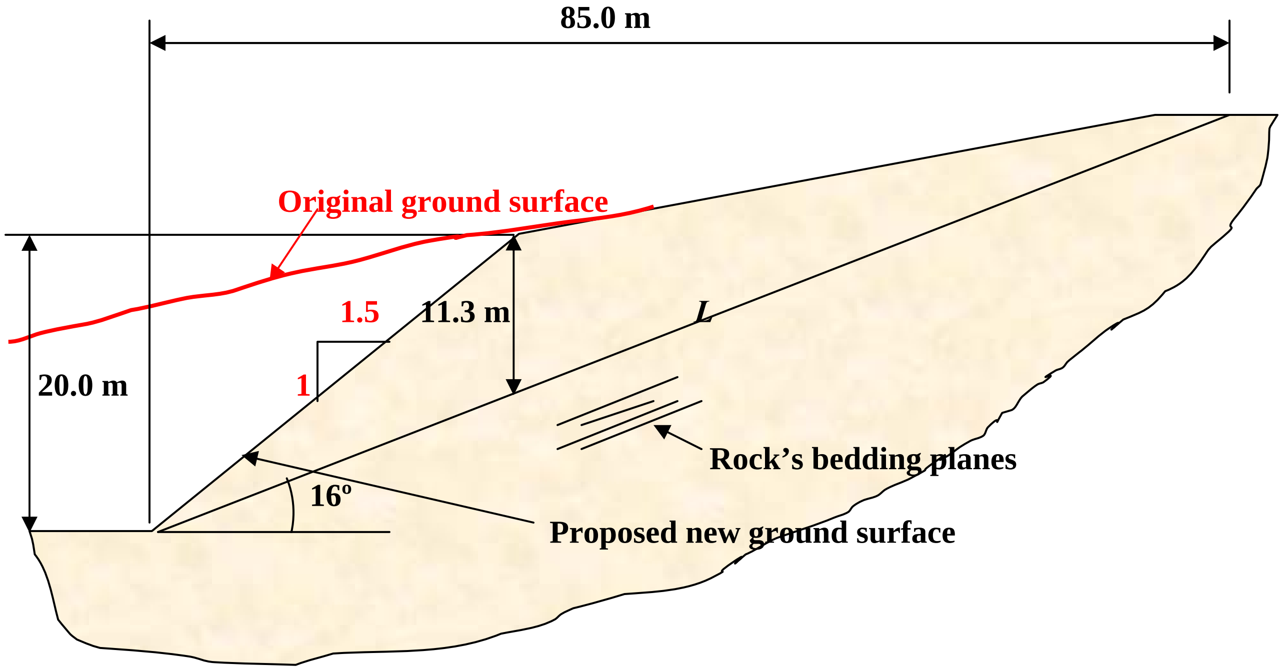
13 - Slope Stability

***01: Find the FS of a straight wedged element of slope.**
***02: Swedish slip circle used to find the FS of a slope.**
***03: Method of slices to find the FS of a slope.**
***04: Method of slices to find the FS of a slope.**
***05: Field evaluation of the stability of a loaded river bank.**

*Slope-01: *Factor of Safety of a straight line slope failure.*

(Revision: Oct.-08)

A slope cut to 1.5H:1V will be made in a shale rock stratum that has bedding planes that have an apparent dip of 16˚ (see the figure below). If the acceptable factor of safety against failure is at least 2 along the lower-most bedding plane, is this slope stable? Use a unit weight of 20.1 kN/m^3, and bedding strength parameters of c = 22 kPa and φ = 30˚.



Solution:

The traingule of rock above the potential slip plane has a weight W per unit width,

$$W = \frac{1}{2}(85.0m)(11.3m)\left(20.1\frac{kN}{m^3}\right) = 9,650\frac{kN}{m}$$

