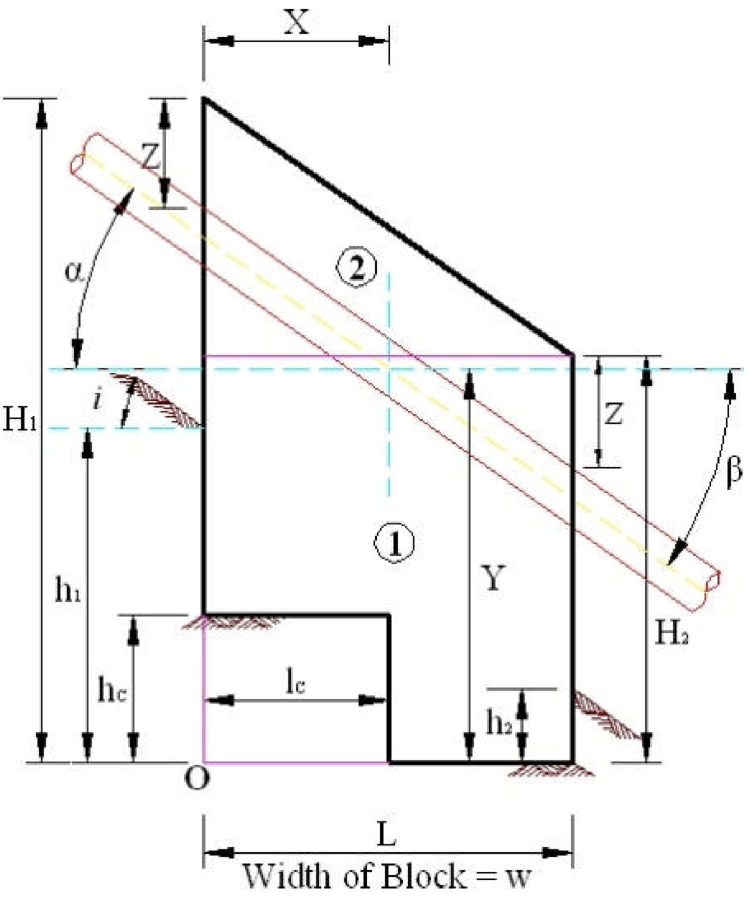
Design of an Anchor Block - Type 1

Model of Type 1 Anchor Block:



Example: Anchor block of *Chandra Jyoti MHP, Kavre*

H_1 = 1.8 m	L = 1.0 m
w = 0.8 m	Z = 0.3 m
h_1 = 0.6 m	h_2 = 0.3 m
X = 0.5 m	i = 51°
l_c = 0.5 m	h_c = 0.4 m
a = 35°	b = 35°

Pipe Diameter, d = 130 mm
Pipe Thickness, t = 4 mm
Discharge, Q = 20 lps
Gross Head, h_{gross} = 155 m
Surge Head, h_{surge} = 95 m

Distance to u/s support pier, L_{2u} = 4m
L_{1u} = 2 m
Distance to d/s support pier, L_{2d} = 4m
L_{1d} = 2 m

Distance to u/s expansion joint = 30m
L_{4u} = 30 m
Number of piers at upstream = 7

Relation Used for Area Calculation:		
A_1	H_2L	1.10 m^2
A_2	$\frac{1}{2}L(H_1 - H_2)$	0.35 m^2
Relation Used for Centre of Gravity Calculation:		
X_1	$\frac{1}{2}L$	0.50 m
X_2	$\frac{1}{3}L$	0.33 m
Relation Used for Calculating Deduction Volume Occupied by Penstock:		
V_p	$\frac{p}{4}l_u(d_u + 2t)^2 + \frac{p}{4}l_d(d_d + 2t)^2$	0.02 m^3
Where	$Y = H_1 - Z - \frac{d + 2t}{2\cos a} - X\tan a$	Y = 1.07 m
	$H_2 = Y - (L - X)\tan b + \frac{d + 2t}{2\cos b} + Z$	H_2 = 1.01 m
	$l_u = \frac{X}{\cos a}$	l_u = 0.61 m
	$l_d = \frac{L - X}{\cos b}$	l_d = 0.61 m

Further Design Procedure for the Block,

Total head, h_{total} $= h_{gross} + h_{surge}$ $= 155 + 95$

$= 250$ m

Block volume excluding pipe volume, (V) $= w\,(A_1 + A_2 - l_c\, h_c) - V_p$

$= 0.8\,(1.10 + 0.35 - 0.5 \times 0.4) - 0.02\ m^3$

$= 0.98\ m^3$

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

Weight of block, W_B $= V g_{\,concrete}$

$= 0.98 \times 22$

$= 21.56$ kN

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

Weight of pipe, W_P $= p\,(d + t)tg_{\,steel}$

$= p \times 0.134 \times 0.004 \times 77$

$= 0.13$ kN/m

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

Weight of water, W_W $= \frac{pd^2}{4} \times g_{\,water}$

$= \frac{p\,(0.13)^2}{4} \times 9.81$

$= 0.13$ kN/m

$W_P + W_W$ $= 0.26$ kN/m

Calculation for relevant forces:

