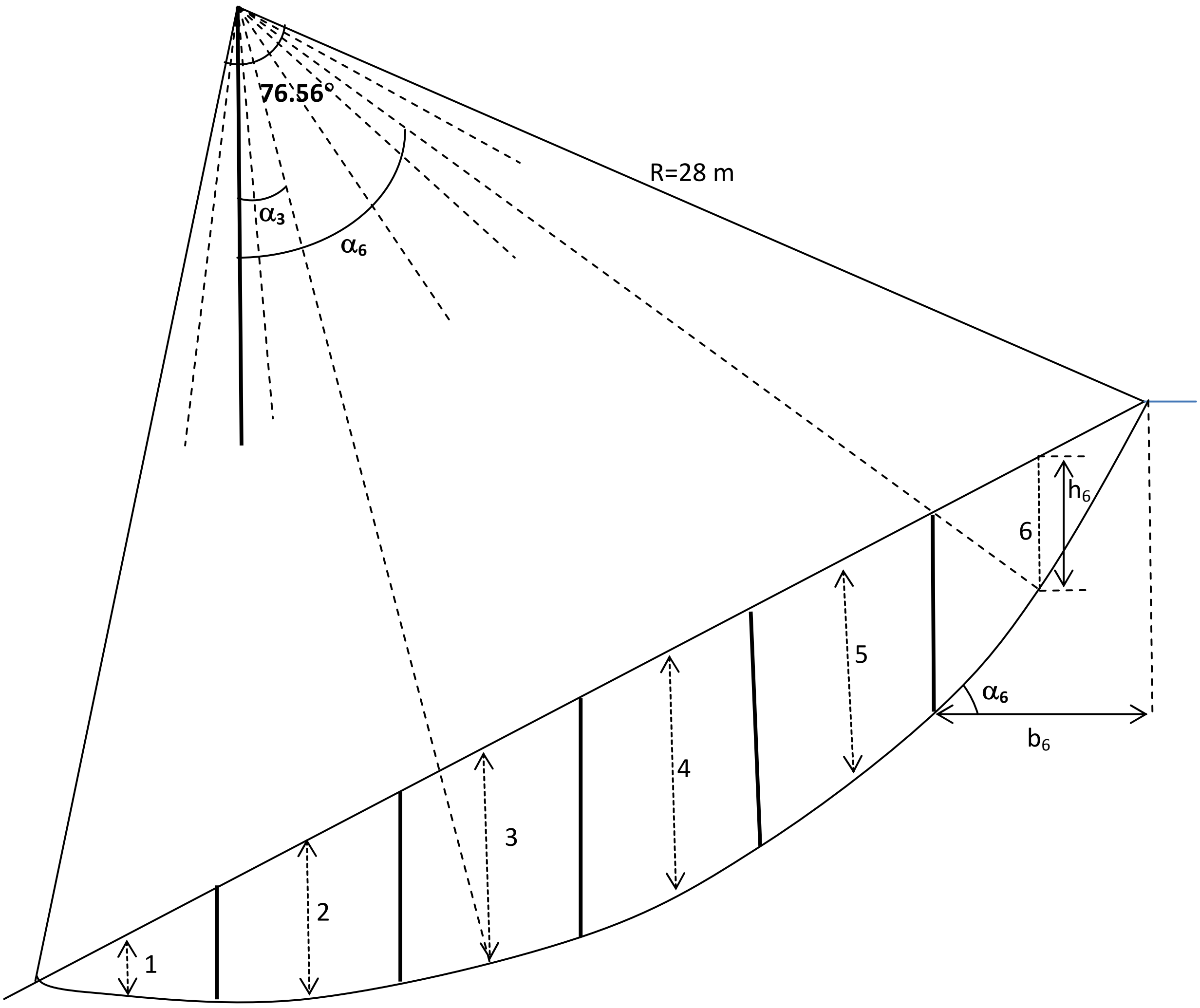
$$F.S. = \frac{M_r}{M_d} = \frac{2125}{1815} = 1.17$$

b) Area removed = (1.7)(3) = 5.1 m^2
Weight removed, ΔW = (5.1)(20) = 102 kN/m
Distance of center of gravity of ΔW from O, z = 1.1(3+3/2) + (1.65/2) = 5.8 m

Decrease in disturbing moment,
$\Delta M_d = \Delta W{*}z$= (102)(5.8) =591 kN.m/m

$$F.S. = \frac{M_r}{M_d - \Delta M_d} = \frac{2125}{1815-591} = 1.74$$

G5)



$$\tau = c' + \sigma' \tan\phi'$$

$$F.S. = \frac{\sum c'l + (W\cos\alpha - ul)\tan\phi'}{\sum W\sin\alpha}$$

Since there is only one type of soil (c' and ϕ' are constant), we can take the relevant terms outside the summation signs.

$$F.S. = \frac{c'\sum l + (\sum W\cos\alpha - \sum ul)\tan\phi'}{\sum W\sin\alpha}$$

where

$$\sum l = \frac{\pi R\theta}{180} = \frac{\pi(28)(76.5)}{180} = 37.41m$$

$$\tan\phi' = \tan 29° = 0.554$$

Slice No	b(m)	h(m)	W (kN/m)	α (degree)	Wsinα	cosα	Wcosα	ℓ =b/cosα	u/γ_w (given)	u (kPa)	ul
1	5	1.66	155.2	-6.75	-18	0.9931	154	5.03	0.5	4.90	25
2	5	4.30	402.1	3.50	25	0.9981	401	5.01	2.3	22.54	113
3	5	6.04	564.7	13.07	135	0.9708	548	5.15	3.1	30.38	156
4	5	6.79	634.9	24.72	265	0.9084	577	5.50	3.0	29.40	162
5	5	6.32	590.9	36.64	353	0.8024	474	6.23	1.4	13.72	85
6	6.09	3.62	412.3	52.64	328	0.6068	250	10.04	0	0	0
					∑=1088		∑=2405				∑ul =541

$$\sum W\cos\alpha - \sum ul = 2405 - 541 = 1864kN/m$$

$$(\sum W\cos\alpha - \sum ul)\tan\phi' = (1864)(0.554) = 1033kN/m$$

$$c'\sum l = (25)(37.41) = 935kN/m$$

$$\sum W\sin\alpha = 1088kN/m$$

$$F.S. = \frac{c'\sum l + (\sum W\cos\alpha - \sum ul)\tan\phi'}{\sum W\sin\alpha} = \frac{935+1033}{1088} = 1.81$$