The length L of the slip plane is,

$$L = \frac{85.0\ m}{\cos 16°} = 88.4\ m$$

Therefore,

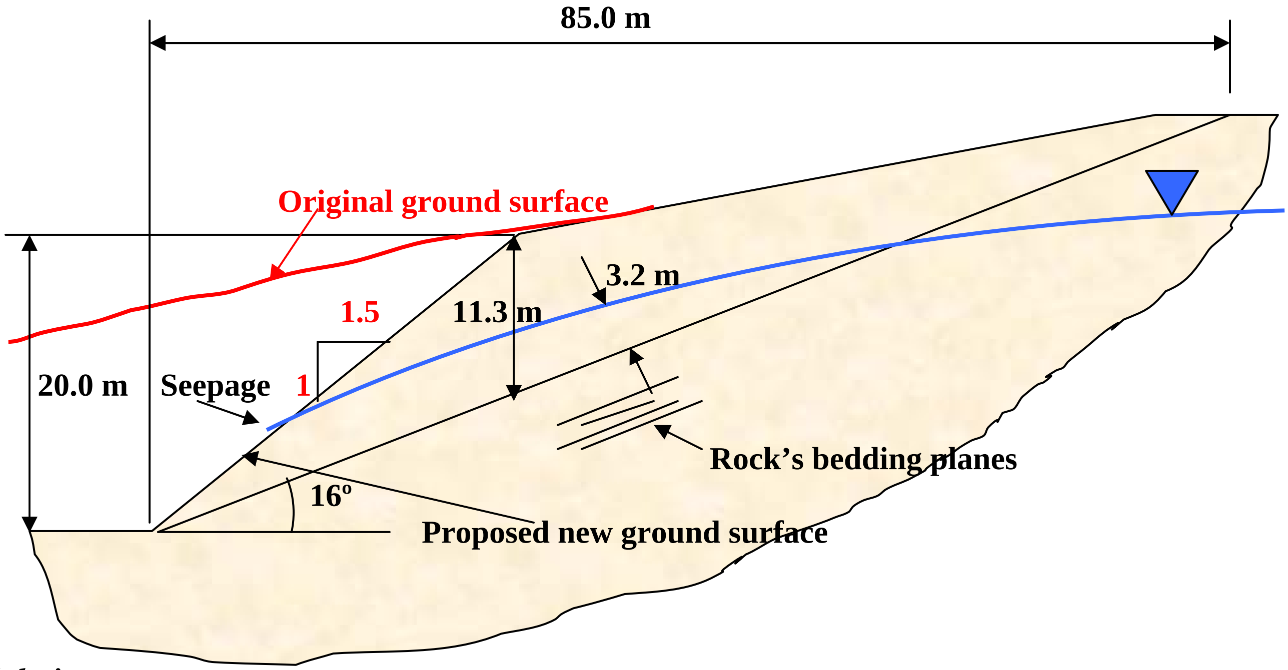
$$FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}} = \frac{cL + \left[(W)\cos\alpha\right]\tan\phi}{(W)\sin\alpha} =$$

$$FS = \frac{\left(22\frac{kN}{m^2}\right)(88.4\ m) + \left[\left(9,650\frac{kN}{m}\right)\cos 16°\right]\tan 30°}{\left(9,650\frac{kN}{m}\right)\sin 16°} = 2.7 > 2 \quad OK$$

*Slope-02: Same as Slope-01 but with a raising WT.

(Revision: Oct.-08)

In the previous problem the slope appeared to be stable with a factor of safety = 2.7. What happens to that factor of safety if the water table rises to the level shown below? Use a unit weight of 20.1 kN/m^3, and bedding strength parameters are reduced by the effective parameters of *c'* = 15 *kPa* and *φ'* = 20˚.



Solution:

The weight W of the rock triangle per unit width is still $9,650\ \frac{kN}{m}$

The length L of the slip plane is still 88.4 m.

The pore water pressure is based on an estimate of its value along the length L, at water depth z_w above the plane that range from 0 to 3.2 m; conservatively,

$$u = \gamma_w z_w = \left(9.81 \frac{kN}{m^3}\right)(3.2\ m) = 31.4\ kPa$$

$$FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}} = \frac{c'L + \left[(W)\cos\alpha - u\right]\tan\phi}{(W)\sin\alpha} =$$

