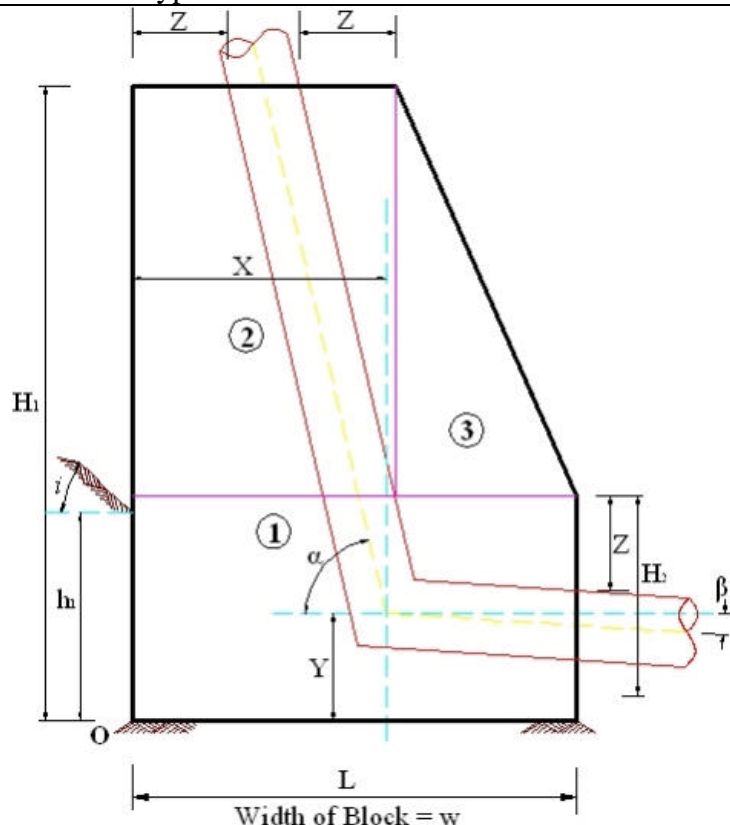


Design of an Anchor Block – Type 4

Model of Type 4 Anchor Block:



Example: Anchor block of *Chhahare Khola MHP, Manang*

$$H_1 = 2.0 \text{ m} \quad L = 1.4 \text{ m}$$

$$w = 1.3 \text{ m} \quad Z = 0.3 \text{ m}$$

$$h_1 = 0.6 \text{ m} \quad h_2 = 0.1 \text{ m}$$

$$X = 0.8 \text{ m} \quad i = 4^\circ$$

$$l_c = 0 \text{ m} \quad h_c = 0 \text{ m}$$

$$a = 77^\circ \quad b = 4^\circ$$

$$\text{Pipe Diameter, } d = 220 \text{ mm}$$

$$\text{Pipe Thickness, } t = 4 \text{ mm}$$

$$\text{Discharge, } Q = 80 \text{ lps}$$

$$\text{Gross Head, } h_{\text{gross}} = 64 \text{ m}$$

$$\text{Surge Head, } h_{\text{surge}} = 5 \text{ m}$$

$$\text{Distance to u/s support pier, } L_{2u} = 4 \text{ m}$$

$$L_{1u} = 2 \text{ m}$$

$$\text{Distance to d/s support pier, } L_{2d} = 4 \text{ m}$$

$$L_{1d} = 2 \text{ m}$$

$$\text{Distance to u/s expansion joint} = 24 \text{ m}$$

$$L_{4u} = 24 \text{ m}$$

$$\text{Number of piers at upstream} = 5$$

Relation Used for Area Calculation:

A_1	$H_2 L$	0.99 m^2
A_2	$(H_1 - H_2) \left[\frac{d + 2t}{\sin a} + 2Z \right]$	1.08 m^2
A_3	$\frac{1}{2} (H_1 - H_2) \left[L - \frac{d + 2t}{\sin a} - 2Z \right]$	0.37 m^2

