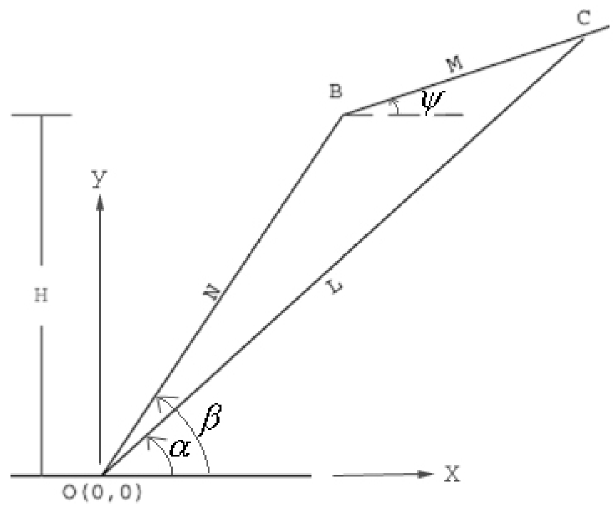
RocPlane

Planar sliding stability analysis for rock slopes

Theory Manual

PLANAR FAILURE

Geometry – No Tension Crack



Known Parameters:
H = Slope Height
β = Slope Dip
α = Failure Plane Dip
ψ = Upper Bench Dip
O = Origin (0,0)
γ = Rock Unit Weight

Unknown Parameters:
B = intersection point, slope & bench
C = intersection point, failure plane & bench
N = slope length, origin → B
M = bench length, B→ C
L = failure plane length, origin → C
A = wedge area
W = wedge weight

$$N = \frac{H}{\sin\beta} \qquad [1]$$

$$B = \{N\cos\beta, H\} = \{H\cot\beta, H\} \qquad [2]$$

To solve for distances L&M, use vector addition:

$$\overrightarrow{OB} + \overrightarrow{BC} = \overrightarrow{OC}$$

$$\begin{Bmatrix} H\cot\beta \\ H \end{Bmatrix} + \begin{Bmatrix} M\cos\psi \\ M\sin\psi \end{Bmatrix} = \begin{Bmatrix} L\cos\alpha \\ L\sin\alpha \end{Bmatrix}$$

This gives two equations:

$$H\cot\beta + M\cos\psi = L\cos\alpha \qquad [3]$$

$$H + M\sin\psi = L\sin\alpha \qquad [4]$$

From equations [4]:

$$M = \frac{L\sin\alpha - H}{\sin\psi} \qquad [5]$$

Substituting [5] into [3]:

$$H\cot\beta + (L\sin\alpha - H)\cot\psi = L\cos\alpha$$

$$H(\cot\beta - \cot\psi) = L(\cos\alpha - \sin\alpha\cot\psi)$$

$$L = \frac{H(1-\cot\beta\tan\psi)}{\sin\alpha - \cos\alpha\tan\psi} \qquad [6]$$

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From equation [3]:

$$M = \frac{L\cos\alpha - H\cot\beta}{\cos\psi} \qquad [7]$$

To calculate L and M, use equations [6] & [7]. Do not use equation [5] because $\psi = 0$ is common & M is irresolvable using [5].

$$C = \{L\cos\alpha, L\sin\alpha\} \qquad [8]$$

Area Calculation:

$$A = \frac{1}{2}\left\| B \times C \right\|$$

$$A = \frac{1}{2}\left\| B_x C_y - B_y C_x \right\| \qquad [9]$$

$$W = A \cdot \gamma \qquad [10]$$

Flow Chart:

1. Solve for N (eq. [1])
2. Solve for B (eq. [2])
3. Solve for L (eq. [6])
4. Solve for M (eq. [7])
5. Solve for C (eq. [8])
6. Solve for A (eq. [9])
7. Solve for W (eq. [10])

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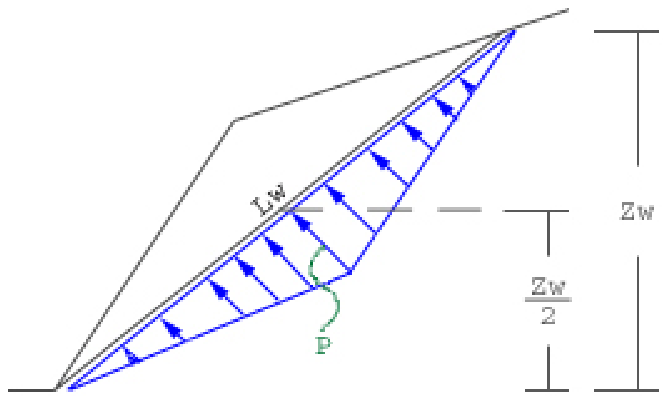
Water Forces – No Tension Crack

