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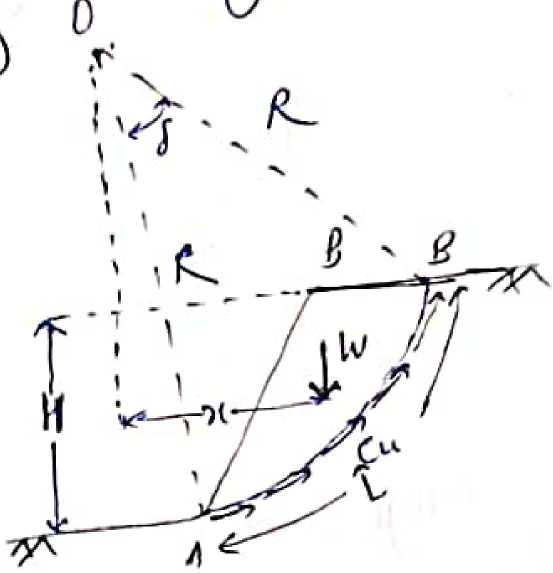
Subject :- Foundation Engineering

ASSIGNMENT-1

Q(1).

Sol: i) Stability Analysis of Cohesive soil by Swedish Circle Method (i.e; $\phi = 0$)



Driving moment, $M_D = W.x$

Resisting force / Shearing resistance developed along slip surface $= C_u \hat{L}$

Resisting moment, $M_R = C_u \hat{L} R$

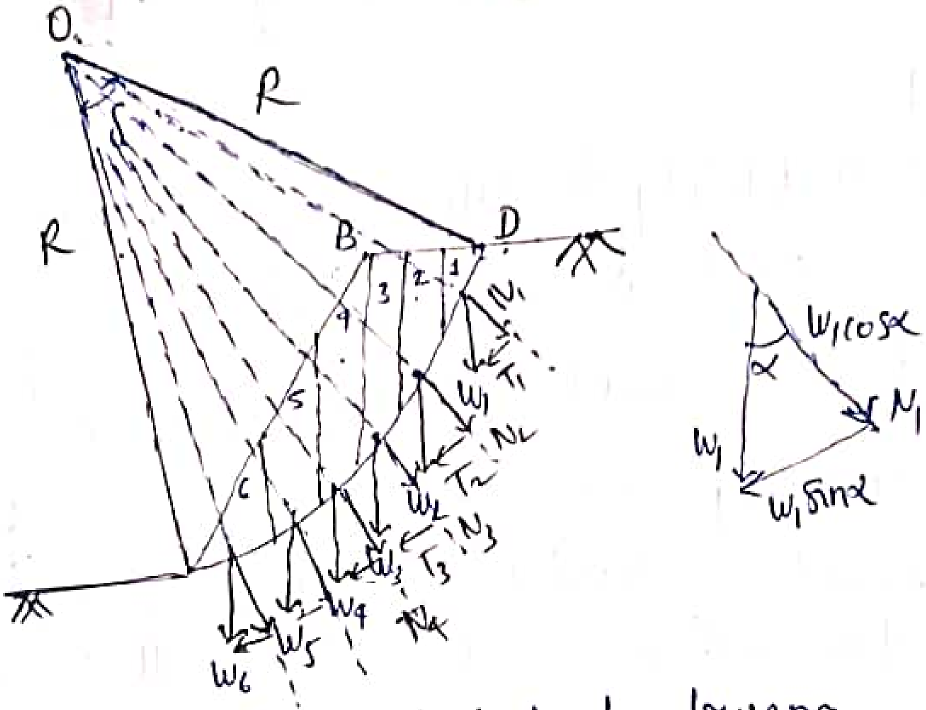
Here; $\hat{L} = \frac{2\pi R\delta}{360^\circ}$