Relation Used for Centre of Gravity Calculation:

X_1	$\frac{1}{2} L$	0.70 m
X_2	$\frac{d + 2t}{2 \sin a} + Z$	0.42 m
X_3	$\frac{1}{3} \left[L + 2 \frac{d + 2t}{\sin a} + 4Z \right]$	1.02 m

Relation Used for Calculating Deduction Volume Occupied by Penstock:

V_p	$\frac{\rho}{4} l_u (d_u + 2t)^2 + \frac{\rho}{4} l_d (d_d + 2t)^2$	0.09 m^3
Where	$Y = H_1 - \left(X - Z - \frac{d + 2t}{2 \sin a} \right) \tan a$ $H_2 = Y - (L - X) \tan b + \frac{d + 2t}{2 \cos b} + Z$ $l_u = \frac{H_1 - Y}{\sin a}$ $l_d = \frac{L - X}{\cos b}$	$Y = 0.34 \text{ m}$ $H_2 = 0.71 \text{ m}$ $l_u = 1.70 \text{ m}$ $l_d = 0.60 \text{ m}$

Further Design Procedure for the Block,

$$\begin{aligned} \text{Total head, } h_{total} &= h_{gross} + h_{surge} &= 64 + 5 \\ & &= 69 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Block volume excluding pipe volume, (V)} &= w (A_1 + A_2 + A_3) - V_p \\ &= 1.30 (0.99 + 1.08 + 0.37) - 0.09 \text{ m}^3 \\ &= 3.08 \text{ m}^3 \end{aligned}$$

$$\text{Unit weight of concrete, (} g_{concrete} \text{)} = 22 \text{ kN/m}^3$$

$$\begin{aligned} \text{Weight of block, } W_B &= V g_{concrete} \\ &= 3.08 \times 22 \\ &= 67.80 \text{ kN} \end{aligned}$$

$$\text{Unit weight of steel, (} g_{steel} \text{)} = 77 \text{ kN/m}^3$$

$$\begin{aligned} \text{Weight of pipe, } W_P &= p(d+t)t g_{steel} \\ &= p \times 0.224 \times 0.004 \times 77 \\ &= 0.22 \text{ kN/m} \end{aligned}$$

$$\text{Unit weight of water, (} g_{water} \text{)} = 9.81 \text{ kN/m}^3$$

$$\begin{aligned} \text{Weight of water, } W_W &= \frac{pd^2}{4} \times g_{water} \\ &= \frac{p \times 0.22^2}{4} \times 9.81 \\ &= 0.37 \text{ kN/m} \end{aligned}$$

$$W_P + W_W = 0.59 \text{ kN/m}$$

Calculation for relevant forces:

$$\begin{aligned} 1. F_{1u} &= (W_P + W_W)L_{1u} \cos a \\ &= 0.59 \times 2 \times \cos 77^\circ = 0.27 \text{ kN} \end{aligned}$$

$$\begin{aligned} 2. F_{1d} &= (W_P + W_W)L_{1d} \cos b \\ &= 0.59 \times 2 \times \cos 4^\circ = 1.18 \text{ kN} \end{aligned}$$

$$\begin{aligned} 3. \text{ Frictional force per support pier:} \\ &= \pm f(W_P + W_W)L_{2u} \cos a \\ \text{Where } f &= 0.6 \text{ for steel on concrete} \\ &= \pm 0.6 \times 0.59 \times 4 \times \cos 77^\circ = \pm 0.32 \text{ kN per support pier} \end{aligned}$$

Since there are 5 support piers then,

$$F_{2u} = \pm 0.32 \times 5 = \pm 1.60 \text{ kN}$$

Note that F_{2d} is zero since an expansion joint is located immediately downstream of the anchor block.