Case 1: Maximum Pressure Mid Height



$0 \le Z_w \le L \sin\alpha$

Lw = wetted length = $\frac{Zw}{\sin\alpha}$

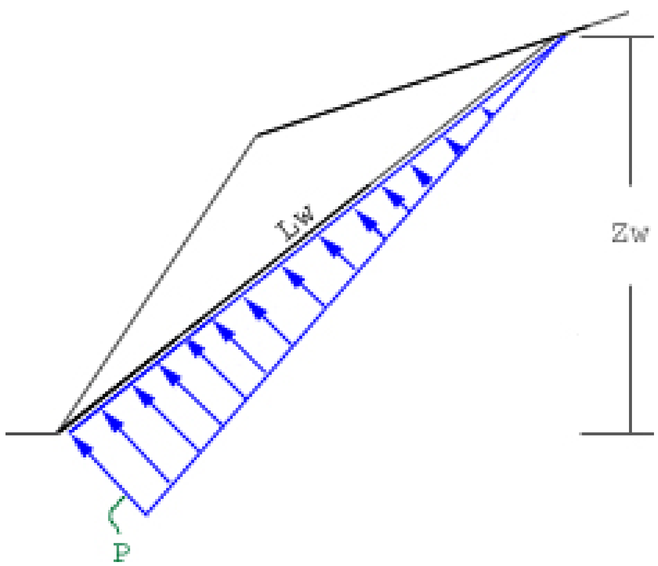
P = Maximum water pressure

$= \frac{1}{2} Z_w \gamma_w$

U = water force = $\frac{1}{2} P \cdot L_w = \frac{1}{2}\left(\frac{1}{2} Z_w \cdot \gamma_w\right)\left(\frac{Z_w}{\sin\alpha}\right)$

U = $\frac{Z_w{}^2 \cdot \gamma_w}{4\sin\alpha}$ [11]

Case 2: Maximum Pressure at Toe



$$Lw = \frac{Z_w}{\sin\alpha}$$

$$P = \gamma Z_w$$

$$U = \frac{1}{2} P \cdot L_w = \frac{1}{2}(\gamma \cdot Z_w)\left(\frac{Z_w}{\sin\alpha}\right)$$

$$U = \frac{Z_w{}^2 \cdot \gamma_w}{2\sin\alpha}$$ [12]

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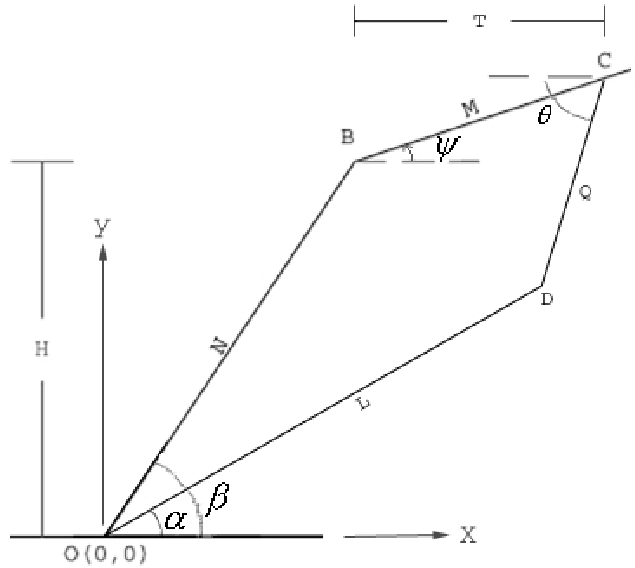
Geometry – Tension Crack



Known Parameters:
H = Slope Height
β = Slope Dip
α = Failure Plane Dip

ψ = Upper Bench Dip
T = Tension Crack Distance
θ = Tension Crack Dip
O = Origin (0,0)
γ = Rock Unit Weight