FOS; factor of safety, $= \frac{\text{Resisting Moment}}{\text{Driving moment}}$

$$F = \frac{M_R}{M_D}$$

$$F = \frac{C_u \hat{L} R}{Wx}$$

ii) Stability analysis of slope for $c-\phi$ soil:-



Tangential components will contribute to driving force,

$\therefore$ Driving ~~force~~, $M_D = \Sigma T$

If C_u is the unit cohesion

ΔL is the length of individual slices

Then, Resisting force, $= C_u \Sigma \Delta L + \tan\phi \, \Sigma N)$

Resisting moment, $M_R = (C_u \hat{L} + \tan\phi \, \Sigma N) R$

Driving moment, $M_D = \Sigma T . R$

Factor of Safety, $FOS = \dfrac{M_R}{M_D}$

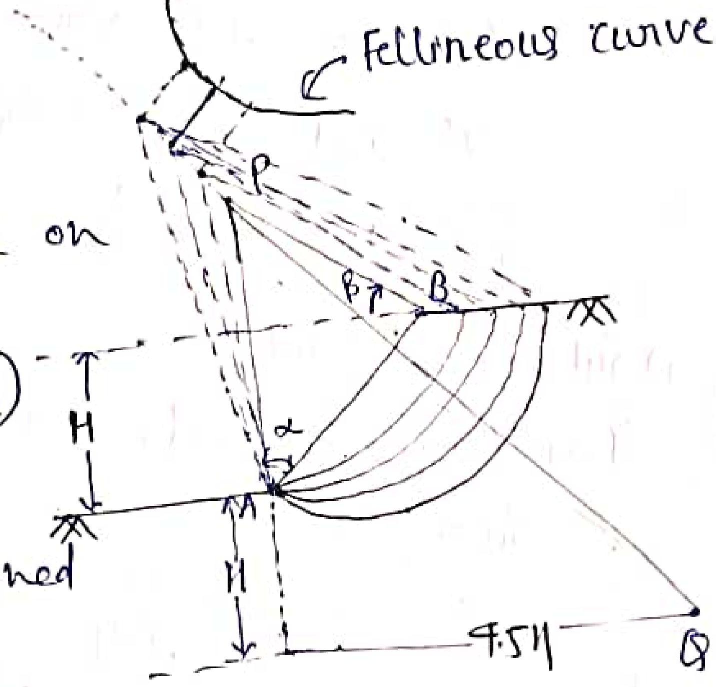
$$= \frac{(C_u \hat{L} + \tan\phi \, \Sigma N) R}{\Sigma T \cdot R}$$

$$\boxed{FOS, = \frac{C_u \hat{L} + \tan\phi \, \Sigma N}{\Sigma T}}$$

→ Fellineous method of locating centre of Critical Slip circle

In both cohesive and cohesionless soil, we assume the failure surface as a arc of a circle. by assuming number of trial slip circle, we find out factor of safety.

The circle which gives the minimum factor of safety is treated as critical slip circle



H = Height of Slope

AB = face of Slope

locating locus of centre on PQ.

Coordinate of $Q \equiv (4.5H, -H)$

Factor of Safety is obtained by slice method

$$\boxed{FOS = \frac{C_u \hat{L} + \tan\phi \, \Sigma N}{\Sigma T}}$$

(b)

Sol:: Given; $H = 3m$, $C = 10 kN/m^2$, $\phi = 15°$, $e = 0.8$, $G = 2.70$

$i = 45°$

$\gamma_w = 9.81 \ kN/m^3$

$$\gamma_{sat} = \left(\frac{G+e}{1+e}\right)\gamma_w$$

$$\gamma_{sat} = \left(\frac{2.70+0.8}{1+0.8}\right) 9.81 = \frac{3.5}{1.8} \times 9.81$$

$$\gamma_{sat} = 19.08 \ kN/m^3$$

$$\gamma' = \gamma_{sat} - \gamma_w = 19.08 - 9.81$$

$$\boxed{\gamma' = 9.26 \ kN/m^3}$$

i) Submerged Condition :-

From Taylor's chart, for these values of i & ϕ,

$S_n = 0.08$

$$\therefore \ S_n = \frac{C_m}{\gamma' \cdot H} \Rightarrow C_m = S_n \gamma' H = 0.08 \times 9.26 \times 3$$

$$C_m = 2.22 \ kN/m^2$$

Factor of safety w.r.t cohesion, $F_c = C/C_m = 10/2.22$

$$\boxed{F_c = 4.50}$$

ii) For Rapid drawdown Condition :-

$$\phi_w = (\gamma'/\gamma_{sat}) \times \phi = \left(9.26/19.08 \times 15\right) = 7.28°$$

