CHAPTER 5 GROUND SILL

5.1. Ground Sill with Head at WF. 124

Location and Purpose

The following groundsill is proposed in the river improvement plan.

Being located at 1,055 m upstream portion from Simongan Weir, this ground sill is placed at the point in which the riverbed elevation changes in the form of step.

The requirements that the ground sill must meet are i) to prevent riverbed degradation ii) to stabilize the upstream and downstream riverbeds and, iii) to maintain longitudinal and cross sectional forms of river channel.

Structural Type

The ground sill (WF 124) is of concrete gravity type connected with an apron to safeguard its own body from hydraulic force during floods. The concrete body is constructed on the hard sandy layer without using foundation piles. Flexible gabion mattresses are placed on upstream and downstream riverbeds of the ground sill with a length of 20 m and 30 m respectively to protect riverbed, while 3.5 m length of RC Sheet piles are provided at both end of main sill body for protection against seepage.

The design of ground sills is made to ensure structural stability against sliding, overturning and bearing capacity of the sub-base ground, and to satisfy hydraulic stability against piping, uplift and scouring.

(1) Structural Dimension, etc

(a) River Channel

		Upstream	downstream
Riverbed width		40.0 m	35.0 m
Elevation of riverbed		EL. +3.843	EL. +2.343
Side slope	(m)	2.0 m	2.0 m
Riverbed slope	(I)	$^1/_{1250}$	$^1/_{1250}$
Manning Coefficient	(n)	0.030	0.030

(b) Hydraulic Drop

Main body height	(H_1)	2.50 m
Main body crown width	(B)	1.50 m
Main body bottom width	(B_o)	2.25 m
Drop height	(p)	1.50 m
Apron thickness	(t)	1.00 m
Apron length	(L)	9.00 m
Total bottom width	(L_o)	10.50 m

(c) Side Wall

		Main wall	Transition wall	
			Upstream end	Downstream end
Total height	(h_o)	2.50 m	2.50 m	1.00 m
Wall height	(h)	2.00 m	2.00 m	0.50 m
Wall thickness	(b_1-b_2)	(0.3 – 0.4) m	(0.3 – 0.4) m	0.30 m
Slab thickness	(h_1)	0.50 m	0.50 m	0.50 m
Bottom width of slab	(b)	1.80 m	1.80 m	0.80 m
Length	(l)	10.50 m	10.90 m	

(d) Revetment

Length	Upstream	20.00 m
	Main structure	10.50 m
	Downstream	30.00 m
Section	as shown on standard drawings	

(e) Riverbed protection

Upstream length	(L_1)	20.00 m
Downstream length	(L_2)	30.00 m
Thickness	(t_1)	0.50 m

5.1.1 Hydraulic Design

(1) Design Condition

(a) Normal condition

Design discharge	Q = 70.0 m^3/s
Upstream water level	EL. + 5.283 m
Downstream water level	EL. + 3.893 m
Upstream water depth	H_o = 1.55 m
Downstream water depth	H = 1.44 m

(b) Flood condition

Design discharge	Q = 790.0 m^3/s
Upstream water level	EL. + 9.743 m
Downstream water level	EL. + 8.843 m
Upstream water depth	H_o = 5.90 m
Downstream water depth	H = 6.50 m

(2) Examination of Apron Length

(a) Normal condition

Δh = (+5.283) – (+3.893) = 1.39 m

> $H_o/3$ (= 0.517 m)

perfect overflow will be occurred.

Upstream channel :

$A = (B + m \cdot H_o) H_o$

$= (40.0 + 2 \times 1.44) \times 1.44 = 61.747 \, m^2$

$V_o = Q/A$

$= 70 / 61.747 = 1.134$ m/s

$V_o^2 / 2g = (1.134)^2 / 2 / 9.8 = 0.065$ m

Examination of hydraulic jump by Bernoulli equation

$d_1 + V_1^2 / 2g = p + H_o + V_o^2 / 2g$

$= 1.5 + 1.44 + 0.065 = 3.005$ m

Trial d_1 = 0.23 m

$V_1 = Q / b / d_1$

$= 70.0 / 39.4 / 0.23 = 7.725$ m/s

$d_1 + V_1^2 / 2g = 0.23 + (7.725)^2 / 2 / 9.8 = 3.044$ m

~ 3.005 m

$F_r = V_1 / (g \cdot d_1)^{1/2}$

$= 7.725 / (9.8 \times 0.23)^{1/2} = 5.145$

$d_2 = d_1 \times 0.5\ ((1 + 8\ F_r^2)^{1/2} - 1)$

$\quad = 0.23 \times 0.5 \times ((1+8 \times (5.145)^2)^{1/2}-1) = 1.56$ m

$L_j = c\ (d_2 - d_1) \qquad ; \quad C = 5$

$\quad = 5 \times (1.56 - 0.23) = 6.65$ m

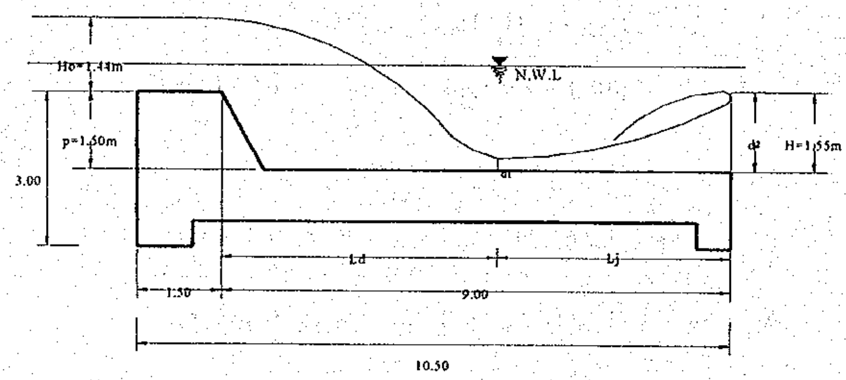
$L_d = V_o\ (2\ (p + H_o/2)/\ g)^{1/2}$

$\quad = 1.134 \times (2 \times (1.5 + 1.44/2)/\ 9.8)^{1/2} = 0.76$ m

$L = L_d + L_j$

$\quad = 6.65 + 0.76 = 7.41$ m

$\qquad <$ adopted L = 9.0 m



(b) Flood condition

$\Delta h = (+9.743) - (+8.843) = 0.90$ m

$\qquad > H_o/3\ (= 1.967$ m)

unperfect overflow will be occurred (No hydraulic jump).

(3) Examination of Apron Thickness

Applying the following formula

$t = 0.1\ (0.6\ p + 3\ H_o - 1.0)$

$\quad = 0.1 \times (0.6 \times 1.5 + 3 \times 1.44 - 1.0) = 0.422$ m

$\qquad <$ adopted t = 1.0 m

(4) Examination of Creep Length

Normal condition, after construction, downstream channel start to fill.

Creep length will be estimated by Lane's method as follows :

$$Cl = (\Sigma L_v + \Sigma L_h / 3) / H$$
$$Cl \geqslant C \ (= 7 \quad \text{for fine sand})$$

The cut off wall of about 3.5 m length are provided at both end.

$H = 1.44 + 1.5 = 2.94$ m
$L_v = 3.0 + 1.5 + 2 \times 0.5 + 4 \times 3.5 = 19.5$ m
$L_h = 10.5$ m
$C_l = (19.5 + 10.5 / 3) / 2.94 = 7.823$
$> C\ (= 7)$

5.1.2 Structural Design

5.1.2.1 Main Sill Body

(1) Design Condition

(a) Hydraulic Condition

(i) Normal Condition

Design discharge	Q = 70.0 m³/s
Upstream water depth	H_o = 1.55 m
Downstream water depth	H = 1.44 m

(ii) Flood condition

Design discharge	Q = 790.0 m³/s
Upstream water depth	H_o = 5.90 m
Downstream water depth	H = 6.50 m

(iii) Seismic condition

Water level	EL. + 5.20
Upstream water depth	H_o = 5.90 m
Downstream water depth	H = 6.50 m

(b) The material data

(i) Soil Material *)

Original soil material

Wet unit weight	γ_t = 1.6 t/m³
Submerged unit weight	γ'_s = 0.8 t/m³
Internal friction angle	ϕ = 27°
Cohesion	c = 0.0 t/m²

Back fill under the main body

Wet unit weight	γ_{t1} = 1.8 t/m³
Submerged unit weight	γ'_{s1} = 1.0 t/m³
Internal friction angle	ϕ_1 = 30°
Cohesion	c_1 = 0.0 t/m²

(ii) Others

Unit weight of mass concrete	γ'_c = 2.35 t/m³
Unit weight of gabion mattress	γ_{gm} = 2.00 t/m³
Unit weight of water	γ_w = 1.0 t/m³
Seismic coefficient	kh = 0.12

*) Based on soil investigation on RB33 and RB34 (Location WF124) soil layer at El. + 0.3m to + 5.0m are silty sand, fine to medium with average N-value of about N = 12.
Soil internal friction angle will be estimated based on N-value as follows : $\phi = 15 + \sqrt{15.N} = 27.25 \sim 27°$
For N=12, assumed γ_t = 1.6 t/m³ (wet), γ_s' = 0.8 t/m³ (submerged)
At main body foundation, original soil material of about 1 m depth will be excavated and to be filled by very fine sand with an internal friction angle of about ϕ_1 = 30°

(c) Design Load

(i) Earth pressure

Coulomb's formula

$\alpha = 0$, $\theta = 0$, $\delta = 0$

Passive earth pressure is omitted.

(ii) Uplift pressure

Effective uplift pressure is 70% only.

(d) The Combination of Load

Load \ Condition		Normal	Flood	Seismic
The vertical load	Weigth of main body	+	+	+
	Weight of water	+	+	+
	Uplift pressure	+	+	+
The horizontal load	Earth pressure	+	+	+
	Water pressure	+	+	+
	Horizontal earthquake pressure			+

"+" consider in the calculation

(2) Stability Analysis

(a) Coefficient of Active earth pressure

Applying Coulomb's formula as follows:

(in ordinary)

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos^2\theta \ \cos(\phi + \delta)\left[1 + \sqrt{\dfrac{\sin(\phi + \delta)\sin(\phi - \alpha)}{\cos(\theta + \delta)\cos(\theta - \alpha)}}\right]^2}$$

(in seismic)

$$K_{ca} = \frac{\cos^2(\phi - \theta_o - \theta)}{\cos\theta_o \cdot \cos^2\theta \cdot \cos(\theta + \theta_o + \delta)\left[1 + \sqrt{\dfrac{\sin(\phi + \delta)\sin(\phi - \alpha - \theta_o)}{\cos(\theta + \theta_o + \delta)\cos(\theta - \alpha)}}\right]^2}$$

$$kh' = \frac{\gamma_s}{\gamma_s - 1} kh$$

$$\tan\theta = \frac{kh}{1-kv} \quad ,kv = 0 \qquad \text{(saturated)}$$

$$\tan\theta_o = \frac{kh'}{1-kv} \qquad \text{(submerged)}$$

For $\theta = 0 \quad ,\delta = 0 \quad ,\alpha = 0$

$$kh' = \frac{1.8}{1.8-1} \times 0.12 = 0.27$$

$$\theta = \text{atan } 0.12 = 6.84$$

$$\theta_o = \text{atan } 0.27 = 15.11$$

(in ordinary)

$$Ka = \frac{\cos^2(27)}{1+\sqrt{\sin^2(27)}} = 0.376$$

(in seismic)

$$K_{ea} = \frac{\cos^2(27-6.84)}{\cos 6.84 \times \cos 6.84 \times \left[1+\sqrt{\frac{\sin 27 \times \sin (27-6.84)}{\cos (6.84)}}\right]^2}$$

$$= 0.458$$

$$K_{ea} = \frac{\cos^2(27-15.11)}{\cos 15.11 \times \cos 15.11 \times \left[1+\sqrt{\frac{\sin 27 \times \sin (27-15.11)}{\cos (15.11)}}\right]^2}$$

$$= 0.5975$$

(b) Allowable bearing capacity

Bearing capacity beneath structure will be estimated by the following formula:

$$q_u = \alpha . c . k . N_c + k . q . N_q + ½ . \gamma . B . N_\gamma$$

$$k = 1 + 0.3 \; D_f / B$$

$$q_a = q_u / 3$$

q_{ea} = $q_u / 2$

For θ = 27 ,N_q = 14.0

N_γ = 9.0

At upstream end, Df = 3.0 m

k = 1 + 0.3 x 3 / 10.50 = 1.010

q_u = 1.01 x (3.0 x 0.8) x 14.0 + ½ x 1.0 x 10.5 x 9.0

= 64.386 t/m²

q_a = 27.062 t/m² (in ordinary)

q_{ea} = 40.593 t/m² (in seismic)

At downstream end, Df = 1.5 m

k = 1 + 0.3 x 1.5 / 10.50 = 1.02

q_u = 1.02 x (1.5 x 0.8) x 14.0 + ½ x 1.0 x 10.5 x 9.0

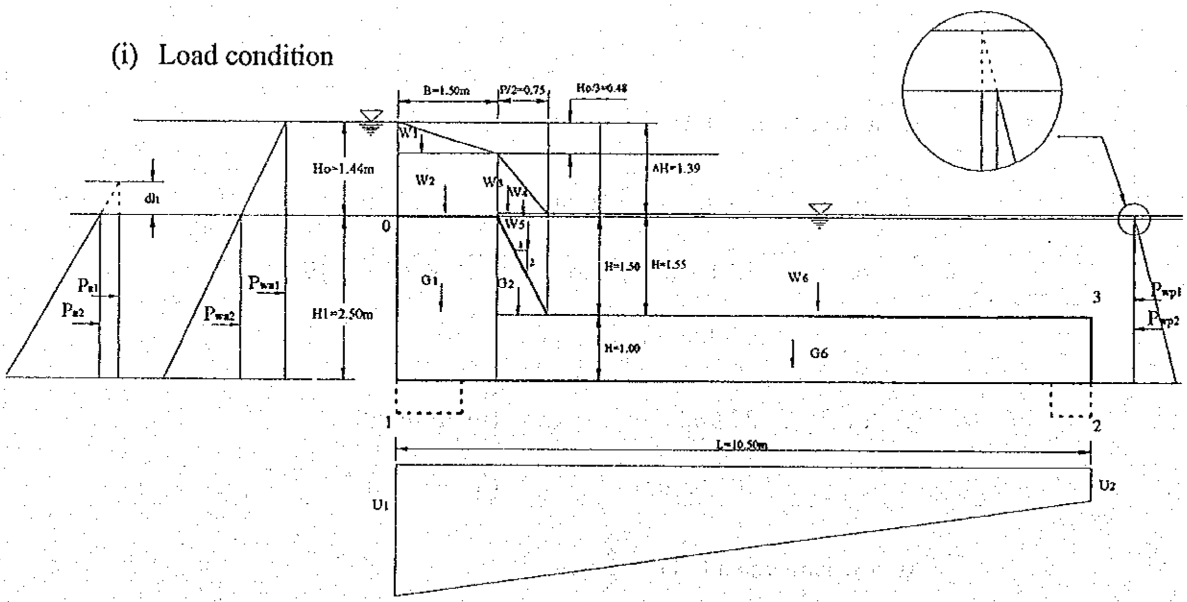
= 54.936 t/m²

q_a = 21.462 t/m² (in ordinary)

q_{ea} = 32.193 t/m² (in seismic)