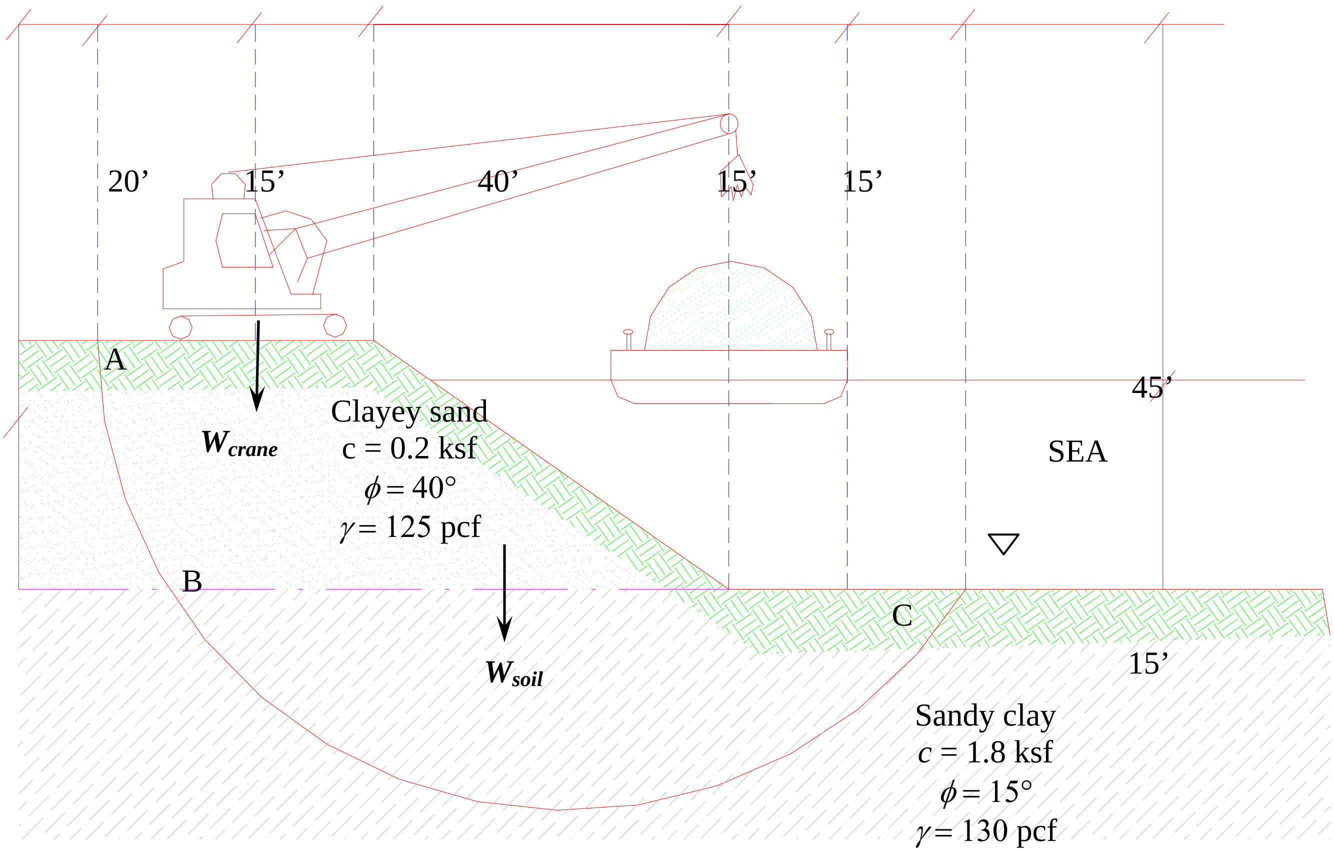
$$FS = \frac{\left(15\frac{kN}{m^2}\right)(88.4m) + \left[\left(9,650\frac{kN}{m}\right)\cos 16° - (31.4kPa)\right]\tan 20°}{\left(9,650\frac{kN}{m}\right)\sin 16°} = 1.76 < 2 \quad NG$$

The computed factor of safety of 1.76 is less than the minimum acceptable value of 2, therefore this design is NOT acceptable. *Notice that a rising WT decreases the stability of the slope.*

*Slope-03: *Is a river embankment safe with a large crane?*

(Revision: Oct.-08)

Determine if the work site shown below is safe, provided you consider the minimum acceptable factor of safety for the man-made waterfront slope shown below to be 2. Assume the arc radius is 80 feet; the circular lengths are AB = 22 feet and BC = 102 feet. The total weight of the soil per unit width are W_{soil} = 205 kips and W_{crane} =70 kips. The site is located in a seismic zone with a seismic coefficient of 0.15.