For $i = 45°$, & $\phi = 7.28°$, $S_n = 0.113$

$$S_n = \frac{C_m}{\gamma_{sat} H} \Rightarrow$$

$$C_m = S_n \gamma_{sat} H = 0.113 \times 19.08 \times 3$$

$$\boxed{C_m = 6.47 \ kN/m^2}$$

factor of safety with respect to cohesion

$$F_c = \frac{c}{C_m}$$

$$F_c = \frac{10}{6.47}$$

$$\boxed{F_c = 1.55}$$

8(2)

Sol: The friction circle method is graphical procedure that can be used for analyzing the stability of homogeneous slopes. It was popularized by Taylor in 1937. With the help of results obtained by this method, graphs were plotted between the angle of inclination and stability number to calculate factor of safety.

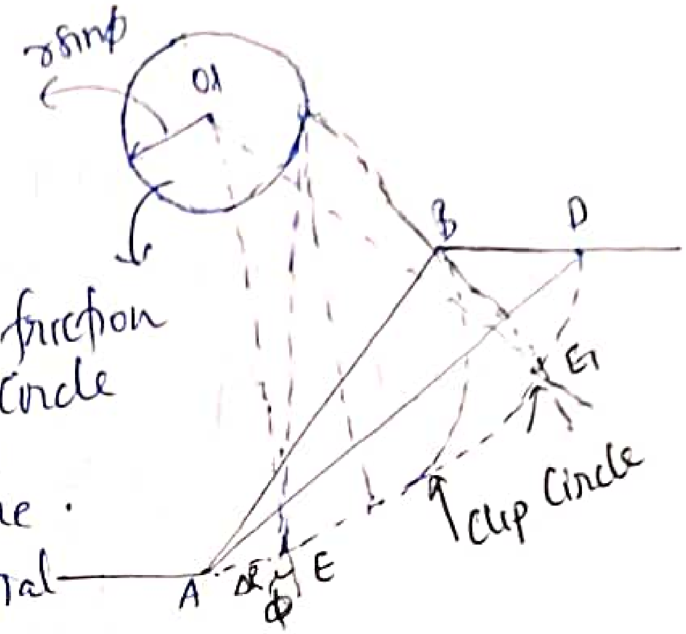
The reaction P is inclined at angle ϕ_m to the normal to the slip surface.

Elementary cohesive force for element $\Delta L = C_m \Delta L$

L_c = Length of the chord AC

Resultant cohesive force = $C_m L_c$

- Friction circle method also assumes the failure surface as the arc of circle
- Any vector representing reaction ΔR at an obliquily ϕ to an element of failure. arc AD will be tangential to small circle



Friction circle

This small circle of radius $r \sin\phi$ is called friction circle or ϕ circle

→ The force acting on sliding wedge ABDA are

i) The weight W of wedge
ii) the total frictional resistance of resultant R
iii) total cohesive resistance C_1 developed along soil circle

If we divide this slip arc into the elementary arc of length ΔL, the elementary reaction ΔR of each other arc, acting at an obliquity ϕ to normal to arc, will be tangential to friction circle.

→ If R is resultant reaction, at an obliquity ϕ to the normal direction, it will miss the friction circle by small margin, in fact it will be tangential to another circle, the radius $K r \sin\phi$

8

C_m = mobilised cohesion

$\Delta L = C_m \Delta L$

$C_m \hat{l} = C_m \Sigma \Delta L$ = Total resistant cohesive

$\hat{l}$ = length of chord AD

$AD = C_m \hat{l}$

$(C_m \hat{l})a = (C_m \Sigma \Delta L)r = C_m \hat{l} r$

$$\boxed{F_c = \frac{c}{C_m}}$$

The no. of slip circles are taken and factor safety of arc is found.