(c) Stability analysis on Normal Condition

(i) Load condition



(ii) Weight of structure

G_1 = (p + t) x B x γ'c
= 2.5 x 1.5 x 2.35 = 8.812 t/m
x_1 = 10.5 – 1.5/2 = 9.750 m

G_2 = ¼ p² x γ'c
= ¼ x (1.5)² x 2.35 = 1.322 t/m
x_2 = 10.5–1.5–0.75/3 = 8.750 m

G_3 = (L – B)x t x γ'c
= 9 x 1.0 x 2.35 = 21.150 t/m
x_3 = (10.5 – 1.5)/ 2 = 4.500 m

(iii) Uplift pressure

Applying the following formula:

$U_x = H_x - L_x / L \cdot \Delta H$

ΔH = 1.39 m

L = 3.0 + 10.5 + 1.5 + 4 x 3.5 = 30 m

Point	H_x	L_x	u_x
0	1.44	0.00	1.440
1	4.44	3.00	4.301
2	4.44	28.50	3.120
3	2.94	30.00	1.550

$U_{1\text{-}2}$ = $(U_1 + U_2)/2 \times L \times \gamma_w$

= $(4.301 + 3.120)/2 \times 10.5 \times 1.0$ = 38.960 t/m

x_u = $10.5 - (4.301+2 \times 3.12)/7.421 \times 10.5/3$ = 5.529 m

(iv) Water pressure

Vertical

W_1 = $\frac{1}{2} \times (H_o/3) \times B \times \gamma_w$

= $\frac{1}{2} \times (0.48) \times 1.5 \times 1.0$ = 0.360 t/m

x_{w1} = $10.5 - 1.5/2$ = 10.000 m

W_2 = $(^2/_3 H_o) \times B \times \gamma_w$

= $0.96 \times 1.50 \times 1.0$ = 1.440 t/m

x_{w2} = $10.5 - 1.5/3$ = 9.750 m

W_3 = $\frac{1}{2} \times (\frac{1}{2}p) \times (\Delta H - H_o/3) \times \gamma_w$

= $\frac{1}{2} \times 0.75 \times 0.91 \times 1.0$ = 0.341 t/m

x_{w3} = $10.5 - 1.5 - 0.75/2$ = 8.750 m

W_4 = $(\frac{1}{2}p) \times (H-p) \times \gamma_w$

= $0.75 \times 0.05 \times 1.0$ = 0.380 t/m

x_{w4} = $10.5 - 1.5 - 0.75/2$ = 8.625 m

W_5 = $\frac{1}{2} \times (\frac{1}{2}p) \times p \times \gamma_w$

= $\frac{1}{2} \times 0.75 \times 1.5 \times 1.0$ = 0.563 t/m

x_{w5} = $10.5 - 1.5 - ^2/_3 \times 0.75$ = 8.500 m

W_6 = $H \times (L - B - p/2) \times \gamma_w$

= $1.55 \times 8.25 \times 1.0$ = 12.787 t/m

x_{w6} = $(10.5 - 2.25)/2$ = 4.125 m

Horizontal

P_{wa1} = $H_o \times \gamma_w \times H_1$

$= 1.44 \times 1.0 \times 2.5 \quad = 3.600$ t/m

$y_{wa1} = H_1/2 \quad = 1.250$ m

$P_{wa2} = ½ \times H_1 \times \gamma_w$

$= ½ \times (2.5)^2 \times 1.0 \quad = 3.125$ t/m

$y_{wa2} = H_1/3 \quad = 0.8333$ m

$P_{wp1} = (H - p) \times \gamma_w \times H_1$

$= 0.05 \times 1.0 \times 2.5 \quad = 0.125$ t/m

$y_{wp1} = 1.250$ m

$P_{wp2} = ½ \times H_1^2 \times \gamma_w$

$= ½ \times (2.5)^2 \times 1.0 \quad = 3.125$ t/m

$y_{wp2} = 0.833$ m

(v) Earth pressure

Surcharge due to gabion :

$dh = (t_1 \times \gamma_{gm}) / \gamma'_s - t_1$

$= (0.5 \times 1.20) / 0.8 - 0.5 \quad = 0.250$ t/m

Active earth pressure :

$P_{a1} = dh \times \gamma'_s \times K_a \times H_1$

$= 0.25 \times 0.8 \times 0.376 \times 2.5 \quad = 0.188$ t/m

$y_{a1} = H_1/2 \quad = 1.250$ m

$P_{a2} = ½ \times H_1^2 \times \gamma'_s \times K_a$

$= ½ \times (2.5)^2 \times 0.8 \times 0.376 \quad = 0.940$ t/m

$y_{a2} = H_1/3 \quad = 0.833$ m

(vi) Vertical Force and Moment

Vertical Force (t/m)		Arm (m)	Vertical Moment (tm/m)
G_1	8.812	9.750	85.917
G_2	1.322	8.750	11.568
G_3	21.150	4.500	95.175
W_1	0.360	10.000	3.600
W_2	1.440	9.750	14.040
W_3	0.341	8.750	2.984
W_4	0.038	8.625	0.328
W_5	0.563	8.500	4.786
W_6	12.787	4.125	52.746
U_{1-2}	−27.272	5.529	−150.787
FV	19.541	MV	120.357

* Effective uplift of about 70%.

(vii)Horizontal Force and Moment

Horizontal Force (t/m)		Arm (m)	Horizontal Moment (tm/m)
Pa_1	0.138	1.250	0.235
Pa_2	0.940	0.833	0.783
Pwa_1	3.600	1.250	4.500
Pwa_2	3.125	0.833	2.604
Pwp_1	−0.125	1.250	−0.156
Pwp_2	−3.125	0.833	−2.604
FH	4.603	MH	5.362

* Effective uplift of about 70%.

(viii)Check of stability

Stability against sliding

$SF = FV / FH \cdot \tan \phi_1$

$= 19.541 / 4.603 \times \tan 30 = 2.451$

> 1.5

Stability against overturning

$e = L/2 - (MV - MH)/ FV$

$= 10.5/2 - (120.357 - 5.362)/ 19.541 = 0.635\ (-)$

$< L/6\ (1.75\ m)$

Stability of bearing strata

$q = FV/L\ (1 \pm 6\ e / L)$

$q_{max} = 19.541 / 10.5 \times (1 + 6 \times 0.635/10.5) = 2.536\ t/m^2$

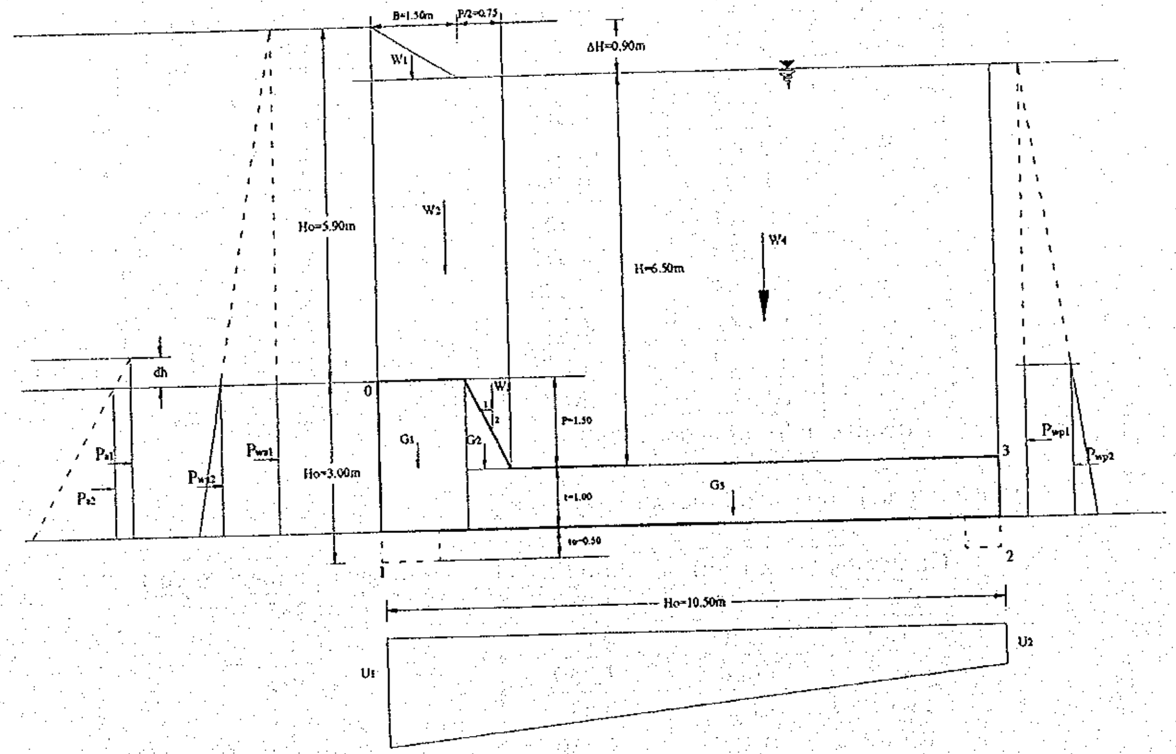
$< q_a = 21.462\ t/m^2$

$q_{min} = 19.541 / 10.5 \times (1 - 6 \times 0.635/10.5) = 1.186\ t/m^2$

$< q_a = 27.062\ t/m^2$

(d) Stability analysis on Flood Condition

(i) Load condition



(ii) Weight of structure

G_1	=	$(p + t) \times B \times \gamma'c$	
	=	$2.5 \times 1.5 \times 2.35$	= 8.812 t/m
x_1	=	$10.5 - 1.5/2$	= 9.750 m
G_2	=	$\frac{1}{4} p^2 \times \gamma'c$	
	=	$\frac{1}{4} \times (1.5)^2 \times 2.35$	= 1.322 t/m
x_2	=	$10.5 - 1.5 - 0.75/3$	= 8.750 m
G_3	=	$(L - B) \times t \times \gamma'c$	
	=	$9 \times 1.0 \times 2.35$	= 21.150 t/m
x_3	=	$(10.5 - 1.5)/2$	= 4.500 m

(iii) Uplift pressure

Applying the following formula:

$$U_x = H_x - L_x / L \cdot \Delta H$$

$$\Delta H = 0.90 \text{ m}$$

$L \quad = \; 3.0 + 10.5 + 1.5 + 4 \times 3.5 = 30$ m

Point	H_x	L_x	U_x
0	5.90	0.00	5.900
1	8.90	3.00	8.810
2	8.90	28.50	8.045
3	7.40	30.00	6.500

$U_{1\text{-}2} = (U_1 + U_2)/2 \times L \times \gamma_w$

$= (8.810 + 8.045) / 2 \times 10.5 \times 1.0 \qquad = 88.489$ t/m

$x_u = 10.5 - (8.81 + 2 \times 8.045)/16.855 \times 10.5/3 = 5.329$ m

(iv) Water pressure

Vertical

$W_1 = ½ \times \Delta H \times B \times \gamma_w$

$= ½ \times 0.90 \times 1.5 \times 1.0 \qquad = 0.675$ t/m

$x_{w1} = 10.5 - 1.5 / 3 \qquad = 10.000$ m

$W_2 = (B + p/2) \times (H\text{-}p) \times \gamma_w$

$= 2.25 \times 5.00 \times 1.0 \qquad = 11.250$ t/m

$x_{w2} = 10.5 - (B + p/2)/2 \qquad = 9.375$ m

$W_3 = ½ \times p(½p) \times \gamma_w$

$= ½ \times 1.50 \times 0.75 \times 1.0 \qquad = 0.563$ t/m

$x_{w3} = 10.5 - 1.5 - 2/3 * 0.75 \qquad = 8.500$ m

$W_4 = H \times (L\text{-}B\text{-}p/2)$

$= 6.5 \times (10.5\text{-}2.25) \qquad = 53.625$ t/m

$x_{w4} = 8.250 / 2 \qquad = 4.125$ m

Horizontal

$P_{wa1} = H_o \times \gamma_w \times H_1$

$= 5.90 \times 1.0 \times 2.5 \qquad = 14.750$ t/m

$y_{wa1} = H_1/2 \qquad = 1.250$ m

$P_{wa2} = ½ \times H_1 \times \gamma_w$

$= ½ \times (2.5)^2 \times 1.0 \qquad = 3.125$ t/m

$y_{wa2} = H_1/3 \qquad = 0.833$ m

$P_{wp1} = (H - p) \times \gamma_w \times H_1$

$= 5.00 \times 1.0 \times 2.5 \qquad = 12.500$ t/m

$y_{wp1} = 1.250$ m

P_{wp2} = ½ x H_1^2 x γ_w

= ½ x $(2.5)^2$ x 1.0 = 3.125 t/m

y_{wp2} = 0.833 m

(v) Earth pressure

Surcharge due to gabion :

dh = $(t_1 \times \gamma'_{gm})/\gamma'_s - t_1$

= (0.5 x 1.20)/ 0.8 – 0.5 = 0.250 t/m

Active earth pressure :

P_{a1} = dh x γ'_s x K_a x H_1

= 0.25 x 0.8 x 0.376 x 2.5 = 0.188 t/m

y_{a1} = $H_1/2$ = 1.250 m

P_{a2} = ½ x H_1^2 x γ'_s x K_a

= ½ x $(2.5)^2$ x 0.8 x 0.376 = 0.940 t/m

y_{a2} = $H_1/3$ = 0.833 m

(vi) Vertical Force and Moment

Vertical Force (t/m)		Arm (m)	Vertical Moment (tm/m)
G_1	8.812	9.750	85.917
G_2	1.322	8.750	11.568
G_3	21.150	4.500	95.175
W_1	0.675	10.000	6.750
W_2	11.250	9.375	105.469
W_3	0.563	8.500	4.786
W_4	53.625	4.125	221.203
U_{1-2}	–61.942	5.329	–330.089
FV	35.455	MV	200.779

* Effective uplift of about 70%.