Unknown Parameters:
B = Slope/Bench intersection point
C = Tension Crack/Bench intersection point
D = Failure Plane/Tension Crack intersection point
N = Slope Length, O → B
M = Bench Length, B → C
L = Failure Plane Length, O → D
Q = Tension Crack Length, D → C
A = Wedge Area
W = Wedge Weight

As in the no tension crack case:

$$N = \frac{H}{\sin\beta}$$

$$B = \{H\cot\beta, H\}$$

Now,

$$C = B + \{T, T\tan\psi\} \quad [13]$$

$$M = \frac{T}{\cos\psi} \quad [14]$$

Let's solve for D,Q,L:

$$D = C - \{Q\cos\theta, Q\sin\theta\} \quad [15]$$

$$D = \{L\cos\alpha, L\sin\alpha\} \quad [16]$$

Equate equations [15]&[16]:

$$\{C_x, C_y\} - \{Q\cos\theta, Q\sin\theta\} = \{L\cos\alpha, L\sin\alpha\}$$

or $$L = \frac{C_x - Q\cos\theta}{\cos\alpha} \quad [17]$$

and $$L = \frac{C_y - Q\sin\theta}{\sin\alpha} \quad [18]$$

Equate equations [17]&[18] and solve for Q:

$$Q = \frac{C_y \cot\alpha - C_x}{\sin\theta\cot\alpha - \cos\theta} \quad [19]$$

Area Calculation:

$$A = \frac{1}{2}\left\| B \times D \right\| + \frac{1}{2}\left\| (D - B) \times (C - B) \right\|$$

$$A = \frac{1}{2}\left\| B_x D_y - B_y D_x \right\| + \frac{1}{2}\left\| (D_x - B_x)(C_y - B_y) - (D_y - B_y)(C_x - B_x) \right\| \quad [20]$$

$$W = A \cdot \gamma$$

Flow Chart:

1. Solve for N (eq. [1])
2. Solve for B (eq. [2])
3. Solve for C (eq. [13])
4. Solve for M (eq. [14])
5. Solve for Q (eq. [19])
6. Solve for L (eq. [17])
7. Solve for D (eq. [16])
8. Solve for A (eq. [20])
9. Solve for W (eq. [10])

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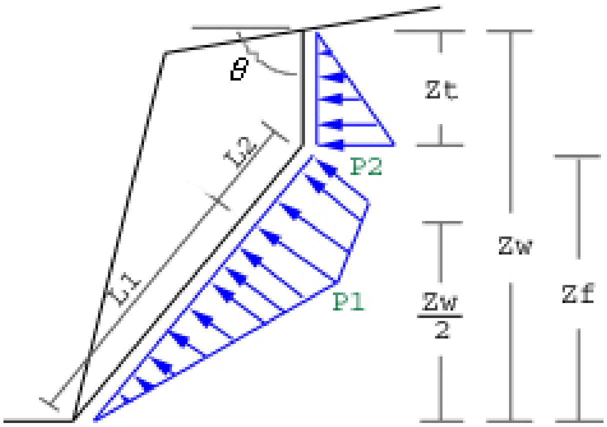
Water Forces – Tension Crack

Case 1: Maximum Pressure Mid Height



$Z_t = Z_w - Z_f$
$Z_f = D_y = L \sin\alpha$
U = Water force on failure plane
V = Water force on tension crack

Type A. If $Z_w \leq Z_f$

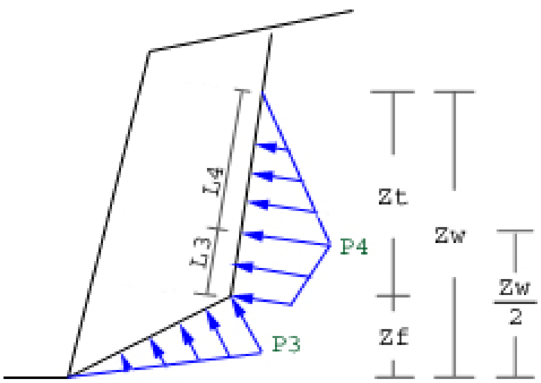
$$U = \frac{Z_w{}^2 \cdot \gamma_w}{4\sin\alpha} \quad ; \qquad V = 0 \qquad [20]$$