→ Taylor's Stability Number :-

- The total cohesive force $c\hat{l}$ which resists the slipping along the slip arc at critical equilibrium is proportional to cohesion c and height H of slope.
- The force causing instability is weight of wedge which is equal to unit weight γ and the area of wedge which is proportional to square of height H

The height of wedge proportional to $\gamma \times H^2$

$$\therefore S_n = \frac{cH}{F_c \gamma H^2} = \frac{c}{F_c \gamma H}$$

$$\boxed{S_n = \frac{c}{F_c \gamma H}}$$

S_n dimension-less quantity $\frac{c}{F_c \gamma H}$ is called Taylor's stability number

$$C_m = \frac{c}{F_c}$$

$$F_c = \frac{H_c}{H}$$

When a soil possesses both cohesion and friction, The factor of safety F is to provided with respect to cohesion as well as friction.

$$S = \frac{c}{F} + \frac{\sigma \tan\phi}{F}$$

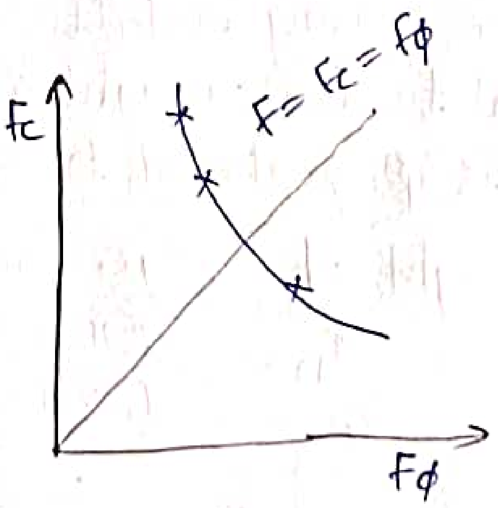
→ For purely frictional soil $(c=0)$

- Stability no. is 0 and Taylor's Stability curves do not apply.
- Stability of slope depend upon angle of slope i

$$\boxed{F = F_c = F_\phi}$$

$$\boxed{F_c = \frac{c}{S_n \gamma H}}$$

→ Long term Stability



→ Stability of Submerged Slope

$$\tan\phi_w = \frac{\gamma' \tan\phi}{\gamma_{sat}\, F_\phi}$$

if $F_\phi = 1$, $\phi_m = \phi$

$$\therefore \boxed{\phi_w = \frac{\gamma'}{\gamma_{sat}}\phi}$$

Q(4) Discuss the stability of an earth dam
i) D/S slope during steady seepage
ii) U/S slope during sudden draw down

Sol: i) <u>Stability of down stream slope during steady seepage</u>

- Critical condition of downstream slope occurs when the reservoir is full and percolation is at its maximum rate.
- The direction of seepage force tends to down the stability

The factor of safety, $F = \dfrac{c' + \tan\phi\, \Sigma(N-U)}{\Sigma T}$

- The area of U-diagram can be measured with help of planimeter.

$$\boxed{\Sigma U = A_u r^2 \gamma_w \ \ kN}$$

ii) Stability of Upstream during Sudden drawdown

- For upstream slope, the critical condition is when the reservoir is suddenly emptied without allowing any appreciable change in water level within the saturated mass of soil. This state is known as Sudden drawdown.

- Steady seepage does not represent the critical state, because seepage pressure then acts inward from this slope and tends the increase the stability on upstream side