(vii)Horizontal Force and Moment

Horizontal Force (t/m)		Arm (m)	Horizontal Moment (tm/m)
Pa_1	0.188	1.250	0.235
Pa_2	0.940	0.833	0.783
Pwa_1	14.750	1.250	18.438
Pwa_2	3.125	0.833	2.604
Pwp_1	–12.500	1.250	–15.625
Pwp_2	–3.125	0.833	–2.604
FH	3.378	MH	3.831

* Effective uplift of about 70%.

(viii)Check of stability

Stability against sliding

$SF = FV / FH \cdot \tan\phi$

$= 35.455 / 3.378 \times \tan 27 = 6.060$

> 1.5

Stability against overturning

$e = L/2 - (MV - MH)/ FV$

$= 10.5 / 2 - (200.779 - 3.831)/ 35.455 = 0.305\ (-)$

$< L/6\ (1.75\ m)$

Stability of bearing strata

$q = FV/L\ (1 \pm 6\ e / L)$

$q_{max} = 35.455 / 10.5 \times (1 + 6 \times 0.305/10.5) = 3.965\ t/m^2$

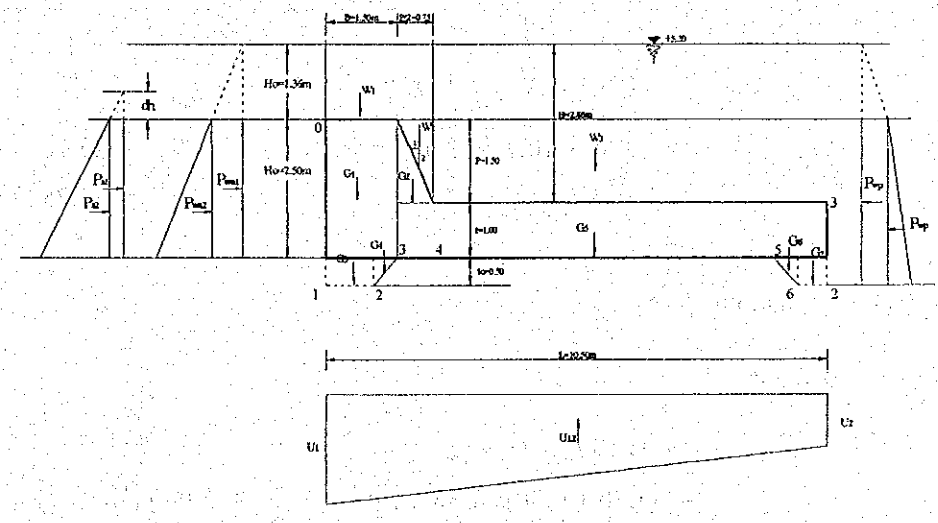
$< q_a = 21.462\ t/m^2$

$q_{min} = 35.455 / 10.5 \times (1 - 6 \times 0.305/10.5) = 2.788\ t/m^2$

$< q_a = 27.062\ t/m^2$

(e) Stability analysis on Seismic Condition

(i) Load condition



(ii) Weight of Structure

$G_1 = (p + t) \times B \times \gamma'c$

$= 2.5 \times 1.5 \times 2.35 \qquad = 8.812$ t/m

$x_1 = 10.5 - 1.5/2 \qquad = 9.750$ m

$G_2 = \frac{1}{4} p^2 \times \gamma'c$

$= \frac{1}{4} \times (1.5)^2 \times 2.35 \qquad = 1.322$ t/m

$x_2 = 10.5-1.5-0.75/3 \qquad = 8.750$ m

$G_3 = (L-B_1-B_2) \times t \times \gamma'c$

$= 9 \times 1.0 \times 2.35 \qquad = 21.150$ t/m

$x_3 = (10.5 - 1.5)/2 \qquad = 4.500$ m

(iii) Uplift pressure

Applying the following formula:

$U_x = H_x - L_x / L \cdot \Delta H$

$\Delta H = 0.00$ m

$L = 30.0$ m

Point	H_x	L_x	U_x
0	1.36	0.00	1.36
1	4.36	3.00	4.36
2	4.36	28.50	4.36
3	2.86	30.00	2.86

$U_{1\text{-}2} = (U_1 + U_2)/2 \times L \times \gamma_w$

$= 4.36 \times 10.5 \times 1.0 \qquad = 45.78$ t/m

$x_{1\text{-}2} = 10.5 / 2 \qquad = 5.25$ t/m

(iv) Water pressure

Vertical

$W_1 = (B + p/2) \times H_o \times \gamma_w$

$= (1.50 + 0.50) \times 1.36 \times 1.0 \qquad = 3.060$ t/m

$x_{w1} = 10.5 - 2.25 / 2 \qquad = 9.375$ m

$W_2 = \frac{1}{2} \times (p/2) \times p \times \gamma_w$

$= \frac{1}{2} \times 0.75 \times 1.50 \times 1.0 \qquad = 0.563$ t/m

$x_{w2} = 10.5 - 1.5 - 2/3 \times 0.75 \qquad = 8.500$ m

W_3 = $(L - B - p/2) \times H \times \gamma_w$

= $(10.5 - 1.50 - 0.75) \times 2.86 \times 1.0$ = 23.595 t/m

x_{w3} = $(10.5 - 1.5 - 0.75)/2$ = 4.125 m

Horizontal

P_{wa} = P_{wp} (balance)

(v) Earth pressure

Surcharge due to gabion :

dh = $(t_1 \times \gamma'_{gm})/\gamma'_s - t_1$

= $(0.5 \times 1.20)/0.8 - 0.5$ = 0.250 m

Active earth pressure :

P_{ea1} = $dh \times \gamma_s' \times K'_{ea} \times H_1$

= $0.25 \times 0.8 \times 0.598 \times 2.5$ = 0.299 t/m

$\square_{ea1}$ = $H_1/2$ = 1.250 m

P_{ea2} = $\frac{1}{2}(H_1)^2 \times \gamma'_s \times K'_{ea}$

= $\frac{1}{2}(2.5)^2 \times 0.8 \times 0.598$ = 1.495 t/m

$\square_{ea2}$ = $H_1/3$ = 0.833 m

(vi) Earthquake pressure

G_{e1} = $G_1 \times kh$

= 8.812×0.12 = 1.057 t/m

y_{e1} = $2.5/2$ = 1.250 m

G_{e2} = $G_2 \times kh$

= 1.322×0.12 = 0.159 t/m

y_{e2} = $1.0 + 1.50/3$ = 1.50 m

G_{e3} = $G_3 \times kh$

= 21.150×0.12 = 2.538 t/m

y_{e3} = $0.5 + 1.0/2$ = 0.50 m

(vii) Vertical Force and Moment

Vertical Force (t/m)		Arm (m)	Vertical Moment (tm/m)
G_1	8.812	9.750	85.917
G_2	1.322	8.750	11.568
G_3	21.150	4.500	95.175
W_1	3.060	9.375	28.688
W_2	0.563	8.500	4.786
W_3	23.595	4.125	97.329
U_{1-2}	−32.046	5.250	−168.242
FV_e	26.456	MV_e	155.221

* Effective uplift of about 70%.

(viii) Horizontal Force and Moment

Horizontal Force (t/m)		Arm (m)	Horizontal Moment (tm/m)
G_{e1}	1.057	1.250	1.321
G_{e2}	0.159	1.500	0.239
G_{e3}	2.538	0.500	1.269
P_{ea1}	0.299	1.250	0.374
P_{ea2}	1.495	0.833	1.246
FH_e	5.548	MH_e	4.449

- Effective Uplift of about 70%.

(ix) Check of stability

Stability against sliding

$SF = FV_e / FH_e \cdot \tan \phi_1$

$= 26.456 / 5.548 \times \tan 30 \quad = 2.753$

> 1.200

Stability against overturning

$e = L/2 - (MV_e - MH_e)/ FV_e$

$= 10.5/2 - (155.221 - 4.449)/ 26.456 \quad = 0.449\ (-)$

$< L/3\ (3.50\ m)$

Stability of bearing strata

$q = FV_e/L\ (1 \pm 6\ e / L)$

q_{max} = 26.456 / 10.5 x(1 + 6 x 0.449/10.5) = 3.166 t/m²

< q_{ea} = 32.193 t/m²

q_{min} = 26.456 / 10.5 x(1 - 6 x 0.449/10.5) = 1.873 t/m²

< q_{ea} = 40.593 t/m²

5.1.2.2 Approach Wall

Design Condition

(a) Hydraulic Condition

(i) Normal Condition

- No water in the river
- Ground water level 1.0 m above bottom level

(ii) Seismic Condition

- No water in the river
- Ground water level 1.0 m above bottom level
- kh = 0.12

(b) The Material Data

(i) Soil Material

Wet unit weight	γ_t = 1.6 t/m³
Saturated unit weight	γ_s = 1.8 t/m³
Submerged unit weight	γ'_s = 0.8 t/m³
Internal friction angle	ϕ = 27°
Cohesion	c = 0.0 t/m²

(ii) Others

Unit weight of R.C.	γ_c = 2.50 t/m³
Unit weight of mass concrete	γ'_c = 2.35 t/m³
Unit weight of wet masonry	γ_m = 2.30 t/m³
Unit weight of gravel	γ_g = 2.00 t/m³
Allowable compressive strength of concrete (K_{225})	$\overline{\sigma}_b$ = 75 kg/m²
Allowable compressive strength of steel (U_{24})	$\overline{\sigma}_a$ = 1400 kg/m²
Variable – n	n = 21

(c) Design Load

(i) Earth pressure

- Coulomb's formula
- Mean ground surface slope α=26.56°(=atn0.5)
- Angle between backside of wall & vertical plane θ=2.86°(=atn0.05)
- Friction angle at wall (δ)

		Normal	Seismic
Stability calculation	Soil to soil	ϕ	$\phi/2$
Structural calculation	Soil to concrete	$\phi/3$	0

(ii) Surcharge due to Revetment

dh = (t1 x γm + t2 x γg)/ γs – (t1 + t2) = 0.097 ~ 0.10 m

(iii) Surcharge due to Apron

dh1 = (t3 x γ'c)/ γs – t3 = 0.305 ~ 0.3 m

(d) The Combination of Load

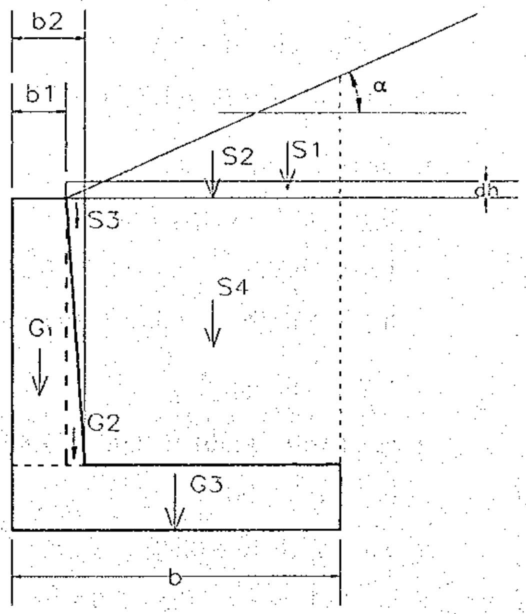
Load \ Condition		Normal	Seismic
The vertical load	Weight of main wall	+	+
	Weight of soil	+	+
The horizontal load	Earth pressure	+	+
	Water pressure	+	+
	Horizontal earthquake pressure		+

"+" consider in the calculation

Stability Analysis

(a) Center gravity of Structure

(i) Proposed condition



(ii) Weight of wall body

$G_1 = b_1 \times h \times \gamma_c$

$= 0.3 \times 2.0 \times 2.50 = 1.500$ t/m

$x_1 = b_1 / 2 = 0.15$ m

$y_1 = h_1 + h / 2 = 0.50 + 2.0 / 2 = 1.50$ m

$G_2 = ½ (b_2 - b_1) \times h \times \gamma_c$

$= ½(0.4 - 0.3) \times 2.0 \times 2.50 = 0.250$ t/m

$x_2 = b_1 + (b_2 - b_1)/3 = 0.3 + (0.4 - 0.3)/3 = 0.333$ m

$y_2 = h_1 + h/3 = 0.50 + 2.0 / 3 = 1.167$ m

$G_3 = b \times h_1 \times \gamma_c$

$= 1.80 \times 0.50 \times 2.50 = 2.250$ t/m

$x_3 = b/2 = 1.80/2 = 0.90$ m

$y_3 = h_1/2 = 0.5/2 = 0.250$ m

(iii) Weight of soil

$S_1 = \frac{1}{4}(b-b_1)^2 \times \gamma_s$

$= \frac{1}{4} \times (1.80 - 0.30)^2 \times 1.80 = 1.013$ t/m

$x_{S1} = b_1 + \frac{2}{3}(b - b_1)$

$= 0.3 + \frac{2}{3}(1.8 - 0.3) = 1.300$ m

$y_{S1} = h + h_1 + dh + (b - b_1)/2/3$

$= 2.0 + 0.5 + 0.10 + (1.8 - 0.3)/2/3 = 2.850$ m

$S_2 = dh \times (b - b_1) \times \gamma_s$

$= 0.10 \times (1.8 - 0.3) \times 1.8 = 0.270$ t/m

$x_{S2} = b_1 + (b - b_1)/2 = 0.3 + (1.8 - 0.3)/2 = 1.050$ m

$y_{S2} = h + h_1 + dh/2 = 2.50 + 0.10/2 = 2.600$ m

$S_3 = \frac{1}{2}(b_2 - b_1) \times h \times \gamma_s$

$= \frac{1}{2} \times (0.40 - 0.30) \times 2.00 \times 1.80 = 0.180$ t/m

$x_{S3} = b_1 + {}^2/_3 (b - b_1)$

$= 0.3 + {}^2/_3 (0.40 - 0.30) = 0.367$ m

$y_{S3} = h_1 + {}^2/_3 h = 0.5 + 2.0 \times {}^2/_3 = 1.833$ m

$S_4 = (b - b_2) \times h \times \gamma_s$

$= (1.80 - 0.40) \times 2.00 \times 1.80 = 5.040$ t/m

$x_{S4} = b_2 + (b - b_2)/2$

$= 0.4 + (1.8 - 0.4)/2 = 1.100$ m

$y_{S4} = h_1 + h/2$

$= 0.5 + 2.00/2 = 1.500$ m

(iv) Buoyant Force / Uplift

$U = b \times (h + h_1 - z) \times \gamma_w$

$= 1.8 \times (2.0 + 0.5 - 1.5) \times 1.0 = 1.800$ t/m

$x_u = b/2 = 1.8/2 = 0.900$ m

$y_u = (h + h_1 - z)/2$

$= (2.0 + 0.5 - 1.5)/2 = 0.500$ m

(v) Center Gravity of Structure

Weight, w (t/m)		x (m)	W.x (tm/m)	y (m)	W.y (tm/m)
G_1	1.500	0.150	0.225	1.500	2.250
G_2	0.250	0.333	0.083	1.167	0.292
G_3	2.250	0.900	2.025	0.250	0.563
S_1	1.012	1.300	1.316	2.850	2.884
S_2	0.270	1.050	0.284	2.600	0.702
S_3	0.180	0.367	0.066	1.833	0.330
S_4	5.040	1.100	5.544	1.500	7.560
U	-1.800	0.900	-1.620	0.500	-0.900
Σ	8.702		7.922		13.680