Solution:

Mr = R[S1(AB)+S2(BC)] = R[$(C_1'+\sigma_1'\tan\phi_1)$AB + $(C_2'+\sigma_2'\tan\phi_2)$BC]

= 80’[(0.2+0.125(8’)(tan40)22’ + (1.8+(0.130 – 0.064)(21)(tan15)(102)] =

80[23k + 221k] **= <u>19,500 k-ft</u>**

$$\mathbf{Mo = Wb_1 - W_{wH}(d_1) - W_{wv}(b_2) + Vb_3 + \frac{Wae(d_2)}{g}}$$

$= 205(40)–(1/2)(0.064)(15)^2$ - (0.064)[30(15)+(1/2)(40)(15)]15+70(55)+205(0.15)(50)

Mo = 8,200 - 7.2 –720 +3850 +1540 = **12,900 k-ft**

Therefore: FS = Mr/Mo = 19,500/12,900 = 1.51

➔Not Good!

Removing Crane ➔ Mo =9,050 k-ft

Therefore: FS = Mr/Mo = 19,500/9050 = 2.15

➔ GOOD!

*Slope-04: Simple method of slices to find the FS.

(Revision: Oct.-08)

The stability of a slope was analyzed by the method of slices. One of the trial curved surfaces through the soil mass yielded the shearing and normal components of each slice as listed below. The curved length of the trial curved surface is 40 feet, the soil parameters are c = 225 lb/ft^2 and φ = 15º. Determine the factor of safety along this trial surface.

Solution:

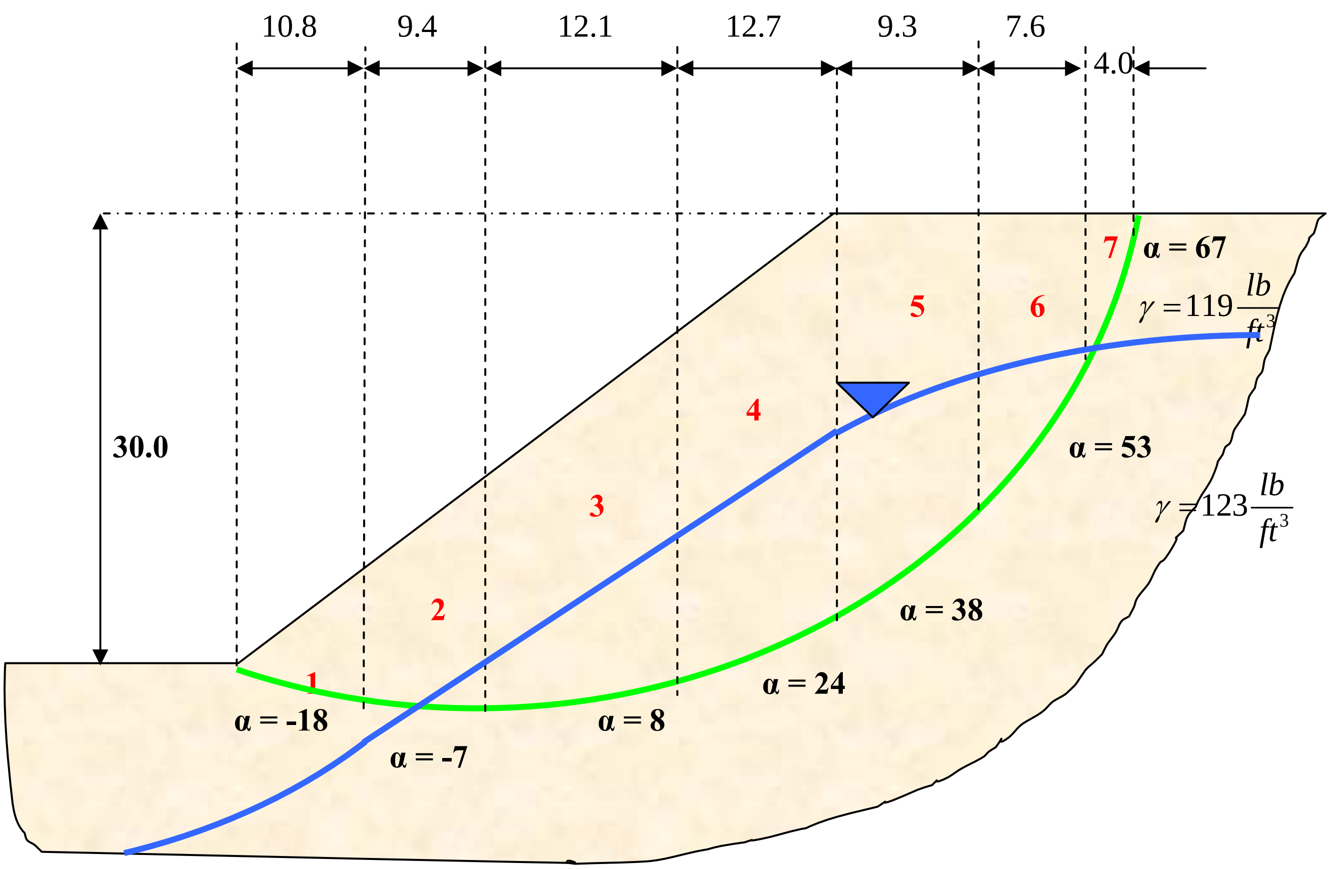
Slice Number	Shearing Component (W sin α) (lb/ft)	Normal Component (W cos α) (lb/ft)
1	-38	306
2	-74	1410
3	124	2380
4	429	3050
5	934	3480
6	1570	3540
7	2000	3210
8	2040	2190
9	766	600
	∑ = 7,751 lb/ft	∑ = 20,166 lb/ft