$$\begin{aligned} 4. F_3 &= 2g_{water} h_{total} \frac{pd^2}{4} \sin\left(\frac{b-a}{2}\right) \\ &= 2 \times 9.81 \times 69 \times \frac{p \times 0.22^2}{4} \times \sin\left(\frac{4-77}{2}\right) = -30.61 \text{ kN} \end{aligned}$$

$$5. F_{4u} = W_p L_{4u} \sin \alpha$$

$$= 0.22 \times 24 \times \sin 77^\circ = 5.14 \text{ kN}$$

F_{4d} is negligible since an expansion joint is placed immediately downstream of the anchor block, i.e., $L_{4d} \sim 0$ and therefore $F_{4d} \sim 0$

$$6. F_5 = Ea\Delta T p(d+t)t$$

Since the expansion joint is installed between the blocks,

$$F_5 = 0$$

$$7. F_6 = \pm 100d$$

$$= \pm 100 \times 0.22 = \pm 22 \text{ kN}$$

$$8. F_7 = g_{water} h_{total} p(d+t)t$$

$$F_{7u} = 9.81 \times (69 - 24 \sin \alpha) \times p \times 0.224 \times 0.004$$

$$= 1.26 \text{ kN}$$

$$F_{7d} = 9.81 \times 69 \times p \times 0.224 \times 0.004$$

$$= 1.91 \text{ kN}$$

Note that as discussed earlier the resultant of these forces is insignificant.

$$9. F_8 = \frac{8Q^2}{pd^2} \sin\left(\frac{b-a}{2}\right)$$

$$= \frac{8 \times 0.08^2}{p \times 0.22^2} \sin\left(\frac{4-77}{2}\right)$$

$$= -0.20 \text{ kN}$$

Note that as discussed earlier, this force is insignificant.

$$10. F_9 = g_{water} h_{total} \frac{p}{4} (d_u^2 - d_d^2)$$

Since the pipe diameter does not change,

$$F_9 = 0$$

11. Soil force, F_{10}

$$\text{Unit weight of concrete, } (\gamma_{soil}) = 20 \text{ kN/m}^3$$

$$\text{For stiff clay and stiff sandy clay } (\phi) = 32^\circ$$

$$K_a = \frac{\cos i - \sqrt{\cos^2 i - \cos^2 \phi}}{\cos i + \sqrt{\cos^2 i - \cos^2 \phi}}$$

Since, $i = 4^\circ$, then $K_a = 0.31$

$$F_{10} = K_a \gamma \frac{h_1^2}{2} \cos i$$

But in this example,

$$h_1 - h_2 = 0.6 - 0.1 = 0.5 < 1, \text{ So } F_{10} \text{ is insignificant, therefore } F_{10} = 0$$

Resolution of forces:

$$\mathbf{a} = 77^\circ, \mathbf{b} = 4^\circ$$

Forces (kN)	X – component (kN) → +	Y – component (kN) ↓ +
$F_{1u} = 0.27$	$- F_{1u} \sin \mathbf{a} = - 0.26$	$+ F_{1u} \cos \mathbf{a} = + 0.06$
$F_{1d} = 1.18$	$- F_{1u} \sin \mathbf{b} = - 0.08$	$+ F_{1u} \cos \mathbf{b} = + 1.18$
$F_{2u} = \pm 1.60$	$\pm F_{2u} \cos \mathbf{a} = \pm 0.36$ Negative during ¹ expansion Positive during ² contraction	$\pm F_{2u} \sin \mathbf{a} = \pm 1.56$ Negative during ¹ expansion Positive during ² contraction
$F_3 = - 30.61$	$+ F_3 \sin \left(\frac{\mathbf{b} + \mathbf{a}}{2} \right) = - 19.88$	$- F_3 \cos \left(\frac{\mathbf{b} + \mathbf{a}}{2} \right) = + 23.28$
$F_{4u} = 5.14$	$+ F_{4u} \cos \mathbf{a} = + 1.16$	$+ F_{4u} \sin \mathbf{a} = + 5.01$
$F_6 = \pm 22$	$\pm F_6 (\cos \mathbf{a} - \cos \mathbf{b}) = \pm (- 17.00)$ Positive during ¹ expansion Negative during ² contraction	$\pm F_6 (\sin \mathbf{b} - \sin \mathbf{a}) = \pm (- 19.90)$ Positive during ¹ expansion Negative during ² contraction
$F_{7u} = 1.26$	$+ F_{7u} \cos \mathbf{a} = + 0.28$	$+ F_{7u} \sin \mathbf{a} = + 1.23$
$F_{7d} = 1.91$	$- F_{7d} \cos \mathbf{b} = - 1.90$	$- F_{7d} \sin \mathbf{b} = - 0.13$
$F_8 = - 0.20$	$+ F_8 \sin \left(\frac{\mathbf{b} + \mathbf{a}}{2} \right) = - 0.13$	$- F_8 \cos \left(\frac{\mathbf{b} + \mathbf{a}}{2} \right) = + 0.15$
$W_B = 67.80$	0	+ 67.80
SUM	$\sum H = - 38.17$ ¹ Expansion $\sum H = - 3.45$ ² Contraction	$\sum V = + 77.12$ ¹ Expansion $\sum V = + 120.04$ ² Contraction