$x_o = \Sigma W_x / \Sigma W = 0.910$ m

$y_o = \Sigma W_y / \Sigma W = 1.572$ m

For without uplift :

$\Sigma W = 10.502$

$\Sigma W_x = 9.543$

$\Sigma W_y = 14.581$

$x_o' = 0.909$ m

$y_o' = 1.388$ m

(b) Bearing Capacity Beneath Slab

$q_u = \alpha \cdot c \cdot k \cdot N_c + k \cdot q \cdot N_q + ½ \cdot \gamma \cdot \beta \cdot B \cdot N_\gamma$

$\alpha = \beta = 1.0$

$c = 0$

$Df = 1.00$ m

$k = 1 + 0.3\ D_f / B$

$= 1 + 0.3\ (1.0 / 1.8) = 1.167$

$q = Df \times \gamma'_c$

For $\phi = 27°$; $\theta = 0$; $N_q = 14.0$

$N_\gamma = 9.0$

$q_u = 1.167 \times (1.0 \times 2.35) \times 14.0 + ½ \times 0.8 \times 1.0 \times 1.8 \times 9.0$

$= 44.874$ t/m²

$q_a \quad = q_u / 3 \qquad = \quad 14.958 \text{ t/m}^2 \qquad$ (in ordinary)

$q_{ea} \quad = q_u / 2 \qquad = \quad 22.437 \text{ t/m}^2 \qquad$ (in seismic)

(c) Coefficient of Earth Pressure

Applying Coulomb's formula as follows:

(in ordinary)

$\theta = 2.86° \quad ; \alpha = 26.56° \quad ; \delta = \phi = 27$

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos^2\theta \ \cos(\theta + \delta)\left[1 + \sqrt{\dfrac{\sin(\phi+\delta) \ \sin(\phi - \alpha)}{\cos(\theta+\delta) \ \cos(\theta - \alpha)}}\right]^2}$$

$$K_a = \frac{\cos^2(27 - 2.86)}{\cos^2(2.86) \text{ x } \cos(2.86 + 27)\left[1 + \sqrt{\dfrac{\sin(27+27) \times \ \sin(27\text{-}26.56)}{\cos(2.86+27) \ \times \ \cos(2.86\text{-}26.56)}}\right]^2}$$

$= 0.818$

$$K_p = \frac{\cos^2(\phi + \theta)}{\cos^2\theta \ \cos(\theta + \delta)\left[1 - \sqrt{\dfrac{\sin(\phi-\delta) \ \times \ \sin(\phi + \alpha)}{\cos(\theta+\delta) \ \cos(\theta - \alpha)}}\right]^2}$$

$$K_p = \frac{\cos^2(27 + 2.86)}{\cos^2(2.86) \text{ x } \cos(2.86 + 27)\left[1 - \sqrt{\dfrac{\sin(27-27) \times \sin(27\text{-}26.56)}{\cos(2.86+27) \ \times \ \cos(2.86\text{-}26.56)}}\right]^2}$$

$= 0.869$

(in seismic)

$\theta \quad = 6.84° \quad ; \quad \theta_o' = 15.11°$

$\delta \quad = \phi/2 = 13.5° \ ; \ \theta = 2.86° \ ; \ \alpha = 26.56°$

$$K_{ea} = \frac{\cos^2(\phi - \theta_o - \theta)}{\cos\theta_o \cdot \ \cos^2\theta \ \cdot \ \cos(\theta + \theta_o + \delta)\left[1 + \sqrt{\dfrac{\sin(\phi+\delta) \ \sin(\phi - \alpha - \theta_o)}{\cos(\theta + \theta_o + \delta) \ \cos(\theta - \alpha)}}\right]^2}$$

$$K_{ea} = \frac{\cos^2(27 - 6.84 - 2.86)}{\cos(6.84) \times \cos^2(2.86) \times \cos(2.86 + 6.84 + 13.5)\left[1 + \sqrt{\dfrac{\sin(27+13.5) \times \sin(27\text{-}26.56 - 6.84)}{\cos(2.86+6.84+13.5) \times \cos(2.86\text{-}26.56)}}\right]^2}$$

$= 1.001$

$$K_{ea}' = \frac{\cos^2(\phi - \theta'_o - \theta)}{\cos\theta'_o \cdot \cos^2\theta \cdot \cos(\theta + \theta'_o + \delta)\left[1 + \sqrt{\frac{\sin(\phi+\delta)\ \sin(\phi - \alpha - \theta'_o)}{\cos(\theta + \theta'_o + \delta)\ \cos(\theta - \alpha)}}\right]^2}$$

$$K_{ea}' = \frac{\cos^2(27 - 15.11 - 2.86)}{\cos(15.11) \times \cos^2(2.86) \times \cos(2.86 + 15.11 + 13.5)\left[1 + \sqrt{\frac{\sin(27 + 13.5) \times \sin(27 - 26.56 - 15.11)}{\cos(2.86 + 15.11 + 13.5) \times \cos(2.86 - 26.56)}}\right]^2}$$

$= 1.187$

$$K_{ep} = \frac{\cos^2(\phi - \theta_o + \theta)}{\cos\theta_o \cdot \cos^2\theta \cdot \cos(\theta - \theta_o + \delta)\left[1 - \sqrt{\frac{\sin(\phi-\delta)\ \sin(\phi + \alpha - \theta_o)}{\cos(\theta - \theta_o + \delta)\ \cos(\theta - \alpha)}}\right]^2}$$

$$K_{ep} = \frac{\cos^2(27 - 6.84 + 2.86)}{\cos(6.84) \times \cos^2(2.86) \times \cos(2.86 - 6.84 + 13.5)\left[1 - \sqrt{\frac{\sin(27 - 13.5) \times \sin(27 + 26.56 - 6.84)}{\cos(2.86 - 6.84 + 13.5) \times \cos(2.86 - 26.56)}}\right]^2}$$

$= 2.705$

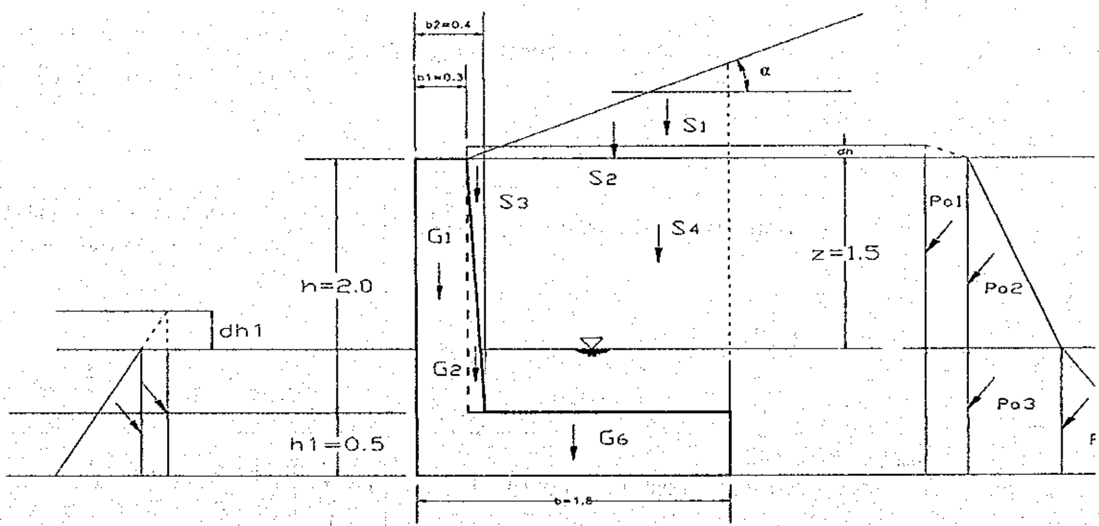
$$K_{ep}' = \frac{\cos^2(\phi - \theta'_o + \theta)}{\cos\theta'_o \cdot \cos^2\theta \cdot \cos(\theta - \theta'_o + \delta)\left[1 - \sqrt{\frac{\sin(\phi-\delta)\ \sin(\phi + \alpha - \theta_o)}{\cos(\theta - \theta_o + \delta)\ \cos(\theta - \alpha)}}\right]^2}$$

$$K_{ep}' = \frac{\cos^2(27 - 15.11 + 2.86)}{\cos(15.11) \times \cos^2(2.86) \times \cos(2.86 - 15.11 + 13.5)\left[1 - \sqrt{\frac{\sin(27 - 13.5) \times \sin(27 + 26.56 - 15.11)}{\cos(2.86 - 15.11 + 13.5) \times \cos(2.86 - 26.56)}}\right]^2}$$

$= 2.682$

(d) Stability analysis on Normal Condition

(i) Load Condition



(ii) External Force

Active earth pressure :

P_{a1} = $dh \times \gamma_s \times K_a \times (h+h_1)$

= $0.10 \times 1.8 \times 0.818 \times 2.50$ = 0.368 t/m

P_{a2} = $\frac{1}{2} \times z^2 \times \gamma_s \times K_a$

= $\frac{1}{2} \times (1.5)^2 \times 1.8 \times 0.818$ = 1.656 t/m

P_{a3} = $z \times \gamma_s \times K_a \times (h + h_1 - z)$

= $1.5 \times 1.8 \times 0.818 \times 1.0$ = 2.209 t/m

P_{a4} = $\frac{1}{2} \times (h + h_1 - z) \times \gamma'_s \times K_a$

= $\frac{1}{2} \times (1.0)^2 \times 0.8 \times 0.818$ = 0.327 t/m

Horizontal Active Earth Pressure

P_{ah1} = $P_{a1} \times \cos(\theta + \delta)$

= $0.368 \times \cos(2.86 + 27)$ = 0.319 t/m

y_{a1} = $(h + h_1)/2$ = $2.5 / 2$ = 1.250 m

P_{ah2} = $P_{a2} \times \cos(\theta + \delta)$

= $1.656 \times \cos(29.86)$ = 1.437 t/m

y_{a2} = $(h + h_1 - z) + z/3$ = $1.0 + 1.5 / 3$ = 1.500 m

P_{ah3} = P_{a3} x cos (θ + δ)

= 2.209 x cos (29.86) = 1.915 t/m

y_{a3} = (h + h_1 - z)+ z/2 = 1.0 / 2 = 0.500 m

P_{ah4} = P_{a4} x cos (θ + δ)

= 0.327 x cos (29.86) = 0.284 t/m

y_{a4} = (h + h_1 - z)/ 3 = 1.0 / 3 = 0.333 m

Vertical Active Earth Pressure

P_{av1} = P_{a1} x sin (θ + δ)

= 0.368 x sin (29.86) = 0.183 t/m

x_{a1} = 1.800 m

P_{av2} = P_{a2} x sin (θ + δ)

= 1.656 x sin (29.86) = 0.825 t/m

x_{a2} = 1.800 m

P_{av3} = P_{a3} x sin (θ + δ)

= 2.209 x sin (29.86) = 1.100 t/m

x_{a3} = 1.800 m

P_{av4} = P_{a4} x sin (θ + δ)

= 0.327 x sin (29.86) = 0.163 t/m

y_{a4} = 1.800 m

Passive earth pressure :

P_{p1} = dh_1 x γ_s x K_p x (h - h_1 - z)

= 0.30 x 1.8 x 0.869 x 1.0 = 0.469 t/m

P_{p2} = ½ x (h - h_1 - z)² x γ_s x K_p

= ½ x (1.0)² x 1.8 x 0.869 = 0.782 t/m

Horizontal Passive Earth Pressure

P_{ph1} = P_{p1} x cos (θ - δ)

= 0.469 x cos (2.86 - 27) = 0.201 t/m

y_{p1} = (h + h_1 - z)/ 2 = 0.500 m

P_{ph2} = P_{p2} x cos (θ - δ)

= 0.782 x cos (24.14) = 0.714 t/m

y_{p2} = (h + h_1 - z)/ 3 = 0.333 m

Water Pressure

$P_{wa} = ½ (h + h_l - z)^2 \times \gamma_w$

$= ½. (1.0)^2 \times 1.0 \qquad = 0.500$ t/m

$y_w = (h + h_l - z)/ 3 \quad = 1.0/3 \qquad = 0.333$ m

(iii) Vertical Force and Moment

Vertical Force (t/m)		Arm (m)	Vertical Moment (tm/m)
Pav_1	0.183	1.800	0.329
Pav_2	0.825	1.800	1.485
Pav_3	1.100	1.800	1.980
Pav_4	0.163	1.800	0.293
W	8.702	0.910	7.919
FV	10.973	MV	12.006

