

Slope Stability Analysis

- ❖ The preliminary section should be checked against different loading conditions to satisfy the safety criteria:(critical condition must be analyzed)
 - ✓ End of construction(both slopes)
 - ✓ Sudden drawdown(U/s face critical)
 - ✓ Steady state Seepage, reservoir full(D/s slope critical)
 - ✓ Steady state seepage with earthquake
- ❖ Three considerations govern the design of an earth embankment:
 - ✓ Side slopes must be stable;
 - ✓ Dimensions must be sufficient to control seepage;
 - ✓ Base width must be long enough to distribute weight of dam over sufficient area to prevent overstress in the foundation.

Case	Loading Condition	Critical Slope	FS min (As Per USACE)
1	End of construction	Upstream	1.3
		Downstream	1.3
2	Sudden drawdown	Upstream	1.3
3	Steady state Seepage	Upstream	1.5
		Downstream	1.5
4	Steady state seepage with earthquake	Upstream	1.1
		Downstream	1.1

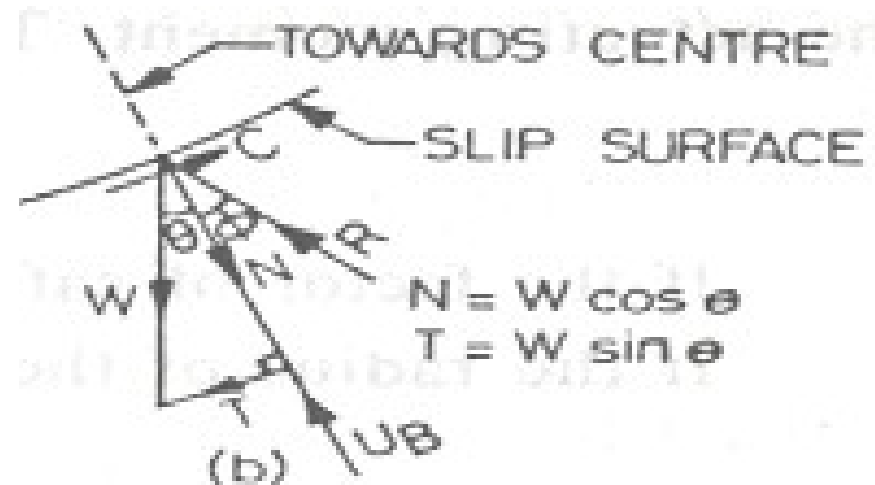
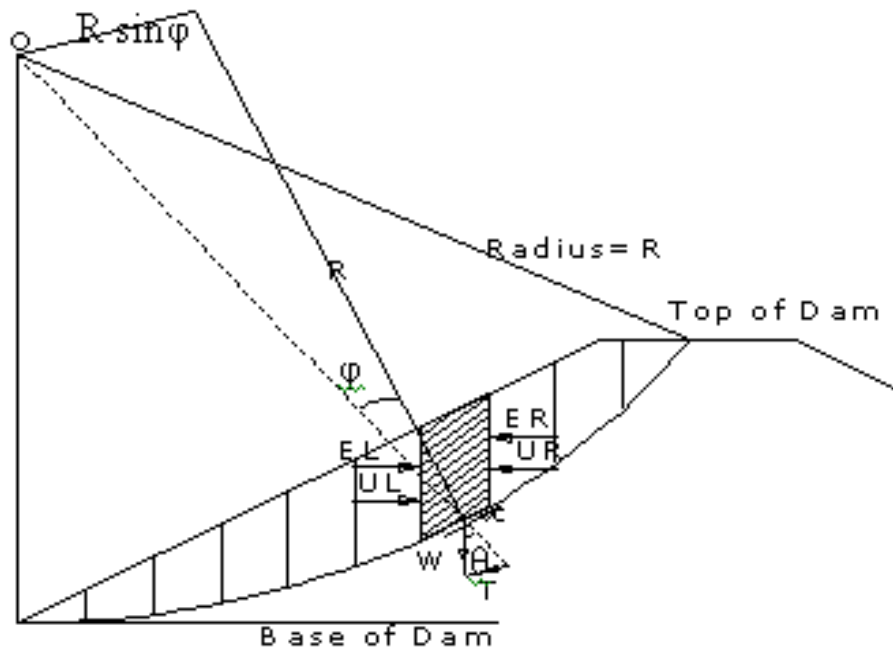
Slope Stability Analysis...