$$FS = \frac{cL + \sum (W\cos\alpha)\tan n\phi}{\sum W\sin\alpha} = \frac{(225\,psf)(40\,ft) + 20{,}166\,plf}{7{,}751\,plf} = 1.86 < 2 \quad NG$$

**Slope-05: *Method of slices to find the factor of safety of a slope with a WT.*

(Revision: Oct.-08)

A 30 ft tall, 1.5H:1V slope is to be built as shown below. The soil is homogeneous, with $c' = 400 \frac{lb}{ft^2}$ and $\phi' = 29°$. The unit weight is 119 pcf above the groundwater table, and 123 pcf below. Using the ordinary method of slices, compute the factor of safety along the trial circle.



Weights:

$$\frac{W_1}{b} = 10.8\left(\frac{10.3}{2}\right)119 = 6,620\,\frac{lb}{ft}$$

$$\frac{W_2}{b} = 9.4\left(\frac{10.3+12.5}{2}\right)119 + 9.4\left(\frac{5.2}{2}\right)123 = 15,800\,\frac{lb}{ft}$$

$$\frac{W_3}{b} = 12.1\left(\frac{12.5+14.6}{2}\right)119 + 12.1\left(\frac{5.2+10.0}{2}\right)123 = 30,800\,\frac{lb}{ft}$$

$$\frac{W_4}{b} = 2.9\left(\frac{5.0}{2}\right)17.0 + 7.1\left(\frac{12.9+8.0}{2}\right)17.8 = 1620\,\frac{lb}{ft}$$

$$\frac{W_5}{b} = 9.3\left(\frac{16.8+12.8}{2}\right)119 + 9.3\left(\frac{10.7+7.3}{2}\right)123 = 39,900\ \frac{lb}{ft}$$

$$\frac{W_6}{b} = 7.6\left(\frac{12.8+9.9}{2}\right)119 + 7.6\left(\frac{7.3}{2}\right)123 = 26,700\ \frac{lb}{ft}$$

$$\frac{W_7}{b} = 4.0\left(\frac{9.9}{2}\right)119 = 2,400\ \frac{lb}{ft}$$

Average pore water pressure at base of each slice:

$$u_1 = 0$$

$$u_2 = \left(\frac{5.2}{2}\right)62.4 = 160\ \frac{lb}{ft^2}$$

$$u_3 = \left(\frac{5.2+10.0}{2}\right)62.4 = 470\ \frac{lb}{ft^2}$$

$$u_4 = \left(\frac{10.0+10.7}{2}\right)62.4 = 650\ \frac{lb}{ft^2}$$

$$u_5 = \left(\frac{10.7+7.3}{2}\right)62.4 = 560\ \frac{lb}{ft^2}$$

$$u_6 = \left(\frac{7.3}{2}\right)62.4 = 230\ \frac{lb}{ft^2}$$

$$u_7 = 0$$

Slice	$\frac{W}{b}(lb)$	α (Deg)	$c'\left(\frac{lb}{ft^2}\right)$	ϕ (Deg)	$u\left(\frac{lb}{ft^2}\right)$	$l\ (ft)$	$c'l + \left(\frac{W}{b}\right)(\cos\alpha - ul)\tan\phi'$	$\frac{W}{b}(lb)$
1	6,620	- 18	400	29	0	11.4	8,000	-2,000
2	15,800	- 7	400	29	160	9.5	11,700	-1,900
3	30,800	8	400	29	470	12.2	18,600	4,300
4	39,900	24	400	29	650	13.9	20,800	16,200
5	26,700	38	400	29	560	11.8	12,700	16,400
6	13,700	53	400	29	230	12.6	8,000	10,900
7	2,400	67	400	29	0	10.2	4,600	2,200
							$\Sigma = 84,400$	$\Sigma = 46,100$

Therefore, the factor of safety is,

$$FS = \frac{c'l + \left(\frac{W}{b}\right)(\cos\alpha - ul)\tan\phi'}{\left(\frac{W}{b}\right)} = \frac{84,400}{46,100} = 1.83 < 2 \quad NG$$

Note how slices # 1 and 2 have a negative α because they are inclined backwards.

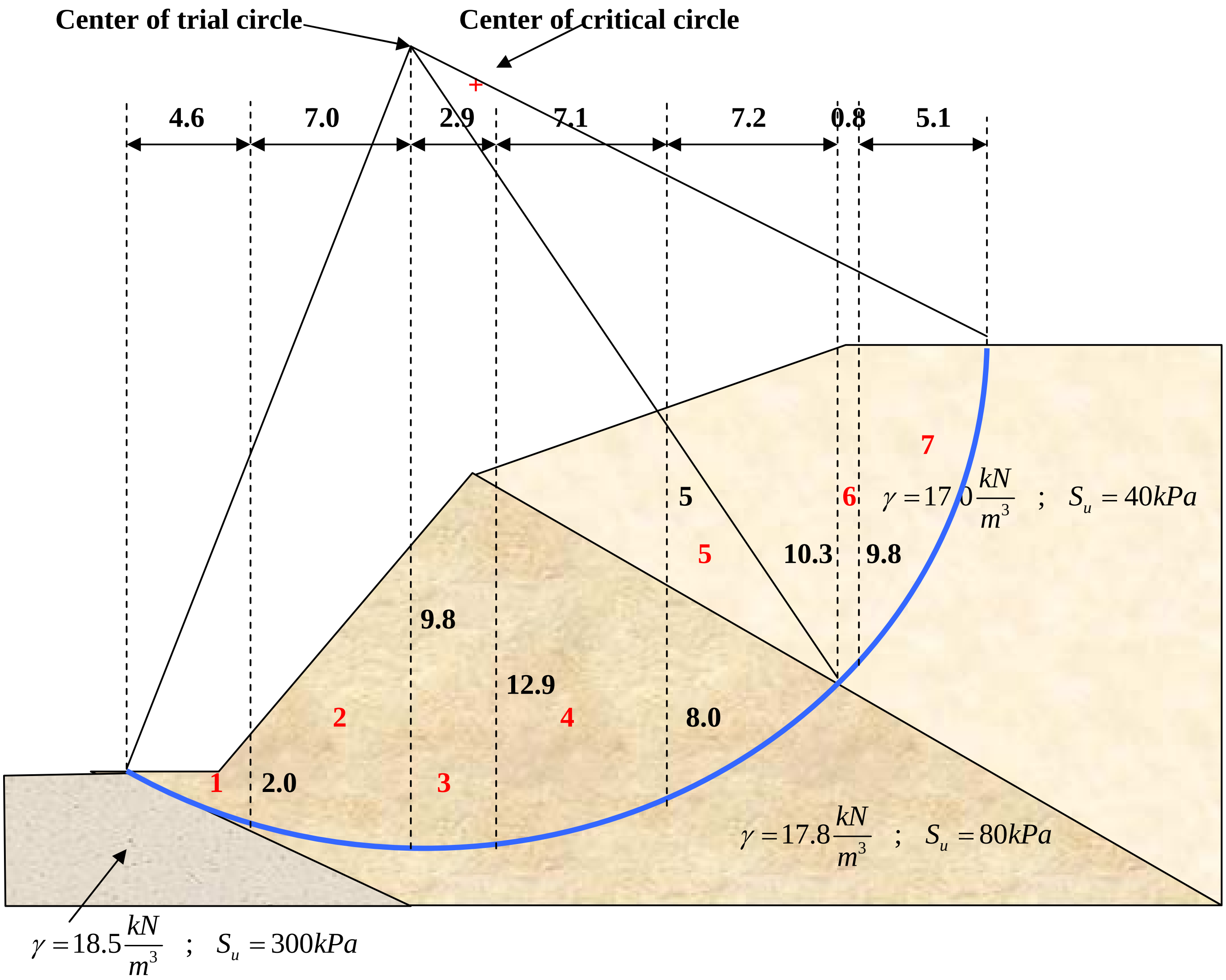
**Slope-06: Swedish slip circle solution of a slope stability.