(iv) Horizontal Force and Moment

Horizontal Force (t/m)		Arm (m)	Horizontal Moment (tm/m)
Pah1	0.319	1.250	0.399
Pah2	1.437	1.500	2.156
Pah_1	1.915	0.500	0.958
Pah_2	0.284	0.333	0.095
Pwa	0.500	0.167	0.084
Pph1	-0.201	0.500	-0.101
Pph2	-0.714	0.333	-0.238
FH	3.540	MH	3.353

(v) Check of stability

Stability against sliding

$SF = FV / FH . \tan \phi$

$= 10.973 / 3.540 \times \tan 27 \qquad = 1.565$

> 1.5

Stability against overturning

$e = b/2 - (MV - MH)/ FV$

$= 1.8/2 - (12.006 - 3.353)/ 10.973 \qquad = 0.111$ (--)

$<$ B/6 (=0.30 m)

Stability against bearing strata

$q = FV/b (1 \pm 6 e / L)$

$q_{max} = 10.973 / 1.8 \times (1 + 6 \times 0.111/1.8) \qquad = 8.352$ t/m²

$< q_a = 14.958$ t/m

(e) Stability analysis on Seismic Condition

(i) External Force

Active earth pressure :

P_{ea1}	= $dh \times \gamma_s \times K_{ea} \times (h+h_l)$		
	= $0.10 \times 1.8 \times 1.001 \times 2.50$	=	0.450 t/m
P_{ea2}	= $½ \times z^2 \times \gamma_s \times K_{ea}$		
	= $½ \times (1.5)^2 \times 1.8 \times 1.001$	=	2.027 t/m
P_{ea3}	= $z \times \gamma_s \times K_{ea} \times (h + h_l - z)$		
	= $1.5 \times 1.8 \times 1.001 \times 1.0$	=	2.703 t/m
P_{ea4}	= $½ \times (h + h_l - z) \times \gamma'_s \times K_{ea}$		
	= $½ \times (1.0)^2 \times 0.8 \times 1.187$	=	0.475 t/m

Horizontal Active Earth Pressure

P_{eah1}	= $P_{ea1} \times \cos(\theta + \delta)$		
	= $0.450 \times \cos(2.86 + 13.5)$	=	0.432 t/m
y_{ea1}	= 1.250 m		
P_{eah2}	= $P_{ea2} \times \cos(\theta + \delta)$		
	= $2.027 \times \cos(16.36)$	=	1.945 t/m
y_{ea2}	= 1.000 m		
P_{eah3}	= $P_{ea3} \times \cos(\theta + \delta)$		
	= $2.703 \times \cos(16.36)$	=	2.593 t/m
y_{ea3}	= 0.500 m		
P_{eah4}	= $P_{ea4} \times \cos(\theta + \delta)$		
	= $0.475 \times \cos(16.36)$	=	0.455 t/m
y_{ea4}	= 0.333 m		

Vertical Active Earth Pressure

P_{eav1}	= $P_{ea1} \times \sin(\theta + \delta)$		
	= $0.450 \times \sin(16.36)$	=	0.127 t/m
x_{ea1}	= 1.800 m		

P_{eav2} = P_{ea2} x sin (θ + δ)

= 2.027 x sin (16.36) = 0.571 t/m

x_{ea2} = 1.800 m

P_{eav3} = P_{ea3} x sin (θ + δ)

= 2.703 x sin (16.36) = 0.761 t/m

x_{ea3} = 1.800 m

P_{eav4} = P_{ea4} x sin (θ + δ)

= 0.475 x sin (16.36) = 0.134 t/m

y_{ea4} = 1.800 m

Passive earth pressure :

P_{ep1} = $dh_1 \times \gamma_s \times K_{ep} \times (h + h_1 - z)$

= 0.30 x 1.8 x 2.705 x 1.0 = 1.461 t/m

P_{ep2} = $\frac{1}{2} \times (h + h_1 - z)^2 \times \gamma_s \times K_{ep}$

= $\frac{1}{2} \times (1.0)^2 \times 1.8 \times 2.705$ = 2.455 t/m

Horizontal Passive Earth Pressure

P_{eph1} = P_{ep1} x cos (θ - δ)

= 1.461 x cos (2.86 – 13.5) = 1.436 t/m

y_{ep1} = 0.500 m

P_{eph2} = P_{ep2} x cos (θ - δ)

= 2.435 x cos (10.64) = 2.393 t/m

y_{ep2} = 0.333 m

Water Pressure

P_{wa} = $\frac{1}{2} (h + h_1 - z)^2 \times \gamma_w$

= ½. $(1.0)^2$ x 1.0 = 0.500 t/m

y_w = $(h + h_1 - z)/ 3$ = 1.0/3 = 0.333 m

Earthquake Force

W_e = W x kh

= 10.502 x 0.12

= 1.260 t/m

y_e = 1.388 m

(ii) Vertical Force and Moment

Vertical Force (t/m)		Arm (m)	Vertical Moment (tm/m)
$Peav_1$	0.127	1.800	0.229
$Peav_2$	0.571	1.800	1.028
$Peav_3$	0.761	1.800	1.370
$Peav_4$	0.134	1.800	0.241
W	8.702	0.910	7.919
FV_e	10.295	MV_e	10.787

(iii) Horizontal Force and Moment

Horizontal Force (t/m)		Arm (m)	Horizontal Moment (tm/m)
$Peah_1$	0.432	1.250	0.540
$Peah_2$	1.945	1.000	1.945
$Peah_3$	2.593	0.500	1.297
$Peah_4$	0.455	0.333	0.152
Pw	0.500	0.333	0.167
Peph1	-1.436	0.500	-0.718
Peph2	-2.393	0.333	-0.797
W_e	1.260	1.388	1.749
FH	3.356	MH_e	4.335

(iv) Check of stability

Stability against sliding

$SF = FV_e / FH_e \cdot \tan\phi$

$= 10.295 / 3.356 \times \tan 27 \qquad = 1.561$

> 1.2

Stability against overturning

$e = b/2 - (MV_e - MH_e) / FV_e$

$= 1.8/2 - (10.787 - 4.335) / 10.295 \qquad = 0.273$

$< B/3\ (=0.60\ m)$

Stability of bearing strata

$q = FV_e/b\,(1 \pm 6\,e/b)$

$q_{max} = 10.787 / 1.8 \times (1 + 6 \times 0.273/1.8) \qquad = 11.446\ t/m^2$

$< q_{ea} = 22.437\ t/m$

(3) Stress Strain Analysis

(a) Coefficient of Active Earth Pressure

Applying Coulomb's formula as follows:

(in ordinary)

$\theta = 2.86°$; $\alpha = 26.56°$; $\delta = \phi/3 = 9°$

$$K_a = \frac{\cos^2(\phi-\theta)}{\cos^2\theta\ \cos(\phi+\delta)\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\sin(\phi-\alpha)}{\cos(\theta+\delta)\cos(\theta-\alpha)}}\right]^2}$$

$$K_a = \frac{\cos^2(27-2.86)}{\cos^2(2.86)\times\cos(2.86+9)\left[1+\sqrt{\dfrac{\sin(27+9)\sin(27-26.56)}{\cos(2.86+9)\times\cos(2.86-26.56)}}\right]^2}$$

$= 0.744$

(in seismic)

$\theta = 6.84°$; $\theta_o' = 15.11°$; $\theta = 2.86°$; $\alpha = 26.56°$; $\delta = 0$

$$K_{ea} = \frac{\cos^2(\phi-\theta_o-\theta)}{\cos\theta_o\cdot\cos^2\theta\cdot\cos(\theta+\theta_o+\delta)\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\sin(\phi-\alpha-\theta_o)}{\cos(\theta+\theta_o+\delta)\cos(\theta-\alpha)}}\right]^2}$$

$$K_{ea} = \frac{\cos^2(27-6.84-2.86)}{\cos(6.84)\times\cos^2(2.86)\times\cos(2.86+6.84+0)\left[1+\sqrt{\dfrac{\sin(27+0)\times\sin(27\text{-}26.56-6.84)}{\cos(2.86+6.84+0)\times\cos(2.86\text{-}26.56)}}\right]^2}$$

$= 0.934$

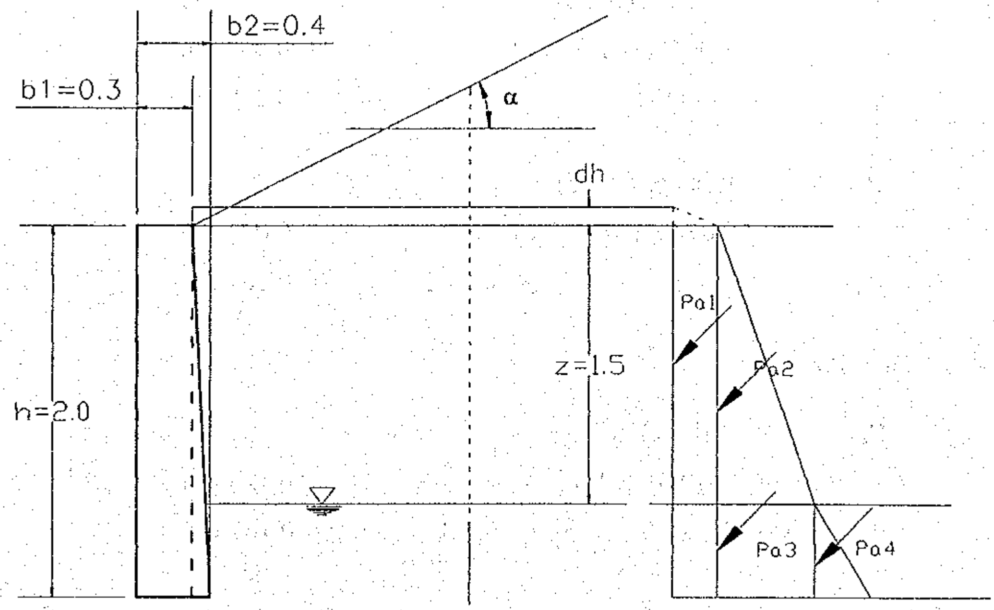
$$K_{ea}' = \frac{\cos^2(\phi-\theta_o'-\theta)}{\cos\theta_o'\cdot\ \cos^2\theta\ \cdot\ \cos(\theta+\theta_o'+\delta)\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\ \sin(\phi-\alpha--\theta_o')}{\cos(\theta+\theta_o'+\delta)\ \cos(\theta-\alpha)}}\right]^2}$$

$$K_{ea}' = \frac{\cos^2(27-5.11-2.86)}{\cos(15.11)\times\cos^2(2.86)\times\cos(2.86+15.11)\left[1+\sqrt{\dfrac{\sin(27)\times\sin(27\text{-}26.56-15.11)}{\cos(2.86+15.11)\times\cos(2.86\text{-}26.56)}}\right]^2}$$

$= 1.065$

(b) Wall

(i) Load Condition



(ii) External Force and Moment

(in ordinary)

Earth pressure :

P_{a1} = $dh \times \gamma_s \times K_a \times h$
= $0.10 \times 1.8 \times 0.744 \times 2.0$ = 0.268 t/m

P_{a2} = $\frac{1}{2} \times z^2 \times \gamma_s \times K_a$
= $\frac{1}{2} \times (1.5)^2 \times 1.8 \times 0.744$ = 1.507 t/m

P_{a3} = $z \times \gamma_s \times K_a \times (h - z)$
= $1.5 \times 1.8 \times 0.744 \times 0.5$ = 1.004 t/m

P_{a4} = $\frac{1}{2} \times (h - z)^2 \times \gamma'_s \times K_a$
= $\frac{1}{2} \times (0.5)^2 \times 0.8 \times 0.744$ = 0.074 t/m

Horizontal Earth Pressure

P_{ah1} = $P_{a1} \times \cos(\theta + \delta)$
= $0.268 \times \cos(2.86 + 9)$ = 0.262 t/m

y_{a1} = $h / 2$ = 1.000 m

P_{ah2}	$= P_{a2} \times \cos(\theta + \delta)$			
	$= 1.507 \times \cos(11.86)$			$= 1.474$ t/m
y_{a2}	$= (h - z) + z/3$	$= 0.5 + 1.5 / 3$		$= 1.000$ m
P_{ah3}	$= P_{a3} \times \cos(\theta + \delta)$			
	$= 1.004 \times \cos(11.86)$			$= 0.983$ t/m
y_{a3}	$= (h - z)/ 2$	$= 0.5 / 2$		$= 0.250$ m
P_{ah4}	$= P_{a4} \times \cos(\theta + \delta)$			
	$= 0.074 \times \cos(11.86)$			$= 0.073$ t/m
y_{a4}	$= (h - z)/ 3$	$= 0.5 / 3$		$= 0.167$ m

Water Pressure

P_w	$= \frac{1}{2} (h - z)^2 \times \gamma_w$		
	$= \frac{1}{2}. (0.5)^2 \times 1.0$		$= 0.125$ t/m
y_w	$= (h - z)/ 3$	$= 0.5/3$	$= 0.167$ m

Horizontal Force and Moment

Horizontal Force (t/m)		Arm (m)	Horizontal Moment (tm/m)
Pah1	0.262	1.000	0.262
Pah2	1.474	1.000	1.474
Pah_3	0.983	0.250	0.246
Pah_4	0.073	0.167	0.012
Pw	0.125	0.167	0.021
FH	2.917	MH	2.015

(in seismic)

Earth pressure :

P_{ea1}	$= dh \times \gamma_s \times K_{ea} \times h$	
	$= 0.10 \times 1.8 \times 0.934 \times 2.0$	$= 0.336$ t/m
P_{ea2}	$= \frac{1}{2} \times z^2 \times \gamma_s \times K_{ea}$	
	$= \frac{1}{2} \times (1.5)^2 \times 1.8 \times 0.934$	$= 1.891$ t/m
P_{ea3}	$= z \times \gamma_s \times K_{ea} \times (h - z)$	
	$= 1.5 \times 1.8 \times 0.934 \times 0.5$	$= 1.261$ t/m
P_{ea4}	$= \frac{1}{2} \times (h - z)^2 \times \gamma'_s \times K_{ea}$	
	$= \frac{1}{2} \times (0.5)^2 \times 0.8 \times 1.065$	$= 0.107$ t/m

Horizontal Earth Pressure

P_{eah1} = P_{ea1} x cos (θ + δ)
= 0.336 x cos (2.86) = 0.336 t/m
y_{ea1} = 1.000 m

P_{eah2} = P_{ea2} x cos (θ + δ)
= 1.891 x cos (2.86) = 1.889 t/m
y_{ea2} = 1.000 m

P_{eah3} = P_{ea3} x cos (θ + δ)
= 1.261 x cos (2.86) = 1.259 t/m
y_{ea3} = 0.250 m

P_{eah4} = P_{ea4} x cos (θ + δ)
= 0.107 x cos (2.86) = 0.106 t/m
y_{ea4} = 0.167 m

Water Pressure

P_w = ½ $(h - z)^2 \times \gamma_w$
= ½. $(0.5)^2$ x 1.0 = 0.125 t/m
y_w = (h - z)/ 3 = 0.5/3 = 0.167 m

Horizontal Force and Moment

Horizontal Force (t/m)		Arm (m)	Horizontal Moment (tm/m)
Peah1	0.336	1.000	0.336
Peah2	1.889	1.000	1.889
$Peah_3$	1.259	0.250	0.315
$Peah_4$	0.106	0.167	0.018
Pw	0.125	0.167	0.021
FH	3.715	MH	2.579

(iii) Bending Moment and Shear Force

FH = 2.917

MH = 2.015

FH_e = 3.715 < 1.5 FH

MH_e = 2.579 < 1.5 MH

Therefore bending moment and shear force in normal condition will be adopted for strain stress calculation.