❖ **Swedish Slip Circle Method or the Slices Method:**

- ✓ used for examining the stability of slopes of earthen embankments

Steps:

- ✓ Assume the location of the centre of the possible failure arc.
- ✓ The earth mass is divided into a number of vertical segments (slices)
- ✓ O is the center and R is the radius of the possible



Slope Stability Analysis....

- ❖ The following forces act on one slice for the equilibrium;
 - ✓ **Self weight, W** acting downward through its center of gravity
 - ✓ **Cohesive force, C** along the curved surface in the direction opposite to the direction of movement of the wedge.
 - ✓ **$C = c\Delta L$** , where c is the unit cohesion and ΔL is length of base strip
 - ✓ **Reaction R** at the base of the strip, acting a line inclined at an angle ϕ to the normal, where ϕ is the angle of shearing resistance of the soil.
 - ✓ **Soil reactions ER and EL** acting on the vertical sides of the slice exerted by the adjacent slices on the right and left.
 - ✓ **ER and EL are equal and opposite**
 - ✓ pore water pressure **UL , UR and UB** acting on the left, right and base of the slices.
 - ✓ **UL and UR are opposite in direction and balanced. UB acts in the normal direction**
- ✓ for analysis using ***Swedish circle method***, only four forces (**W , C , R and UB**) remain.
 - ✓ UB is due to pore water pressure and will be zero, if the soil is dry.

Slope Stability Analysis...

- ❖ The weight (W) be resolved in to normal (N) and tangential (T) component
- ❖ **$N = W \cos \theta$** and **$T = W \sin \theta$** , θ = angle which the normal makes with the vertical
- ❖ Resolving all the forces in the normal direction:
 - ✓ **$N - UB = R \cos \varphi$ ----- (a)**
- ❖ Resolving all the forces in the tangential direction:
 - ✓ **$T - C = R \sin \varphi$ ----- (b)**
- ❖ Substituting the value of R from eqn (a) in to (b):
 - ✓ **$T - C = [(N - UB) / \cos \varphi] \sin \varphi$**
 - ✓ **$T - C = (N - UB) \tan \varphi$** , where: **$C = c * \Delta L$**
 - ✓ **$T = (N - UB) \tan \varphi + c \Delta L$**
- ❖ The **tangent component of the force** (actuating) is balanced by the **frictional resistance** and **cohesion resistance** (resisting).

Slope Stability Analysis...

❖ Thus the factor of safety is given by:

✓ **$F_s = (\text{Sum of the resisting moment}) / (\text{sum of the acting moment})$**

$$F_s = \frac{\tan \phi \sum (W \cos \theta - u \Delta L) + \sum c \Delta L}{\sum W \sin \theta}$$

✓ **ΔL is the arc of the slice ($b \sec \theta$)**

$$F_s = \frac{\tan \phi \sum (W \cos \theta - ub \sec \theta) + \sum cb \sec \theta}{\sum W \sin \theta}$$