Type B. If $Z_w > Z_f$ and $Z_w/2 < Z_f$

$$L_1 = \frac{Zw}{2\sin\alpha}$$
$$L_2 = L - L_1$$
$$P_1 = \frac{1}{2} Z_w \cdot \gamma_w$$
$$P_2 = \gamma_w \cdot Z_t$$
$$U = \frac{1}{2} P_1 \cdot L_1 + \frac{1}{2}(P_1 + P_2) L_2$$
$$V = \frac{Z_t{}^2 \cdot \gamma_w}{2\sin\theta}$$

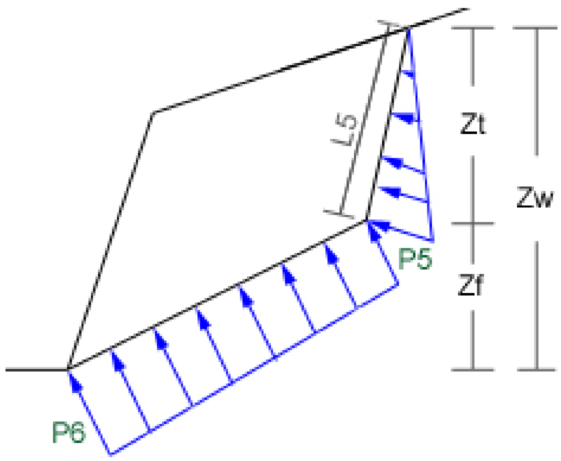
[21]

Type C. If $Z_w > Z_f$ and $Z_w/2 \geq Z_f$



$$
\left.
\begin{aligned}
P_3 &= \gamma \cdot Z_f \\
P_4 &= \frac{1}{2}\gamma \cdot Z_w \\
L_3 &= \frac{\left(\frac{Z_w}{2} - Z_f\right)}{\sin\theta} \\
L_4 &= \frac{Z_w}{2\sin\theta} \\
U &= \frac{1}{2}L \cdot P_3 \\
V &= \frac{1}{2}(P_3 + P_4)L_3 + \frac{1}{2}P_4 L_4
\end{aligned}
\right] \qquad [22]
$$

Case 2: Maximum Pressure at Toe



$$
\left.
\begin{aligned}
P_5 &= \gamma \cdot Z_t \\
P_6 &= \gamma \cdot Z_w \\
L_5 &= \frac{Z_t}{\sin\theta} \\
U &= \frac{1}{2}(P_5 + P_6)L \\
V &= \frac{1}{2}P_5 \cdot L_5
\end{aligned}
\right] \qquad [23]
$$

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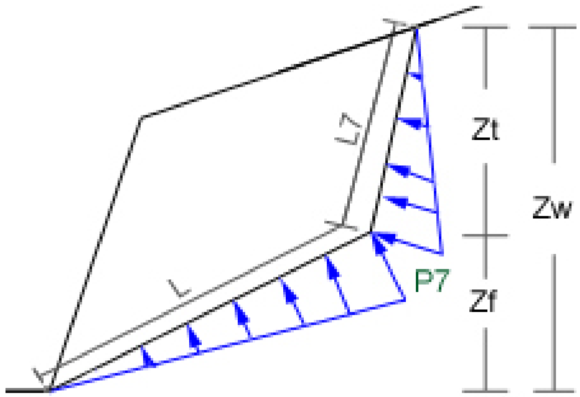
Case 3: Maximum Pressure at Base of Tension Crack



$Z_t = Z_w - Z_f$

$$\left.\begin{aligned} P_7 &= \gamma \cdot Z_t \\ L_7 &= \frac{Z_t}{\sin\theta} \\ U &= \frac{1}{2} P_7 \cdot L \\ V &= \frac{1}{2} P_7 \cdot L_7 \end{aligned}\right] \qquad [24]$$