(iv) Required Re-Bar

ht = 40 cm; d = 5 cm; h = 35 cm

$\phi_o = \sigma_a / n\,\sigma_b$

$= 1400 / (21 \times 25) = 0.889$

$$C_a = \frac{h}{\sqrt{\dfrac{n \times M}{b \times \sigma_a}}}$$

$$= \frac{35}{\sqrt{\dfrac{21 \times 201500}{100 \times 1400}}}$$

$= 6.366$

For $C_a = 6.366$

$\delta = 0.2$

$\phi = 3.930$

$\phi' = 7.754$

$n_\omega = 0.0265$

Stresses:

$\sigma_s = \overline{\sigma}_a = 1400$ kg/cm²

$$\sigma'_b = \frac{\overline{\sigma}_a}{n\phi} = \frac{1400}{21 \times 3.93} = 16.96 \text{ kg/cm}^2$$

$$\sigma'_s = \frac{\overline{\sigma}_a}{\phi'} = \frac{1400}{7.754} = 180.552 \text{ kg/cm}^2$$

Re-bar will be arranged

$A = \omega\, b\, h$

$= 0.0265 / 21 \times 100 \times 35 = 4.417$ cm²

A_s	=	0.2 x A		= 0.883 cm²
A'	=	δ . A		= 0.883 cm²
A'_s	=	0.2 x A'		= 0.176 cm²

Re-bar : $D_{13\text{-}25}$, A = 5.32 cm²

$D_{13\text{-}25}$, A_s = 5.32 cm²

(c) Slab

(i) Load Condition

See sketch of load condition for stability analysis.

(ii) Reaction beneath slab

(in ordinary)

Active earth pressure :

P_{a1} = dh x γ_s x K_a x ($h+h_1$)
= 0.10 x 1.8 x 0.744 x 2.50 = 0.335 t/m

P_{a2} = ½ x z^2 x γ_s x K_a
= ½ x $(1.5)^2$ x 1.8 x 0.744 = 1.507 t/m

P_{a3} = z x γ_s x K_a x ($h + h_1 - z$)
= 1.5 x 1.8 x 0.744 x 1.0 = 2.009 t/m

P_{a4} = ½ x ($h + h_1 - z$) x γ_s x K_a
= ½ x $(1.0)^2$ x 0.8 x 0.744 = 0.298 t/m

Horizontal Active Earth Pressure

P_{ah1} = P_{a1} x cos (θ + δ)
= 0.335 x cos (11.86) = 0.328 t/m

P_{ah2} = P_{a2} x cos (θ + δ)
= 1.507 x cos (11.86) = 1.474 t/m

P_{ah3} = P_{a3} x cos (θ + δ)
= 2.009 x cos (11.86) = 1.966 t/m

P_{ah4} = P_{a4} x cos (θ + δ)
= 0.298 x cos (11.86) = 0.291 t/m

Vertical Active Earth Pressure

P_{av1} = P_{a1} x sin ($\theta + \delta$)
= 0.335 x sin (11.86) = 0.069 t/m

P_{av2} = P_{a2} x sin ($\theta + \delta$)
= 1.507 x sin (11.86) = 0.310 t/m

P_{av3} = P_{a3} x sin ($\theta + \delta$)
= 2.009 x sin (11.86) = 0.413 t/m

P_{av4} = P_{a4} x sin ($\theta + \delta$)
= 0.298 x sin (11.86) = 0.061 t/m

(in seismic)

P_{ea1} = dh x γ_s x K_{ea} x ($h+h_1$)
= 0.10 x 1.8 x 0.934 x 2.50 = 0.420 t/m

P_{ea2} = ½ x z^2 x γ_s x K_{ea}
= ½ x $(1.5)^2$ x 1.8 x 0.934 = 1.891 t/m

P_{ea3} = z x γ_s x K_{ea} x ($h + h_1 - z$)
= 1.5 x 1.8 x 0.934 x 1.0 = 2.522 t/m

P_{ea4} = ½ x ($h + h_1 - z$) x γ_s x K_{ea}
= ½ x $(1.0)^2$ x 0.8 x 1.065 = 0.426 t/m

Horizontal Active Earth Pressure

P_{eah1} = P_{ea1} x cos ($\theta + \delta$)
= 0.420 x cos (2.86) = 0.420 t/m

P_{eah2} = P_{ea2} x cos ($\theta + \delta$)
= 1.891 x cos (2.86) = 1.889 t/m

P_{eah3} = P_{ea3} x cos ($\theta + \delta$)
= 2.522 x cos (2.86) = 2.519 t/m

P_{eah4} = P_{ea4} x cos ($\theta + \delta$)
= 0.426 x cos (2.86) = 0.425 t/m

Vertical Active Earth Pressure

P_{eav1} = P_{ea1} x sin (θ + δ)
= 0.420 x sin (2.86) = 0.021 t/m

P_{eav2} = P_{ea2} x sin (θ + δ)
= 1.891 x sin (2.86) = 0.094 t/m

P_{eav3} = P_{ea3} x sin (θ + δ)
= 2.522 x sin (2.86) = 0.126 t/m

P_{eav4} = P_{ea4} x sin (θ + δ)
= 0.426 x sin (2.86) = 0.021 t/m

Water Pressure

P_{wa} = ½ $(h + h_1 - z)^2 \times \gamma_w$
= ½. $(1.0)^2$ x 1.0 = 0.500 t/m

Earthquake Force

W_e = W x kh
= 10.502 x 0.12

= 1.260 t/m

y_e = 1.388 m

Vertical Force and Moment

(in ordinary)

Vertical Force (t/m)		Arm (m)	Vertical Moment (tm/m)
W	8.702	0.910	7.919
Pav_1	0.069	1.800	0.124
Pav_2	0.310	1.800	0.558
Pav_3	0.413	1.800	0.743
Pav_4	0.061	1.800	0.110
FV	9.555	MV	9.454

(in seismic)

Vertical Force (t/m)		Arm (m)	Vertical Moment (tm/m)
W	8.702	0.910	7.919
$Peav_1$	0.021	1.800	0.038
$Peav_2$	0.094	1.800	0.169
$Peav_3$	0.126	1.800	0.227
$Peav_4$	0.021	1.800	0.038
FVe	8.964	MVe	8.391

Horizontal Force and Moment

(in ordinary)

Horizontal Force (t/m)		Arm (m)	Horizontal Moment (tm/m)
P_{ah1}	0.328	1.250	0.410
P_{ah2}	1.474	1.500	2.211
P_{ah3}	1.966	0.500	0.983
P_{ah4}	0.291	0.333	0.097
P_w	0.500	0.167	0.084
FH	4.559	MH	3.785

(in seismic)

Horizontal Force (t/m)		Arm (m)	Horizontal Moment (tm/m)
P_{eah1}	0.420	1.250	0.525
P_{eah2}	1.889	1.500	2.834
P_{eah3}	2.519	0.500	1.260
P_{eah4}	0.425	0.333	0.142
P_w	0.500	0.167	0.084
W_e	1.260	1.388	1.749
FH_e	7.013	MH_e	6.594

Reaction beneath Slab.

FV = 9.555

MV = 9.454

FV_e = 8.964 < 1.5 FV

MV_e = 8.391 < 1.5 MV

Therefore, force and moment in normal condition will be adopted on the estimation of Reaction Beneath Slab and Stress Strain analysis.

Reaction beneath slab will be estimated as follows:

$$e = b/2 - (MV - MH)/FV$$
$$= 1.8/2 - (9.454 - 8.391)/9.555$$
$$= 0.30 \text{ m}$$
$$= b/6$$

$$q = FV / b \times (1 \pm 6e/b)$$

$$q_{max} = 2\ FV/b$$
$$= 2 \times 9.555 / 1.8$$
$$= 10.617 \text{ t/m}^2$$

$$q_{min} = 0$$

(iii) Shearing Force and Moment

$$q_1 = 0.5 \times \gamma_c + (h + dh) \times \gamma_s - (h + h_1 - z) \times \gamma_w$$
$$= 0.5 \times 2.5 + 2.10 \times 1.8 - 1.0 \times 1.0$$
$$= 4.030 \text{ t/m}^2$$

$$q_2 = q_1 + (b - b_1) / 2 \times \gamma_s$$
$$= 4.03 + 0.75 \times 1.8$$
$$= 5.380 \text{ t/m}^2$$

$$q = q2 - 0.931x - q_{min} - 5.898x$$
$$= 5.380 - 0.921x - 0 - 5.898x$$
$$= 5.380 - 6.829x$$

$$v = \Box q\,(dx)$$
$$= \int_0^{x=1.45} (5.380 - 6.829x)dx$$
$$= 5.380x - 6.829\frac{x^2}{2}\Big]_0^{1.45}$$
$$= 0.622 \text{ t/m}$$

$$M = \square v\,(dx)$$

$$= \int_{0}^{x=1.45} (5.380x - 6.829\frac{x^2}{2})dx$$

$$= 5.380\frac{x^2}{2} - 6.829\frac{x^3}{6}\Big]_0^{1.45}$$

$$= 2.186 \text{ t.m/m}$$

(iv) Required Re-bar

ht = 50 cm; d = 5 cm; h = 45 cm

$\phi_o = \sigma_a / n\,\sigma_b$

$= 1400 / (21 \times 25) = 0.889$

$$C_a = \frac{h}{\sqrt{\dfrac{n \times M}{b \times \sigma_a}}}$$

$$= \frac{45}{\sqrt{\dfrac{21 \times 218600}{100 \times 1400}}}$$

$= 7.859$

For C_a = 7.859

δ = 0.60

ϕ = 5.050

ϕ' = 12.790

n_ω = 0.0172

Stresses:

$\sigma_a = \overline{\sigma}_a = 1400 \text{ kg/cm}^2$

$$\sigma'_b = \frac{\overline{\sigma}_a}{n\phi} = \frac{1400}{21 \times 5.05} = 13.201 \text{ kg/cm}^2$$

$$\sigma'_a = \frac{\overline{\sigma}_a}{\phi'} = \frac{1400}{12.790} = 109.46 \text{ kg/cm}^2$$

Re-bar will be arranged

$A = \omega \, b \, h$

$= 0.0172 / 21 \times 100 \times 45 = 3.686 \text{ cm}^2$

$A_s = 0.2 \times A = 0.737 \text{ cm}^2$

$A' = \delta \, . \, A = 2.211 \text{ cm}^2$

$A'_s = 0.2 \times A' = 0.442 \text{ cm}^2$

Re-bar : $D_{13\text{-}25}$, $A = 5.32 \text{ cm}^2$

$D_{13\text{-}25}$, $A_s = 5.32 \text{ cm}^2$

5.2 Ground Sill without Head at WF 173

Location and Purpose

The following groundsill is proposed in the river improvement plan.

It is anticipated that riverbed degradation of Garang River channel downstream from the confluence with Kreo River arises after the completion of Jatibarang Dam. Accordingly, the existing structures constructed in the channel may be affected. For this reason, a ground sill aiming at protecting the pier foundation of Toll Road Bridge from riverbed/river bank encroachment is proposed at the immediate downstream portion of about 100 m from the bridge.

Structural Type

On the other hand, the ground sill (WF 173) consists of main sill body made of wet masonry and mounded gabion mattress placed on the upstream and downstream riverbeds. This type of ground sill is flexible to conform the riverbed variations.

The design of ground sills is made to ensure structural stability against sliding, overturning and bearing capacity of the sub-base ground, and to satisfy hydraulic stability against piping, uplift and scouring.

Structural Dimension etc.

(a) River Channel

Riverbed width		40.0 m
Side slope	(m)	2.0
Riverbed Slope	(I)	$^1/_{1250}$
Design Riverbed elevation		EL. + 5.793 m
Existing Lowest riverbed elevation		EL. + 5.030 m

(b) Main Sill Body

Height	(H)	2.0 m
Crown width	(B1)	1.5 m
Bottom width	(B)	2.5 m

(c) Side Wall

Height	(h)	2.5 m
Crown width	(b1)	0.5 m
Bottom width	(b)	1.2 m
Length		26.5 m

(d) Revetment

Length	Upstream	10.0 m
	Main structure	1.5 m
	Downstream	15.0 m

(e) Riverbed Protection

Upstream length	12.0 m
Downstream length	15.0 m
Thickness	0.5 m

5.2.1 Structural Design of Side Wall

Design Condition

(a) Hydraulic Condition

(i) Normal Condition

Water elevation	EL + 5.293
Water Depth	z = 0.30 m
Ground Water Table	EL + 5.593

(ii) Seismic Condition

Water elevation	EL + 5.293
Water Depth	z = 0.30 m
Ground Water Table	EL + 5.593

(b) The Material Data

(i) Soil Material *)

Wet unit weight	γ_t = 1.800 t/m^3
Saturated unit weight	γ_s = 1.955 t/m^3
Submerged unit weight	γ'_t = 0.955 t/m^3
Internal friction angle	ϕ = 42°

*) Basel on geological investigation on RB 47 and RB 48 (Location WF 173) Soil layer at el. 3.00 m to el. 7.00 m are silky gravelly sand, fine to very coarse grained with N-value of about N = 50 and γ_{sat} = 1.955 t/m^2. Soil internal friction angle will be estimated based on N-value as follows $\phi = 15 + \sqrt{15.N} = 42.38 \sim 42°$.