1. F_{1u} $= (W_P + W_W)L_{1u} \cos a$

   $= 0.26 \times 2 \times \cos 35°$ $= 0.43$ kN

2. F_{1d} $= (W_P + W_W)L_{1d} \cos b$

   $= 0.26 \times 2 \times \cos 35°$ $= 0.43$ kN

3. Frictional force per support pier:

   $= \pm f\,(W_P + W_W)L_{2u} \cos a$

   Where $f = 0.6$ for steel on concrete

   $= \pm 0.6 \times 0.26 \times 4 \times \cos 35° = \pm 0.51$ kN per support pier

   Since there are 7 support piers then,

   F_{2u} $= \pm 0.51 \times 7$ $= \pm 3.58$ kN

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

4. F_3 $= 2g_{\,water} h_{total} \frac{pd^2}{4} \sin\left(\frac{b - a}{2}\right)$

   Since, $a = b = 35°$, $F_3 = 0$

5. F_{4u} $= W_P L_{4u} \sin a$

   $= 0.13 \times 30 \times \sin 35°$ $= 2.24$ kN

   Note that F_{4u} is insignificant since a is less than 20° and could have been ignored. F_{4u} has been calculated here only to show how it is done. F_{4d} is negligible since an expansion joint is placed immediately downstream of the anchor block, i.e., L_{4d} ˜ 0 and therefore F_{4d} ˜ 0.

6. F_5 $= Ea\Delta Tp\,(d+t)t$

   Since the expansion joint is installed between the blocks,

   F_5 = 0

7. F_6 $= \pm 100d$

   $= \pm\, 100 \times 0.13$ $= \pm\, 13$ kN

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

   F_{7u} $= 9.81 \times (250 - 30 \sin a) \times p \times 0.134 \times 0.004$

   = 3.85 kN

   F_{7d} $= 9.81 \times 250 \times p \times 0.134 \times 0.004$

   = 4.13 kN

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

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

   Since, $a = b = 35°$,

   F_8 = 0

   Note that as discussed earlier, this force is insignificant.

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

    Since the pipe diameter does not change,

    F_9 = 0

11. Soil force, F_{10}

    Unit weight of concrete, (?$_{soil}$) = 20 kN/m^3

    For stiff clay and stiff sandy clay (Ø) = 30°

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

    Since, Ø = 30° is less than i = 51°, then K_a will be imaginary. So take $K_a = 1$

    $$F_{10} = K_a w \frac{g_{soil} h_1^{\,2}}{2} \cos i$$

    But in this example,

    $h_1 - h_2 = 0.6 - 0.3 = 0.3 < 1$, So F_{10} is insignificant, therefore $F_{10} = 0$

Resolution of forces:

$a = b = 35°$

Forces (kN)	X – component (kN) $\rightarrow$ +	Y – component (kN) $\downarrow$ +
$F_{1u} = 0.43$	$- F_{1u} \sin a = -0.25$	$+ F_{1u} \cos a = +0.35$
$F_{1d} = 0.43$	$- F_{1u} \sin b = -0.25$	$+ F_{1u} \cos b = +0.35$
$F_{2u} = \pm 3.58$	$\pm F_{2u} \cos a = \pm 2.93$ Negative during [1]expansion Positive during [2]contraction	$\pm F_{2u} \sin a = \pm 2.05$ Negative during [1]expansion Positive during [2]contraction
$F_{4u} = 2.24$	$+ F_{4u} \cos a = +1.83$	$+ F_{4u} \sin a = +1.28$
$F_6 = \pm 13$	$\pm F_6 (\cos a - \cos b) = 0$ Positive during [1]expansion Negative during [2]contraction	$\pm F_6 (\sin b - \sin a) = 0$ Positive during [1]expansion Negative during [2]contraction
$F_{7u} = 3.85$	$+ F_{7u} \cos a = +3.15$	$+ F_{7u} \sin a = +2.21$
$F_{7d} = 4.13$	$- F_{7d} \cos b = -3.38$	$- F_{7d} \sin b = -2.37$
$W_B = 21.56$	0	+ 21.56
SUM	$\sum H = -1.83$ [1]Expansion $\sum H = +4.03$ [2]Contraction	$\sum V = +21.33$ [1]Expansion $\sum V = +25.43$ [2]Contraction