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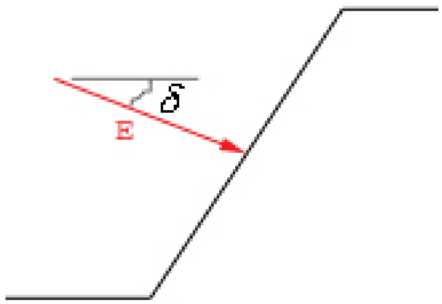
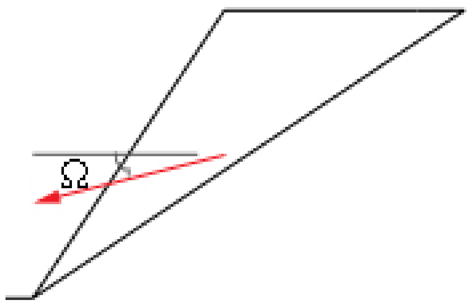
External Force



$$E_x = E \cdot \cos\delta$$
$$E_y = E \cdot \sin\delta$$

Seismic Force

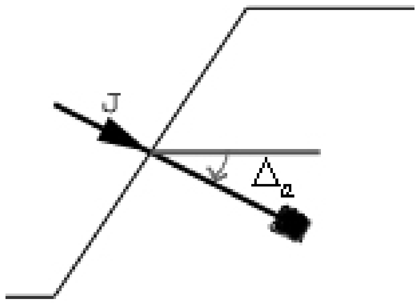


$$S = W_y \cdot \alpha_s$$

α_s = Seismic Coefficient
W = Weight of Wedge
W_y = Directional Weight Component

$$W_y = -W$$
$$S_x = S \cdot \cos\Omega$$
$$S_y = S \cdot \sin\Omega$$

Active Bolt Force



J = Active Bolt Force

$$J_x = J \cdot \cos\Delta_a$$
$$J_y = -J \cdot \sin\Delta_a$$

Passive Bolt Force

$$K_x = K \cdot \cos\Delta_p$$
$$K_y = -K \cdot \sin\Delta_p$$

K = Passive Bolt Force

Active Water Force (Tension Crack)

$$V_x = -V \cdot \sin\theta$$
$$V_y = V \cdot \cos\theta$$

V = Tension Crack Water Force

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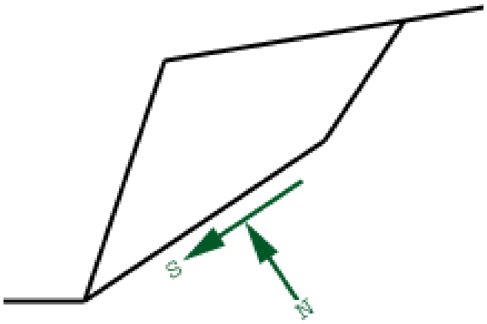
Normal/Shear Force on Failure Plane



W = Wedge Weight
W_y = -W

Active Forces Only:

$\sum F_y + \uparrow$ $$F_y = W_y + E_y + S_y + J_y + V_y$$

$$F_y = -A \cdot \gamma - E \cdot \sin\delta - S \cdot \sin\Omega - J \cdot \sin\Delta_a + V \cdot \cos\theta \quad [24]$$

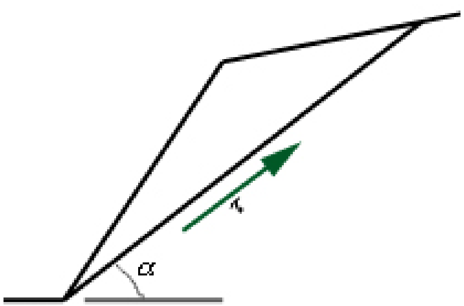
$\sum F_x \xrightarrow{+}$ $$F_x = E_x + S_x + J_x + V_x$$

$$F_x = E \cdot \cos\delta - S \cdot \cos\Omega + J \cdot \cos\Delta_a - V \cdot \sin\theta \quad [25]$$

$$N = -(F_y + K_y)\cos\alpha + (F_x + K_x)\sin\alpha - U \quad [26]$$

$$S = -F_y \cdot \sin\alpha - F_x \cdot \cos\alpha \quad [27]$$

Shear Strength on Failure Plane



Strength Criterion = Mohr Coulomb

C = Cohesion
N = Normal Force
ϕ = Friction Angle
L = Length of Failure Surface

$$\tau = c \cdot L + N \cdot \tan\phi + \underbrace{K_x \cdot \cos\alpha + K_y \cdot \sin\alpha}_{Passive \quad Bolt} \quad [28]$$

Factor of Safety

$$F = \frac{Resisting \quad Forces}{Driving \quad Forces}$$

$$F = \frac{Shear \quad Strength}{Shear \quad Force} = \frac{\tau}{S} \quad [29]$$