Cohesion	C = 0.0 t/m³

(ii) Others

Unit weight of wet masonry	γ_m = 2.30 t/m³
Unit weight of gabion mattress / cobbles	γ_{gm} = 2.20 t/m³
Unit weight of gravel	γ_g = 2.00 t/m³
Unit weight of water	γ_w = 1.00 t/m³

(c) Design Load

(i) Earth Pressure

- Coulomb's formula
- Mean ground surface slope, α = 26.56° (=atn 0.5)
- Angle between backside of wall & vertical plane, θ = 13.50° (=atn 0.6/2.5)
- Friction angle at wall (δ)

  Normal $\delta = \phi$

  Seismic $\delta = \phi/2$
- Horizontal seismic coefficient Kh = 0.12

(ii) Surcharge due to revetment

$$dh = (t_1 \times \gamma_m + t_2 \times \gamma_g) / \gamma_t - (t_1 + t_2)$$

$$= (0.25 \times 2.3 + 0.25 \times 2.0) / 1.8 - 0.5 = 0.10 \text{ m}$$

(iii) Surcharge due to gabion mattress (submerged)

$$dh_1 = (t \times \gamma'_{gm}) / \gamma'_S - t$$

$$= (0.50 \times 1.20) / 0.955 - 0.5 = 0.13 \text{ m}$$

(d) The Combination of Load

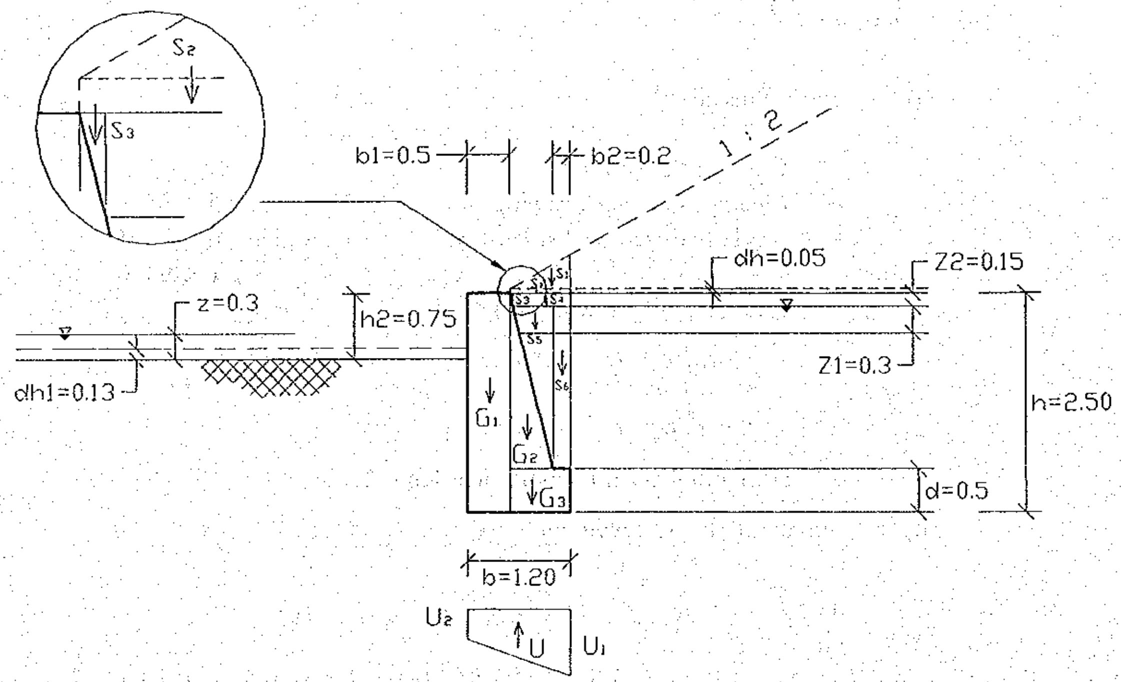
	Load Condition	Normal	Seismic
the vertical load	Weight of wall	+	+
	Weight of soil	+	+
	Uplift pressure	+	+
the horizontal load	Earth Pressure	+	+
	Water Pressure	+	+
	Horizontal Earthquake Pressure		+

" + " Consider in the calculation

Stability Analysis

(a) Center Gravity of Structure

(i) Proposed Condition



(ii) Weight of Wall Body

$G_1 = b_1 \times h \times \gamma_m$				
$= 0.5 \times 2.5 \times 2.30$		=	2.875	t/m
$x_1 = b_1/2 = 0.5/2$		=	0.25	m
$y_1 = h/2 = 2.5/2$		=	1.25	m
$G_2 = (b - b_1 - b_2) \times {}^{(h-d)}/_2 \times \gamma_m$				
$= 0.5 \times {}^{2.00}/_2 \times 2.30$		=	1.150	t/m
$x_2 = b_1 + (b - b_1 - b_2)/3$	$= 0.5 + 0.5/3$	=	0.667	m
$y_2 = {}^{(h-d)}/_3$	$= 2.0/3$	=	0.667	m
$G_3 = (b - b_1) \times d \times \gamma_m$				
$= 0.70 \times 0.50 \times 2.3$		=	0.805	t/m
$x_3 = b_1 + (b - b_1)/2$	$= 0.5 + 0.7/2$	=	0.85	m
$y_3 = d/2$	$= 0.5/2$	=	0.25	m

(iii) Weight of Soil

$S_1 = ¼\,(b - b_1)^2 \times \gamma_t$			
$= ¼\,(0.7)^2 \times 1.80$	=	0.221	t/m

$x_{S1} = b_1 + {}^{2}/_{3}\,(b - b_1)$

$$= 0.5 + {}^{2}/_{3}\ (0.5) \qquad = \quad 0.833 \quad m$$
$$y_{S1} = h + dh + (b - b_1)/2/3$$
$$= 2.5 + 0.10 + (0.7)/6 \qquad = \quad 2.717 \quad m$$

$$S_2 = dh \times (b - b_1) \times \gamma_t$$
$$= 0.10 \times 0.5 \times 1.8 \qquad = \quad 0.09 \quad t/m$$
$$x_{S2} = b_1 + (b - b_1)/2$$
$$= 0.5 + 0.7/2 \qquad = \quad 0.850 \quad m$$
$$y_{S2} = h + dh/2$$
$$= 2.50 + 0.10/2 \qquad = \quad 2.550 \quad m$$

$$S_3 = z_2 \times (z_2/4)/2 \times \gamma_t$$
$$= 0.15 \times (0.15/4)/2 \times 1.8 \qquad = \quad 0.005 \quad t/m$$
$$x_{S3} = b_1 + 2/3\ (z_2/4)$$
$$= 0.5 + 2/3\ (0.15/4) \qquad = \quad 0.525 \quad m$$
$$y_{S3} = h - z_2/3$$
$$= 2.5 - 0.15/3 \qquad = \quad 2.45 \quad m$$

$$S_4 = (b - b1 - z_2/4) \times z_2 \times \gamma_t$$
$$= (0.7 - 0.15/4) \times 0.15 \times 1.8 \qquad = \quad 0.179 \quad t/m$$
$$x_{S4} = b - (b - b1 - z_2/4)/2$$
$$= 1.20 - (0.7 - 0.15/4)/2 \qquad = \quad 0.869 \quad m$$
$$y_{S4} = h - z_2/2$$
$$= 2.5 - 0.15/2 \qquad = \quad 2.425 \quad m$$

$$S_5 = (b - b_1 - b_2 - z_2/4) \times (h - d - z_2)/2 \times \gamma_s$$
$$= 0.463 \times {}^{1.85}/_{2} \times 1.955 \qquad = \quad 0.836 \quad t/m$$
$$x_{S5} = b_1 \times z_2/4 + {}^{2}/_{3}\ (b - b_1 - b_2 - z_2/4)$$
$$= 0.5 + 0.15/4 + 2/3\ (0.5 - 0.15/4) \qquad = \quad 0.846 \quad m$$
$$y_{S5} = d + {}^{2}/_{3}\ (h - d - z_2)$$
$$= 0.5 + {}^{2}/_{3}\ (1.85) \qquad = \quad 1.733 \quad m$$

$$S_6 = (h - d - z_2) \times b_2 \times \gamma_s$$
$$= 1.85 \times 0.2 \times 1.955 \qquad = \quad 0.723 \quad t/m$$
$$x_{S6} = b - b_2/2$$
$$= 1.20 - 0.2/2 \qquad = \quad 1.10 \quad m$$
$$y_{S6} = d + (h - d - z_2)/2$$
$$= 0.5 + 1.85/2 \qquad = \quad 1.425 \quad m$$

(iv) Buoyant Force (Uplift)

$$\Delta H = 0.3 \ m$$

$$u_1 = 2.50 - 0.15 \qquad = \quad 2.35 \quad m$$
$$u_2 = 2.35 - 2.05 \qquad = \quad 2.05 \quad m$$

$$U = b \times (u_1 + u_2)/2 \times \gamma_W$$
$$= 1.20 \times (2.35 + 2.05)/2 \times 1.0 \qquad = \quad 2.640 \quad t/m$$

$$x_U = b - b/3\ (u_1 + 2u_2)/(u_1 + u_2)$$
$$= 1.2 - 1.2/3\ (2.35 + 2 \times 2.05) / 4.40 \qquad = \quad 0.614 \quad m$$

$$y_U = 0.0 \ m$$

(v) Center Gravity of Structure

Weight . Wi (t/m)		xi (m)	$W_i \cdot x_i$ (tm/m)	y_i (m)	$W_i \cdot y_i$ (tm/m)
G_1	2.875	0.250	0.719	1.250	3.594
G_2	1.150	0.667	0.767	0.667	0.767
G_3	0.805	0.850	0.684	0.250	0.201
S_1	0.221	0.833	0.184	2.717	0.600
S_2	0.090	0.850	0.077	2.550	0.230
S_3	0.005	0.525	0.003	2.450	0.012
S_4	0.179	0.869	0.156	2.425	0.434
S_5	0.836	0.846	0.707	1.733	1.449
S_6	0.723	1.100	0.795	1.425	1.030
U	-2.640	0.614	-1.621	0.000	0.000
Σ	4.244		2.470		8.317

$x_o = \Sigma W_i \cdot x_i / \Sigma W$ = 0.582 m
$y = \Sigma W_i \cdot x_i / \Sigma W$ = 1.952 m

For without uplift :

ΣW = 6.884 t/m
$\Sigma W_i \cdot x_i$ = 4.091 m
$\Sigma W_i \cdot x_i$ = 8.317 m
x_o' = 0.594 m
y_o' = 1.208 m

(b) Bearing Capacity Beneath Slab

$$q_U = \alpha \cdot c \cdot k \cdot N + k \cdot g \cdot Nq + ½ \cdot \gamma \cdot \beta \cdot b \cdot N\gamma$$
$\alpha = \beta = 1.0$
$c = 0$
$Df = 1.75$ m

$k = 1 + 0.3\ Df/b$
$= 1 + 0.3\ (1.75 / 1.20) = 1.438$
$q = t \times \gamma'_{gm} + (h_1 - t) \times \gamma'_s$
$= 0.5 \times 1.0 + 1.25 \times 0.955 = 1.694\ t/m^2$

For, $\phi = 42°$; $\theta = 13.5$; $Nq = 33$
$N\gamma = 30$

$q_U = 1.438 \times 1.694 \times 33 + ½ \times 1.20 \times 30$
$= 98.387\ t/m^2$
$qa = q_U/3 = 32.796$ t/m2 (in ordinary)
$qa = q_U/3 = 49.194$ t/m2 (in seismic)

(c) Coefficient of Earth Pressure

Applying Coulomb's formula as follows :

In Ordinary

$\theta = 13.5°$; $\alpha = 26.56°$; $\delta = \phi = 42°$

$$Ka = \frac{\cos^2(\phi-\theta)}{\cos^2\theta\ \cos(\phi+\delta)\left[1+\sqrt{\frac{(\sin\phi+\delta)\sin(\phi-\alpha)}{\cos(\theta+\delta)\cos(\theta-\alpha)}}\right]^2}$$

$$= \frac{\cos^2(42-13.5)}{\cos^2(13.5)\times\cos(13.5+42)\left[1+\sqrt{\frac{\sin(42+42)\times\sin(42-26.56)}{\cos(13.5+42)\times\cos(13.5-26.56)}}\right]^2}$$

$= 0.503$

$$Kp = \frac{\cos^2(\phi+\theta)}{\cos^2\theta\cdot\cos(\theta+\delta)\left[1-\sqrt{\frac{(\sin\phi-\delta)\sin(\phi+\alpha)}{\cos(\theta+\delta)\cos(\theta-\alpha)}}\right]^2}$$

$$= \frac{\cos^2(42+13.5)}{\cos^2 13.5\times\cos(13.5+42)\left[1-\sqrt{\frac{\sin(42-42)\times\sin(42+26.56)}{\cos(13.5+42)\times\cos(13.5-26.56)}}\right]^2}$$