$$F_s = \frac{\tan \phi \sum N' + \sum c L_t}{\sum T}$$

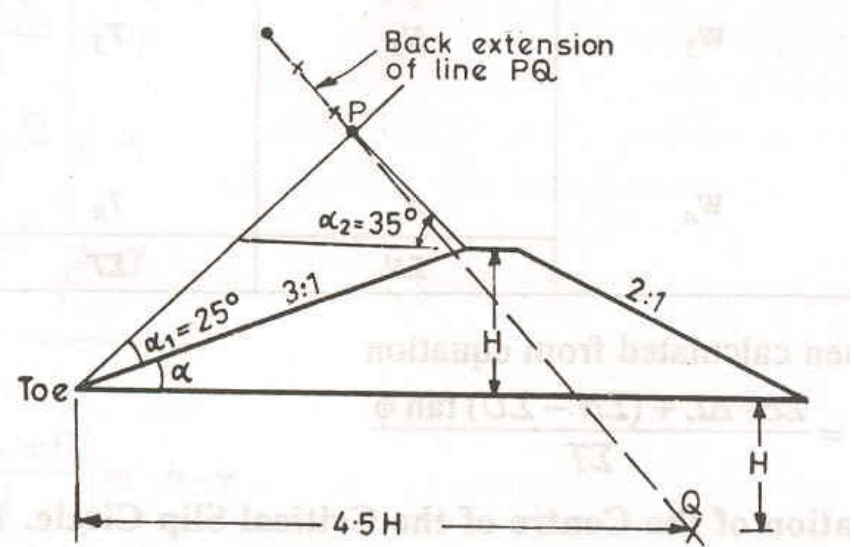
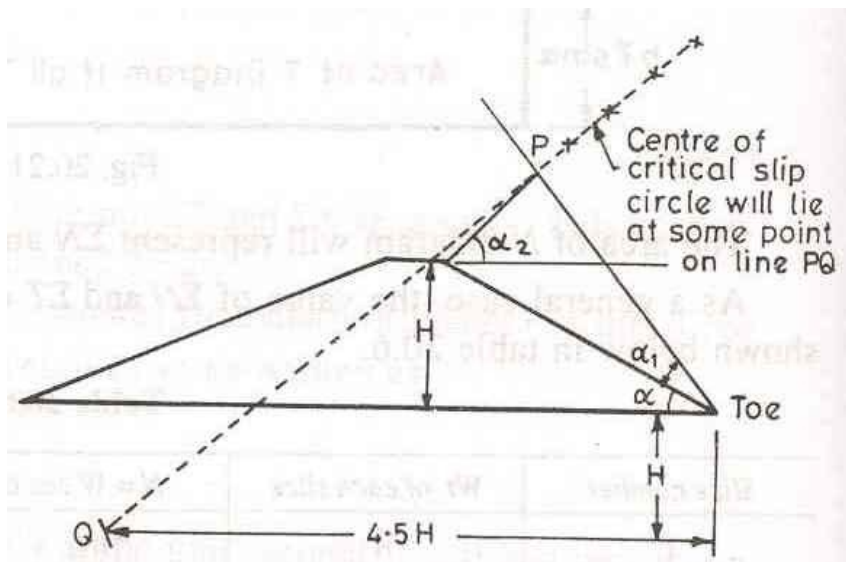
Slope Stability Analysis...

- ❖ *Procedure for the determination of the F_s of the trial slip surface*
 - ✓ Take a trial slip surface and divide the wedge above the slip surface in to 8 to 15 vertical slices;
 - ✓ **Determine the weight** of each slice, $W=(b*Z)*\gamma$, where: b =width of the slice, Z =middle ordinate of the slice, and γ =unit weight of the soil;
 - ✓ **Measure the angle θ** which the normal makes with the vertical & compute the normal (N) & tangential (T) component. **$N = W \cos \theta$ & $T = W \sin \theta$**
 - ✓ Determine the **pore water pressure (u)** at the base of the slice from the flow net and compute the force UB due to pore water pressure. **$UB = u * \Delta L = u * b \sec \theta$**
 - ✓ **Determine the cohesive force, $C = c * b \sec \theta$**
 - ✓ Determine the factor of safety for the trial slip surface:

$$F_s = \frac{\tan \phi \sum (W \cos \theta - ub \sec \theta) + \sum cb \sec \theta}{\sum W \sin \theta}$$
 - ✓ Repeat the above procedure for a number of trial surfaces. The trial surface which gives the minimum factor of safety is the most critical circle. The minimum factor of safety should be greater than the specified safe value of the soil.

Location of the Most Critical Circle

- ✓ **Critical surface slippage** or **Critical slip circle**: slip circle which yields the least factor of safety.
- ✓ Several different surfaces of slippage should be tried as one trial gives the value of factor of safety for that arc only.
- ✓ In order to reduce the number of trials, **Fellenius** has suggested a method of drawing a line, representing the locus of the critical slip circle.
- ✓ To draw **Fellenius line (PQ)**, Q (depth of H) & distance of $(4.5H)$.