Note that forces are positive in X-direction is towards the right and Y-direction downwards.

$$\begin{aligned} \text{Sum of horizontal forces that act at the bend,} &= \sum H - F_{10x} \\ \text{¹Expansion case} &= - 38.17 - 0 &= - 38.17 \text{ kN} \leftarrow \\ \text{²Contraction case} &= - 3.45 - 0 &= - 3.45 \text{ kN} \leftarrow \end{aligned}$$

$$\begin{aligned} \text{Sum of vertical forces that act at the bend,} &= \sum V - F_{10y} - W_B \\ \text{¹Expansion case} &= + 77.12 - 0 - 67.80 = + 9.32 \text{ kN} \downarrow \\ \text{²Contraction case} &= + 120.04 - 0 - 67.80 = + 52.24 \text{ kN} \downarrow \end{aligned}$$

Calculate for the centre of gravity of the block from the upstream face of the block taking the moment of mass. The effect of the pipe passing through the block is considered negligible, so need not be calculated.

$$\begin{aligned} \bar{X} &= \frac{\sum A_i X_i}{\sum A_i} \times \frac{w \mathbf{r}_{concrete}}{w \mathbf{r}_{concrete}} \\ &= \frac{0.99 \times 0.70 + 1.08 \times 0.42 + 0.37 \times 1.02}{0.99 + 1.08 + 0.37} = 0.62 \text{ m} \end{aligned}$$

∴ The weight of the block W_B acts 0.62 m from point O.

A force diagram on the block is as shown in Figure;

Checking for Safety of the Block:

1. Checking safety against overturning

¹Expansion Case

Taking sum of moment about point O with clockwise moments as positive:

$$\begin{aligned}\sum M \text{ at O,} \\ &= 67.80 \times 0.62 + 9.32 \times 0.80 - 38.17 \times 0.34 \\ &= 36.52 \text{ kN-m}\end{aligned}$$

$$\frac{\sum M}{\sum V} = \frac{36.52}{77.12} = 0.48 \text{ m}$$

$$e = \left| \frac{L}{2} - \frac{\sum M}{\sum V} \right| = |0.70 - 0.48| = 0.22$$

$$e_{\text{allowable}} = \frac{L_{\text{base}}}{6} = \frac{1.40}{6} = 0.23$$

$$\therefore e < e_{\text{allowable}} \quad \text{OK}$$

²Contraction Case

Taking sum of moment about point O with clockwise moments as positive:

$$\begin{aligned}\sum M \text{ at O,} \\ &= 67.80 \times 0.62 + 52.24 \times 0.80 - 3.45 \times 0.34 \\ &= 82.66 \text{ kN-m}\end{aligned}$$

$$\frac{\sum M}{\sum V} = \frac{82.66}{120.04} = 0.69 \text{ m}$$

$$e = \left| \frac{L}{2} - \frac{\sum M}{\sum V} \right| = |0.70 - 0.69| = 0.01$$

$$e_{\text{allowable}} = \frac{L_{\text{base}}}{6} = \frac{1.40}{6} = 0.23$$

$$\therefore e < e_{\text{allowable}} \quad \text{OK}$$

Since $e < e_{\text{allowable}}$ for both cases, the structure is safe against overturning.