$$F = \frac{c'L + \tan\phi \, \Sigma(N-U)}{\Sigma T}$$

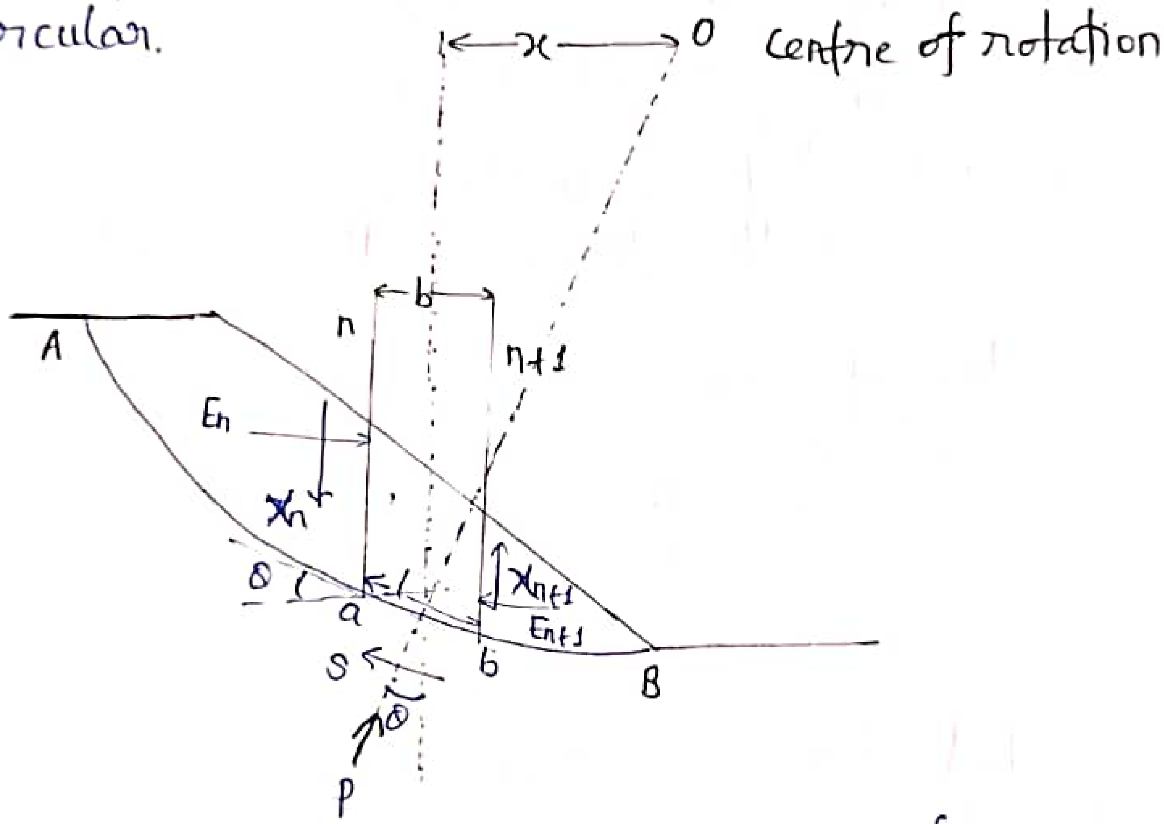
In absence of flow net, the factor of safety

$$F = \frac{cL + \tan\phi \, \Sigma N'}{\Sigma T}$$

Q(3). Discuss Bishop's method of analysis of stability of slopes. Explain in detail how it has been modified by Morgenstern?

Sol^n: In Bishop's method of slices, the effect of the horizontal and shearing forces acting on the slices were neglected.

The shape of the slip surface is assumed to be circular.



let E_n & E_{n+1} = resultant horizontal forces on the section n and n+1 respectively

X_n & X_{n+1} = resultant vertical shear forces.

W = Weight of slice

P = Total normal force acting on the base of the slice

S = shear force acting at the base of the slice

z = height of the slice
l = length of the arc ab of the slice
b = horizontal width of the slice
θ = angle of the base ab of the slice with horizontal
x = horizontal distance of the slice from the centre of the rotation.

$$\text{FOS, } F = \frac{\text{Shear Strength}}{\text{Shear Stress}} = \frac{\tau_f}{\tau} \quad \cdots (i)$$

Total normal stress on the base of the slice, $\sigma = \frac{P}{l \cdot 1}$

effective stress, $\sigma' = \sigma - u = \frac{P}{l} - u \quad \cdots (ii)$

$$\therefore \tau = \frac{1}{F}\tau_f = \frac{1}{F}[c' + (\sigma - u)\tan\phi'] \cdots (iii)$$

$$\tau = \frac{1}{F}[c' + (\frac{P}{l} - u)\tan\phi'] \cdots (iv)$$

Shear force, $S = \tau . l . 1$

→ For equilibrium;

Sliding moment = Restoring or resisting moment

$$\Sigma W . x = \Sigma S . r = \Sigma \tau . l . 1 . r$$

$$\Sigma W . x = \frac{l . r}{F} \Sigma [c' + (\frac{P}{l} - u)\tan\phi']$$

$$\Sigma W . x = \frac{r}{F} \Sigma [c'l + (P - ul)\tan\phi'] \quad \cdots (v)$$

$$\therefore F = \frac{\gamma}{\Sigma W x} \Sigma \left[c'l + (P - ul)\tan\phi' \right] \quad \cdots (v)$$

i) Normal effective force, $P' = P - u.l.1 = P - ul$

ii) Resolving the forces vertically,

Sol:

$$W = P\cos\theta + S\sin\theta \quad \cdots (vi)$$

$$P = P' + ul \quad \& \quad S = \tau l$$

$$\therefore W = (P' + ul)\cos\theta + \tau l \sin\theta$$

$$W = (P' + ul)\cos\theta + \frac{(c'l + P'\tan\phi')\sin\theta}{F}$$

$$W = P'\cos\theta + ul\cos\theta + \frac{c'l\sin\theta}{F} + \frac{P'\tan\phi'\sin\theta}{F}$$

$$W = P'\left(\cos\theta + \frac{\tan\phi'\sin\theta}{F}\right) + l\left(u\cos\theta + \frac{c'\sin\theta}{F}\right)$$

$$\therefore P' = \frac{W - l\left[u\cos\theta + \frac{c'\sin\theta}{F}\right]}{\cos\theta + \frac{\tan\phi\sin\theta}{F}}$$

Substituting the value P' in eq^n (v), we get

$$F = \frac{\gamma}{\Sigma W x} \Sigma \left[c'l + \frac{W - l\left[u\cos\theta + \frac{c'\sin\theta}{F}\right]}{\cos\theta + \frac{\tan\phi'\sin\theta}{F}} \tan\phi' \right]$$

Substituting $x = r\sin\theta$, $b = l\cos\theta$

The pore pressure ratio r_u for any slice is defined as

$r_u = \frac{u}{\gamma z}$ where; z = average height of a slice

$$W = \gamma z b.1$$

$$\gamma_u = \frac{ub}{W}$$

Now;
$$\boxed{F = \frac{1}{\Sigma W \sin\theta} \Sigma \left[\{c'b + W(1-\gamma_u)\tan\phi'\} \frac{\sec\theta}{1 + \frac{\tan\theta \tan\phi'}{F}} \right]}$$

- <u>Bishop and Morgenstern</u>:-

$$F = (m - n\gamma_u)$$

where; m fn stability constant

$$\gamma_u = u/\gamma z$$

$$= \frac{u_z}{\gamma_z} + \frac{\Delta u}{\gamma_z} = \frac{U_z}{\gamma_z} \Big/ \left(B' \frac{\Delta\sigma_1}{\gamma_z} \right)$$

U = pore water pressure

$U_z = 0$ (∵ Compaction at moisture content)

$\gamma_u \doteq B'$ = overall pressure (pore) coefficient

$$= \frac{\Delta U}{\Delta\sigma_1}$$

Schemption pore pressure equation

$$\Delta U = B' [\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)$$

$$B' = \Delta U / \Delta\sigma_1$$

$$B' = B [\Delta\sigma_3 / \Delta\sigma_1 + A(1 - \Delta\sigma_3/\Delta\sigma_1)]$$

Q(5) An 8m deep cut has side slopes of 1.5H : 1V. The soil mass was tested and found to have the following properties : $c = 29.5 kN/m^3$, $\phi = 14°$,

Determine the factor of safety with respect to cohesion against failure of slope when

i) water level in the cut rises upto full height

ii) The water level goes down suddenly $G = 2.7$, $i = 36°$

Sol^n: i) Water level in cut rises upto full height

$$F_c = \frac{c}{\gamma' H S_n}$$

Given, $i = 36°$, $\phi = 14°$, $S_n = 0.061$

$$\gamma_{sat} = \left(\frac{G+e}{1+e}\right)\gamma_w = \left(\frac{2.7+0.8}{1+0.8}\right)9.8$$

$$\gamma_{sat} = 19.075 \ kN/mm^3$$

$$\gamma' = \gamma_{sat} - \gamma = 9.265$$

$$\therefore \quad F_c = \frac{24.5}{9.265 \times 8 \times 0.061}$$

$$\boxed{F_c = 5.418}$$

ii) Water level goes sudden draw down

$$F_c = \frac{c}{\gamma_{sat} H S_n}$$

$F_\phi = 1$, $\cancel{\phi_q}$ $\phi_m = 4°$

$$\phi_w = \phi_m \frac{\gamma'}{\gamma_{sat}}$$

$$\phi_w = \frac{9.265 \times 4}{19.075}$$

$$\phi_w = 6.8^\circ$$

$i = 3.6^\circ$, $\phi = 6.8$, $S_n = 0.11$

$$\therefore F_c = \frac{24.5}{19.075 \times 8 \times 0.11}$$

$$\boxed{F_c = 1.459}$$