Location of the Most Critical Circle...

Slope of the face	<i>Directional angles</i>	
	α_1 in degrees	α_2 in degrees
1:1	28	37
1.5:1	26	35
2:1	25	35
3:1	25	35
5:1	25	35

Design of Filters

- ✓ Filters are required b/n the drain system and the adjoining soil to prevent the migration of the soil particles into the drains which may cause piping.
 - ✓ Filters are graded so that the finer layers are adjacent to the drains.
 - ❖ According to Terzaghi, the two basic requirements of the filter that should be satisfied are:
 - ✓ The filter material should be ***fine enough*** to prevent the particles of the protected soil from being washed into its voids.
 - ✓ *if D15 size of the filter material is not more than 4 to 5 times D85 of the base (protected) material*
 - ✓ The filter material should be ***coarse enough*** so that it acts as a drain for the protected material.
 - ✓ *if the D15 size of the filter material is at least 4 to 5 times the D15 of the protected material.*
- $$\frac{D_{15} \text{ of the filter material}}{D_{85} \text{ of the protected material}} < 4 \text{ to } 5$$

$$\frac{D_{15} \text{ of the filter material}}{D_{15} \text{ of the protected material}} \geq 4 \text{ to } 5$$
- ❖ Both the above criteria can be written as:

Rockfill Dams

- ✓ It is a type of embankment dam in which rock fragments (rock fill) is the main construction material.
- ✓ The mass stability of a rockfill dam is mainly developed by the **friction** and interaction of the particles.
- ❖ A rock dam usually consists of two basic structural elements:
 - ✓ An embankment built of rockfill (for the support and the stability) and
 - ✓ An impervious element (checks the seepage through the dam)
- ❖ There are basically two types of rockfill dams:
 - ✓ Impervious membrane type
 - ✓ Earth core type