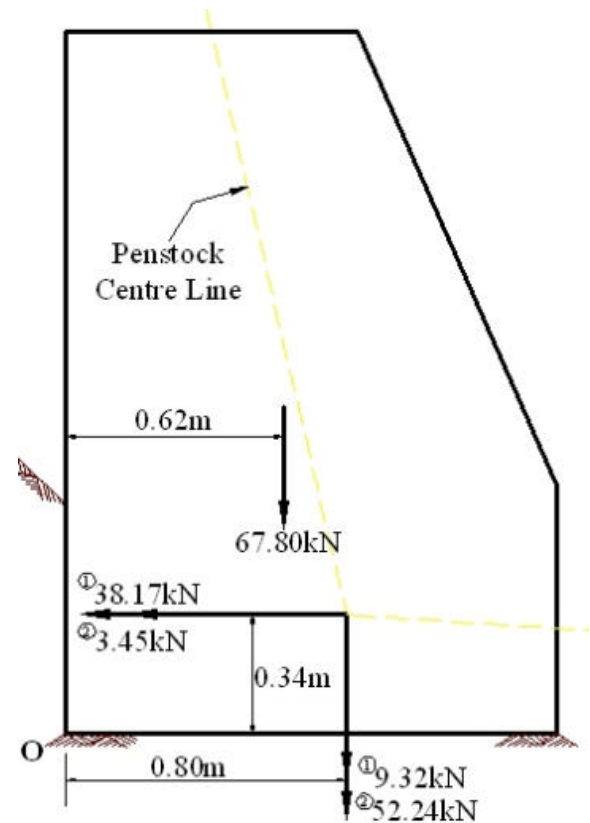
2. Checking safety on bearing capacity

For very stiff boulder clay allowable bearing pressure is 350 kN/m^2

¹Expansion Case

$$P_{\text{base}} = \frac{\sum V}{A_{\text{base}}} \left(1 + \frac{6e}{L_{\text{base}}} \right) = \frac{77.12}{1.4 \times 1.3} \left(1 + \frac{6 \times 0.22}{1.4} \right) = 82.33 \text{ kN/m}^2$$

$$P_{\text{base}} < P_{\text{allowable}} \quad \text{OK}$$



²Contraction Case

$$P_{base} = \frac{\sum V}{A_{base}} \left(1 + \frac{6e}{L_{base}} \right) = \frac{120.04}{1.4 \times 1.3} \left(1 + \frac{6 \times 0.01}{1.4} \right) = 68.78 \text{ kN/m}^2$$

$$P_{base} < P_{allowable} \quad \text{OK}$$

In both cases $P_{base} < P_{allowable} = 350 \text{ kN/m}^2$, \therefore the structure is safe against sinking.

3. Checking safety against sliding

¹Expansion Case

$$\sum H < m \sum V$$

$m = 0.5$ for concrete/masonry on soil

$$38.17 \text{ kN} < 0.5 \times 77.12 \text{ kN}$$

$$38.17 \text{ kN} < 38.56 \text{ kN} \quad \text{OK}$$

²Contraction Case

$$\sum H < m \sum V$$

$m = 0.5$ for concrete/masonry on soil

$$3.45 \text{ kN} < 0.5 \times 120.04 \text{ kN}$$

$$3.45 \text{ kN} < 60.02 \text{ kN} \quad \text{OK}$$

Since, $\sum H < m \sum V$ in both cases the structure is safe against sliding.

\therefore The anchor block is stable.