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

Sum of horizontal forces that act at the bend, $= \sum H - F_{10x}$

[1]Expansion case $= -1.83 - 0$ $= -1.83$ kN $\leftarrow$

[2]Contraction case $= +4.03 - 0$ $= +4.03$ kN $\rightarrow$

Sum of vertical forces that act at the bend, $= \sum V - F_{10y} - W_B$

[1]Expansion case $= +21.33 - 0 - 21.56$ $= -0.23$ kN $\uparrow$

[2]Contraction case $= +25.43 - 0 - 21.56$ $= +3.87$ kN $\downarrow$

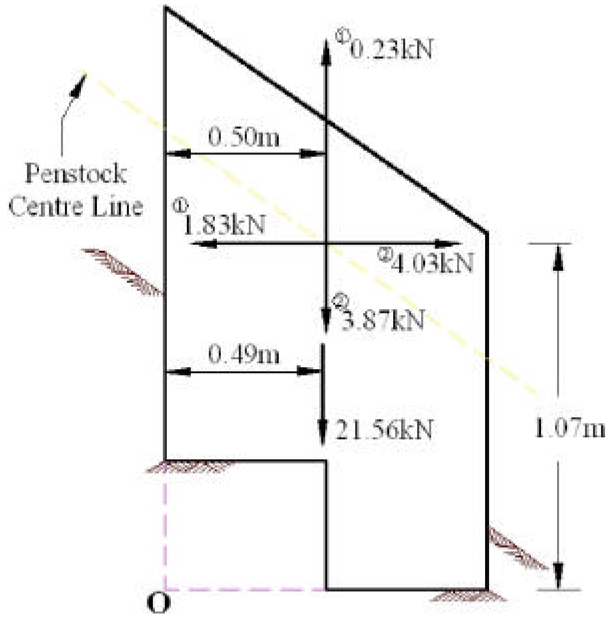
Calculate for the centre of gravity of the block from the upstream face of the block taking the moment of mass. The effect of the pipe passing through the block is considered negligible, so need not be calculated.

$$\overline{X} = \frac{\sum A_i X_i}{\sum A_i} \times \frac{wr_{concrete}}{wr_{concrete}}$$

$$= \frac{1.10 \times 0.50 + 0.35 \times 0.33 - 0.50 \times 0.40 \times 0.25}{1.10 + 0.35 - 0.50 \times 0.40} = 0.49 \text{ m}$$

$\therefore$ The weight of the block W_B acts 0.49 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

[1]*Expansion Case*

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

$\sum$ M at O,

= 21.56×0.49 – 1.83×1.07 – 0.23×0.50

= 8.49 kN-m

$$\frac{\sum M}{\sum V} = \frac{8.49}{21.33} = 0.40 \text{ m}$$

$$e = \left|\frac{L}{2} - \frac{\sum M}{\sum V}\right| = 0.50 - 0.40 = 0.1$$

$$e_{allowable} = \frac{L_{base}}{6} = \frac{1}{6} = 0.17$$

$\therefore e < e_{allowable}$ OK

[2]*Contraction Case*

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

$\sum$ M at O,

= 21.56×0.49 + 4.03×1.07 + 3.87×0.50

= 16.81 kN-m

$$\frac{\sum M}{\sum V} = \frac{16.81}{25.43} = 0.66 \text{ m}$$

$$e = \left|\frac{L}{2} - \frac{\sum M}{\sum V}\right| = 0.50 - 0.66 = 0.16$$

$$e_{allowable} = \frac{L_{base}}{6} = \frac{1}{6} = 0.17$$

$\therefore e < e_{allowable}$ OK

Since $e <_{eallowable}$ for both cases, the structure is safe against overturning.

2. Checking safety on bearing capacity

For stiff clay allowable bearing pressure is 200 kN/m^2

[1]*Expansion Case*

$$P_{base} = \frac{\sum V}{A_{base}}\left(1 + \frac{6e}{L_{base}}\right) = \frac{21.33}{1\times0.8}\left(1 + \frac{6\times0.1}{1}\right) = 42.66 \text{ kN/m}^2$$

$P_{base} < P_{allowable}$ OK

[2]*Contraction Case*

$$P_{base} = \frac{\sum V}{A_{base}}\left(1+\frac{6e}{L_{base}}\right) = \frac{25.43}{1\times 0.8}\left(1+\frac{6\times 0.16}{1}\right) = 62.30 \text{ kN/m}^2$$

$P_{base} < P_{allowable}$ OK

In both cases $P_{base} < P_{allowable}$ = 200 kN/m^2, $\therefore$ the structure is safe against sinking.

3. Checking safety against sliding

[1]*Expansion Case*

$\sum H < m \sum V$
m = 0.5 for concrete/masonry on soil

1.83 kN < 0.5×21.33 kN
1.83 kN < 10.67 kN OK

[2]*Contraction Case*

$\sum H < m \sum V$
m = 0.5 for concrete/masonry on soil

4.03 kN < 0.5×25.43 kN
4.03 kN < 12.72 kN OK

Since, $\sum H < m \sum V$ in both cases the structure is safe against sliding.
$\therefore$ The anchor block is stable.