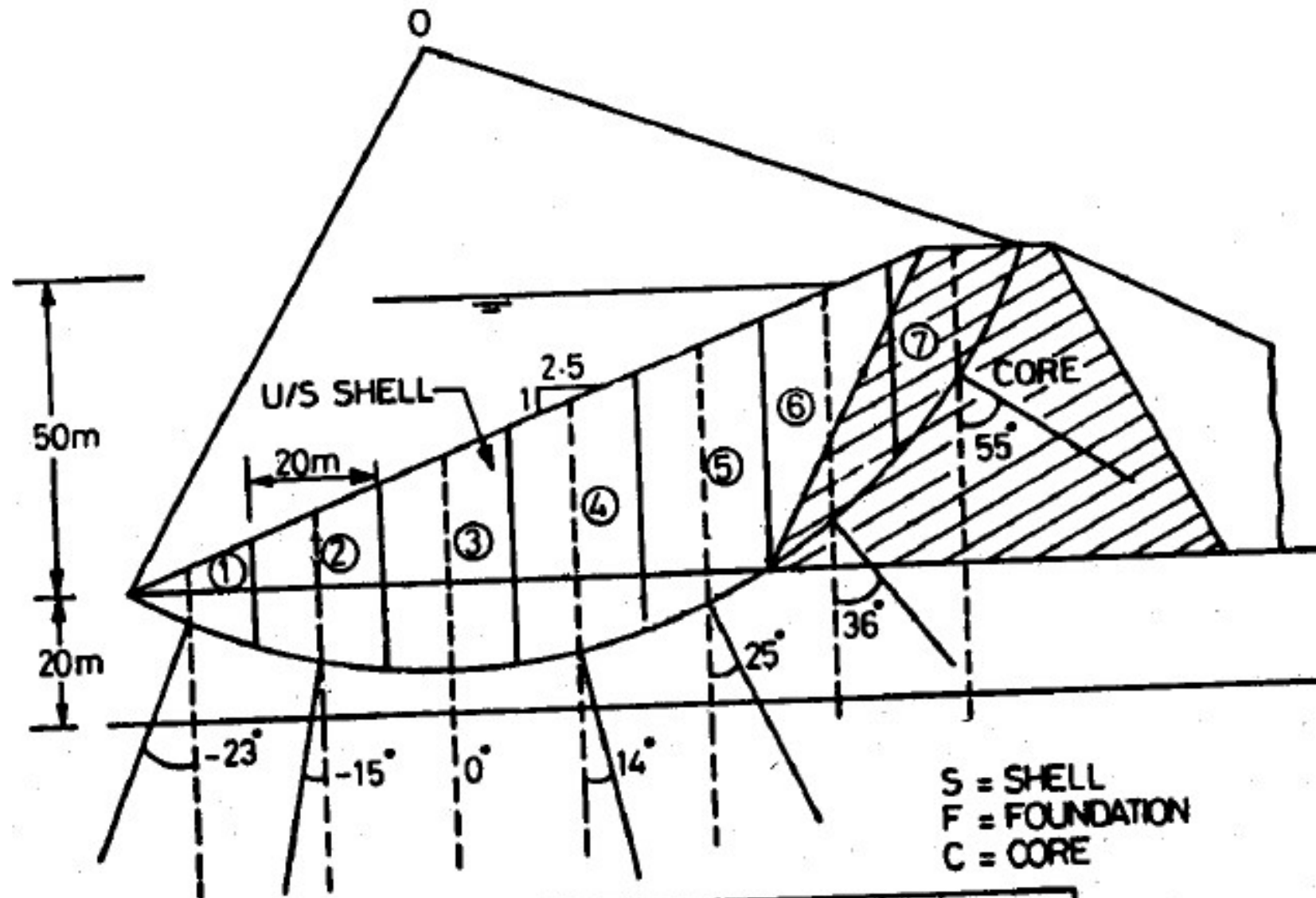
Design consideration of Rockfill dam

- ✓ The design and construction of a rockfill dam is governed by more or less the same principles as those used in an earth dam.
- ✓ Rockfill dams require much strong foundation than earth dams but not strong as concrete dams.

Examples:

1. **Swedish circle method:** *Check the stability of the upstream face slope of the dam for the assumed surface shown. The properties of the shell, core and foundation materials are as follows:*

	Shell	Core	Foundation
<i>Saturated unit weight (kN/m³)</i>	22	21	22
<i>Submerged unit weight (kN/m³)</i>	12	11	12
<i>Moist unit weight (kN/m³)</i>	21	20	21
<i>Angle of internal friction (°)</i>	30	20	30
<i>Unit cohesion (kN/m²)</i>	10	60	10



SLICE	(1)	(2)	(3)	(4)	(5)	(6)	(7)
AREA (S)	80	240	400	560	720	480	40 m ²
AREA (F)	90	220	200	200	80	—	— m ²
AREA (C)	—	—	—	—	—	220	300 m ²

S. No	Area of slice (m ²)			Weights (kN)		θ (°)	$N' = W' \cos \theta$	$T = W \sin \theta$	ϕ (°)	$N' \tan \phi$	c	$b \sec \theta$	$c b \sec \theta$
	Shell (S)	Core (C)	Found (F)	Saturated	Submerged								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1	80	-	90	3740 (=170x22)	2040 (=170x12)	-23	1878	-1461	30	1084	10	21.7	217
2	240	-	220	10120	5520	-15	5332	-2619	30	3078	10	20.7	207
3	400	-	200	13200	7200	0	7200	0	30	4157	10	20.0	200
4	560	-	200	16720	9120	14	8849	4045	30	5109	10	20.6	206
5	720	-	80	17600	9600	25	8700	7438	30	5023	10	22.1	221
6	480	220	-	15180 (=480x22+220x21)	8180 (=480x12+220x11)	36	6618	8923	20	2409	60	24.7	1482
7	40	300	-	7180	3780	55	2168	5882	20	789	60	34.9	2094
						$\Sigma =$	40745	22208		21650			4627

Taking full pore pressure, the factor of safety is computed as

$$F_s = \frac{\tan \phi \sum (N - U) + cL_a}{\sum T} \rightarrow F_s = \frac{\tan \phi \sum N' + cL_a}{\sum T}$$

$$F_s = \frac{21650 + 4627}{22208} = 1.18 < 1.50, \text{ unsafe}$$