(Revision: Oct.-08)

Using the Swedish slip circle method, compute the factor of safety along the trial circle shown in the figure below.

Solution:

Divide the slide mass into vertical slices as shown. One of the slice borders should be directly below the center of the circle (in this case, the border between slices 2 and 3). For convenience of computations, also draw a slice border wherever the slip surface intersects a new soil stratum and whenever the ground surface has a break in slope. Then, compute the weight and moment arm for each slide using simplified computations as follows:



Weights:

$$\frac{W_1}{b} = 4.6\left(\frac{2.0}{2}\right)17.8 = 80\ \frac{kN}{m}$$

$$\frac{W_2}{b} = 7.0\left(\frac{2.0+9.8}{2}\right)17.8 = 130\ \frac{kN}{m}$$

$$\frac{W_3}{b} = 2.9\left(\frac{9.8+12.9}{2}\right)17.8 = 590\ \frac{kN}{m}$$

$$\frac{W_4}{b} = 2.9\left(\frac{5.0}{2}\right)17.0 + 7.1\left(\frac{12.9+8.0}{2}\right)17.8 = 1620\ \frac{kN}{m}$$

$$\frac{W_5}{b} = 7.2\left(\frac{5.0+10.3}{2}\right)17.0 + 7.2\left(\frac{8.0}{2}\right)17.8 = 1450\ \frac{kN}{m}$$

$$\frac{W\ 6}{b} = 0.8\left(\frac{10.3+9.8}{2}\right)17.0 = 140\ \frac{kN}{m}$$

$$\frac{W_7}{b} = 5.1\left(\frac{9.8}{2}\right)17.0 = 420\ \frac{kN}{m}$$

Moment arms:

$$d_1 = -7.0 - \frac{4.6}{3} = -8.5\ \ m$$

$$d_2 = \frac{-7.0}{2} = -3.5\ \ m$$

$$d_3 = \frac{2.9}{2} = 1.5\ \ m$$

$$d_4 = 2.9 + \frac{7.1}{2} = 6.5\ \ m$$

$$d_5 = 2.9 + 7.1 + \frac{7.1}{2} = 10.9\ \ m$$

$$d_6 = 2.9 + 7.1 + 7.2 + \frac{0.8}{2} = 17.6\ \ m$$

$$d_7 = 2.9 + 7.1 + 7.2 + 0.8 + \frac{5.1}{3} = 19.7\ \ m$$

Slice	$S_u\,(kPa)$	$\theta\,(Deg)$	$S_u\;\theta$	$\frac{W}{b}\left(\frac{kN}{m}\right)$	$d\,(m)$	$\left(\frac{W}{b}\right)\,d$
1				80	-8.5	-680
2				130	-3.5	-450
3	80	76	6080	590	1.5	890
4				1620	6.5	10,530
5				1450	10.9	15,800
6	40	30	1200	140	17.6	2,460
7				420	19.7	8,280
			$\Sigma = 7280$			$\Sigma = 36,830$

$$FS = \frac{\pi R^2}{180}\frac{\sum S_u\theta}{\sum\left(\frac{W}{b}\right)d} = \frac{\pi\,(23.6)^2}{180}\;\frac{7,280}{36,830} = 1.92 < 2 \quad \textit{Not Good}$$