$= 0.599$

(In Seismic)

$$Kh' = \frac{\gamma_S}{\gamma_S-1}\times Kh$$

$$= \frac{1.955}{0.955}\ \text{x}\ 0.12 = 0.2456$$

θ_O = atn Kh' = atn 0.12 = 6.84°
θ_O' = atn Kh' = atn 0.2456 = 13.80°

$\delta = \phi/2 = 21°$; $\theta = 13.5°$; $\alpha = 26.56°$

$$K_{ea} = \frac{\cos^2(\phi-\theta_o-\theta)}{\cos\theta_o\cdot\cos^2\theta\cdot\cos(\phi+\theta_o+\delta)\left[1+\sqrt{\frac{(\sin\phi+\delta)\cdot\sin(\phi-\alpha-\theta_o)}{\cos(\theta+\theta_o+\delta)\cdot\cos(\theta-\alpha)}}\right]^2}$$

$$= \frac{\cos^2(42-6.84-13.5)}{\cos(6.84)\times\cos^2(13.5)\times\cos(13.5+6.84+21)\left[1+\sqrt{\frac{\sin(42+21)\times\sin(42-26.56-6.84)}{\cos(13.5+6.84+21)\times\cos(13.5-26.56)}}\right]^2}$$

$= 0.602$

$$K'_{ea} = \frac{\cos^2(42-13.8-13.5)}{\cos(13.8)\times\cos^2(13.5)\times\cos(13.5+1.38+21)\left[1+\sqrt{\frac{\sin(42+21)\times\sin(42-26.56-13.8)}{\cos(13.5+13.8+21)\times\cos(13.5-26.56)}}\right]^2}$$

$= 1.067$

$$K_{ep} = \frac{\cos^2(\phi-\theta_o+\theta)}{\cos\theta_o\cdot\cos^2\theta\cdot\cos(\phi-\theta_o+\delta)\left[1-\sqrt{\frac{(\sin\phi-\delta)\cdot\sin(\phi+\alpha-\theta_o)}{\cos(\theta-\theta_o+\delta)\cdot\cos(\theta-\alpha)}}\right]^2}$$

$$= \frac{\cos^2(42-6.84+13.5)}{\cos(6.84)\times\cos^2(13.5)\times\cos(13.5-6.84+21)\left[1-\sqrt{\frac{\sin(42-21)\times\sin(42+26.56-6.84)}{\cos(13.5-6.84+21)\times\cos(13.5-26.56)}}\right]^2}$$

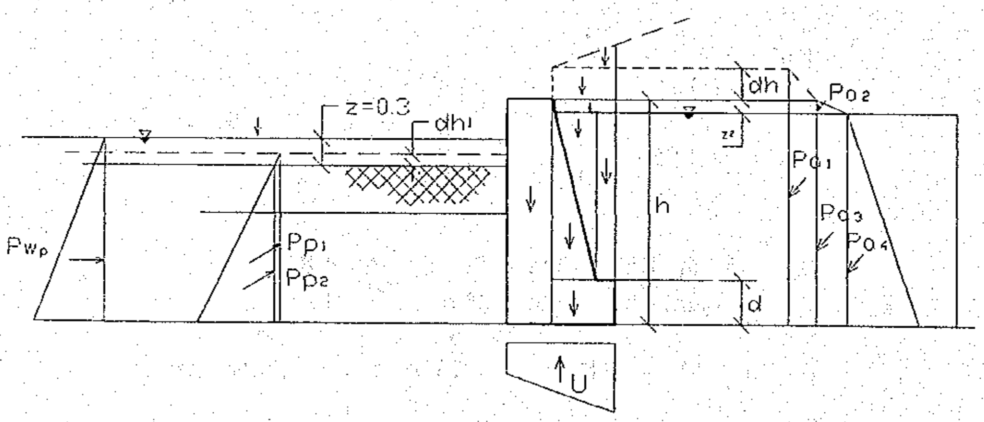
$= 3.360$

$$K'_{cp} = \frac{\cos^2(42-13.8+13.5)}{\cos(13.8)\times\cos^2(13.5)\times\cos(13.5-13.8+21)\left[1-\sqrt{\frac{\sin(42-21)\times\sin(42+26.56-13.8)}{\cos(13.5-13.8+21)\times\cos(13.5-26.56)}}\right]^2}$$

$= 3.458$

(d) Stability analysis on Normal Condition

(i) Load Condition



(ii) External Force

Active Earth Pressure

$Pa_1 = dh \times \gamma_t \times Ka \times h$

$= 0.10 \times 1.80 \times 0.503 \times 2.5 \quad = \quad 0.226$ t/m

$Pa_2 = ½ \times (z_2)^2 \times \gamma_t \times Ka$

$= ½ \times (0.15)^2 \times 1.80 \times 0.503 \quad = \quad 0.010$ t/m

$Pa_3 = z_2 \times \gamma_t \times Ka \times (h + z_2)$

$= 0.15 \times 1.80 \times 0.503 \times 2.35 \quad = \quad 0.319$ t/m

$Pa_4 = ½ \times (h - z_2)^2 \times \gamma'_S \times Ka$

$= ½ \times (2.35)^2 \times 0.955 \times 0.503 \quad = \quad 1.326$ t/m

Horizontal Active Earth Pressure

$Pah_1 = Pa_1 \times \cos(\theta + \delta)$

$= 0.226 \times \cos(13.5 + 42) \quad = \quad 0.128$ t/m

$y_{a1} = h/2 = 2.5/2 \quad = \quad 1.25$ m

$Pah_2 = Pa_2 \times \cos(\theta + \delta)$

$= 0.010 \times \cos(55.5) \quad = \quad 0.006$ t/m

$y_{a2} = z_2 / 3 + (h - z_2)$

$= (0.15) / 3 + 2.35 \quad = \quad 2.400$ m

$Pah_3 = Pa_3 \times \cos(\theta + \delta)$

$= 0.319 \times \cos(55.5) \quad = \quad 0.181$ t/m

$y_{a3} = (h - z_2) / 2$

$= 2.35 / 2 \quad = \quad 1.175$ m

$Pah_4 = Pa_4 \times \cos(\theta + \delta)$

$= 1.326 \times \cos(55.5) \quad = \quad 0.751$ t/m

$y_{a4} = (h - z_2) / 3$

$= 2.35 / 3 \quad = \quad 0.783$ m

Vertical Active Earth Pressure

$Pav_1 = Pa_1 \times \sin(\theta + \delta)$

$= 0.226 \times \sin(55.5) \quad = \quad 0.187$ t/m

$x_{a1} = 1.20$ m

$Pav_2 = Pa_2 \times \sin(\theta + \delta)$

$= 0.010 \times \sin(55.5) \quad = \quad 0.008$ t/m

x_{a2} = 1.20 m

Pav_3 = Pa_3 x sin (θ + δ)

= 0.319 x sin (55.5) = 0.263 t/m

x_{a3} = 1.20 m

Pav_4 = Pa_4 x sin (θ + δ)

= 1.326 x sin (55.5) = 1.093 t/m

x_{a4} = 1.20 m

Passive Earth Pressure

Pp_1 = dh_1 x γ'_S x Kp x h_1

= 0.13 x 0.955 x 0.599 x 1.75 = 0.130 t/m

Pp_2 = ½ x h_1^2 x γ'_S x Kp

= ½ x $(1.75)^2$ x 0.955 x 0.599 = 0.876 t/m

Horizontal Passive Earth Pressure

Pph_1 = Pp_1 x cos (θ – δ)

= 0.130 x cos (13.5 – 42) = 0.114 t/m

y_{p1} = h_1 / 2

= 1.75 / 2 = 0.875 m

Pph_2 = Pp_2 x cos (θ – δ)

= 0.876 x cos (– 28.5) = 0.770 t/m

y_{p2} = h_1 / 3

= 1.75 / 3 = 0.583 m

Water Pressure

P_{wa} = ½ $(h - z_2)^2$ x γ_w

= ½ $(2.35)^2$ x 1.0 = 2.761 t/m

y_{wa} = $(h - z_2)$ / 3

2.35 / 3 = 0.783 m

(iii) Vertical Force and Moment

Vertical Force (t/m)		Arm (m)	Vertical Moment (tm/m)
P_{av1}	0.187	1.200	0.224
P_{av2}	0.008	1.200	0.010
P_{av3}	0.263	1.200	0.316
P_{av4}	1.093	1.200	1.312
W	4.244	-	2.470
FV	5.795	MV	4.331

(iv) Horizontal Force

Horizontal Force (t/m)		Arm (m)	Horizontal Moment (tm/m)
P_{ah1}	0.128	1.250	0.160
P_{ah2}	0.006	2.400	0.014
P_{ah3}	0.181	1.175	0.213
P_{ah4}	0.751	0.783	0.588
P_{ph2}	-0.114*)	0.875	-0.100
P_{wa}	2.761	0.783	2.162
P_{wp}	-2.101	0.683	-1.435
FH	1.726	MH	1.153

*) Passive earth pressure is omitted

(v) Check of Stability

Stability against sliding

$$SF = FV/FH \cdot \tan\phi$$

$$= 5.795/1.726 \times \tan 42 \qquad = 3.02$$

$$> 1.5$$

Stability against overturning

$$C = b/2 - \frac{(MV - MH)}{FV}$$

$$= 1.20/2 - \frac{(4.311 - 1.153)}{5.795} \qquad = 0.052 \text{ m } (-)$$

$$< B/6 \quad (=0.20 \text{ m})$$

Stability of bearing strata

$$q = FV/b \times (1 \pm 6e/b)$$

$$q_{max} = 5.795/1.20 \times \left(1 + 6 \times 0.052/1.20\right) \qquad = 5.085 \text{ t/m}^2$$

$$< q_a = 32.796 \text{ t/m}^2$$

(e) Stability Analysis on Seismic Condition

(i) External Force

Active Earth Pressure

$Pea_1 = dh \times \gamma_T \times Kea \times h$

$= 0.10 \times 1.80 \times 0.602 \times 2.5 = 0.271$ t/m

$Pea_2 = ½ \times (z_2)^2 \times \gamma_t \times Kea$

$= ½ \times (0.15)^2 \times 1.80 \times 0.602 = 0.012$ t/m

$Pea_3 = (z_2) \times \gamma_S \times Kea \times (h - z_2)$

$= 0.15 \times 1.80 \times 0.602 \times 2.35 = 0.382$ t/m

$Pea_4 = ½ \times (h - z_2)^2 \times \gamma'_S \times K'ea$

$= ½ \times (2.35)^2 \times 0.955 \times 1.067 = 2.814$ t/m

Horizontal Active Earth Pressure

$P_{eah1} = P_{ea1} \times \cos(\theta + \delta)$

$= 0.271 \times \cos(13.5 + 21) = 0.223$ t/m

$y_{ea1} = h/2 = 1.25$ m

$P_{eah2} = P_{ea2} \times \cos(\theta + \delta)$

$= 0.012 \times \cos(34.5) = 0.010$ t/m

$y_{ea2} = (z_2)/3 + (h_1 - z) = 2.400$ m

$P_{eah3} = P_{ea3} \times \cos(\theta + \delta)$

$= 0.382 \times \cos(34.5) = 0.315$ t/m

$y_{ea3} = (h - z_2)/2 = 1.175$ m

$P_{eah4} = P_{ea4} \times \cos(\theta + \delta)$

$= 2.814 \times \cos(34.5) = 2.319$ t/m

$y_{ea4} = (h - z_2)/3 = 0.783$ m

Vertical active Earth Pressure

$P_{eav1} = P_{ea1} \times \sin(\theta + \delta)$

$= 0.271 \times \sin(34.5) = 0.153$ t/m

$y_{ea1} = 1.20$ m

P_{eav2} = P_{ea2} x sin (θ + δ)

= 0.012 x sin (34.5) = 0.007 t/m

y_{ea2} = 1.20 m

P_{eav3} = P_{ea3} x sin (θ + δ)

= 0.382 x sin (34.5) = 0.216 t/m

y_{ea3} = 1.20 m

P_{eav4} = P_{ea1} x sin (θ + δ)

= 2.814 x sin (34.5) = 1.594 t/m

y_{ea4} = 1.20 m

Passive Earth Pressure

P_{ep1} = dh_1 x γ'_S x K'ep x h_1

= 0.13 x 0.955 x 3.458 x 1.75 = 0.751 t/m

P_{ep2} = ½ x h_1^2 x γ'_S x K'ep

= ½ x $(1.75)^2$ x 0.955 x 3.458 = 5.057 t/m

Horizontal Passive Earth Pressure

P_{eph1} = P_{ep1} x cos (θ + δ)

= 0.751 x cos (13.5 – 21) = 0.745 t/m

y_{ep1} = h_1 / 3 = 0.875 m

P_{eph2} = P_{ep2} x cos (θ + δ)

= 5.057 x cos (–7.5) = 5.014 t/m

y_{ep2} = h_1 / 3 = 0.583 m

Water Pressure

P_{wa} = 2.761 t/m

y_{wa} = 0.783 t/m

P_{wp} = 2.101 t/m

y_{wp} = 0.683 t/m

Earthquake Force

W_e = W x kh = 0.826 t/m

y_e = 1.208 m

(ii) Vertical Force and Moment

Vertical Force (t/m)		Arm (m)	Vertical Moment (tm/m)
P_{eav1}	0.153	1.200	0.184
P_{eav2}	0.007	1.200	0.008
P_{eav3}	0.216	1.200	0.259
P_{eav4}	1.594	1.200	1.913
W	4.244	-	2.470
FVe	6.214	MVe	4.834

(iii) Horizontal Force and Moment

Horizontal Force (t/m)		Arm (m)	Horizontal Moment (tm/m)
P_{eah1}	0.223	1.250	0.279
P_{eah2}	0.010	2.400	0.024
P_{eah3}	0.315	1.176	0.370
P_{eah4}	2.319	0.783	1.816
P_{eph}	–0.745 *)	0.875	–0.652
P_{wa}	2.761	0.785	2.162
P_{wp}	–2.101	0.683	–1.435
W_e	0.826	1.208	0.998
FHe	4.353	MHe	0.639

*) Passive earth pressure is omitted

(iv) Check Stability

Stability against sliding

$SF = FV_e / FH_e \cdot \tan\phi$

$= 6.214 / 4.353 \times \tan 42° \quad = 1.285$

> 1.2

Stability against overturning

$e = b/2 - (MV_e - MH_e) / FV_e$

$= 1.2/2 - (4.834 - 0.639) / 6.214 \quad = 0.075$ m

$< b/6$ (=0.20 m)

Stability of bearing strata

$q = FV_e/b \, (1 \pm be / b)$

$q_{max} = 6.214/1.2 \, (1 + 6 \times 0.075/1.20) \quad = 7.120$ t/m

$< qea (= 49.194 \text{ t/m}^2)$