DESIGN OF PIER-1 , PIER-2 , PIER-3

KREO BRIDGE

DESIGN OF PIER (P1)

File:Pierl

Case I : Water is empty + 146.33 (NORMAL CONDITION)

Parameter of soil :

	ϕ =	36	degree
	γ =	2.0	t/m^3
	C =	18	t / m^2
Height of Pier	H =	6.0	m
Width of footing Pier	B =	3.5	m
	L =	3.5	m

Compute overturning stability :
Set up table and refer to figure : ....

part	Weight of part (ton)	
1	1.6*0.4*2.5*2.7 =	4.3200
2	(1.6+0.9)/2*0.4*2.5*(2.7+2)/2=	2.9375
3	0.7*4.3*2.5*2.0 =	19.3500
4	(3.5+0.9)/2*0.4*2.5*(3.5+2)/2=	6.0500
5	3.5*0.5*2.5*3.5 =	15.3125
6	P1	46.000
7	P2	46.000
	Total : Σ Fv =	139.970

Checking of Bearing Capacity on soil :

$$Qu = A' * [\alpha * k * c * Nc + k * q * Nq + 0.5 * \gamma_1 * B' * \beta' * N\gamma$$

where :

Qu = ultimate bearing capacity
A' = effective loading area on footing
α, β = coefficient depending on shape of footing
c = cohesion of foundation ground (ton/m^2)
q = ground surface surcharge (t/m^2) q = γ * Df
$\gamma 2$ = unit weight of soil on front of abutments (t/m^3) = 0.8 t/m^3
$\gamma 1$ = unit weight of soil of ground foundation (t/m^3) = 1.0 t/m^3
B',L' = width and length of effective loading area
e = distance from entrance of footing to acting point of resultant force on footing (m)
Df = depth from ground surface on front of abutment to bottom of footing (m)
Df' = height of toe (m) = 0.5 m
k = coefficient ——> k = (1 + 0,3 * Df' / B')
Nq , Nc , Nγ = bearing capacity factors

A' = L' * B' = (B - 2eb) * (L - 2el)

A' =(B - 2*eb) * (L - 2*el) = 12.25 m^2

α = (1 + 0.3B'/L') = 1.30

$\beta = (1 - 4*B'/L') =$ -3

$q = \gamma * Df =$ 6.12 t/m^2

$k = (1 + 0,3 * (Df'/B')) =$ 1.0429

For $\tan\theta = \Sigma Fh / \Sigma Fv = 0$ Nc= 50

$\phi = 36$ Nq = 33

$N\gamma = 40$

Qu = 10170.70 ton

FS = 3

Qsafe = Qu / FS = 3390.232 ton

$q_{max} = \Sigma Fv / B =$ 39.991 t / m'

$q_{max} = \Sigma Fv / A =$ 11.426 t / m^2

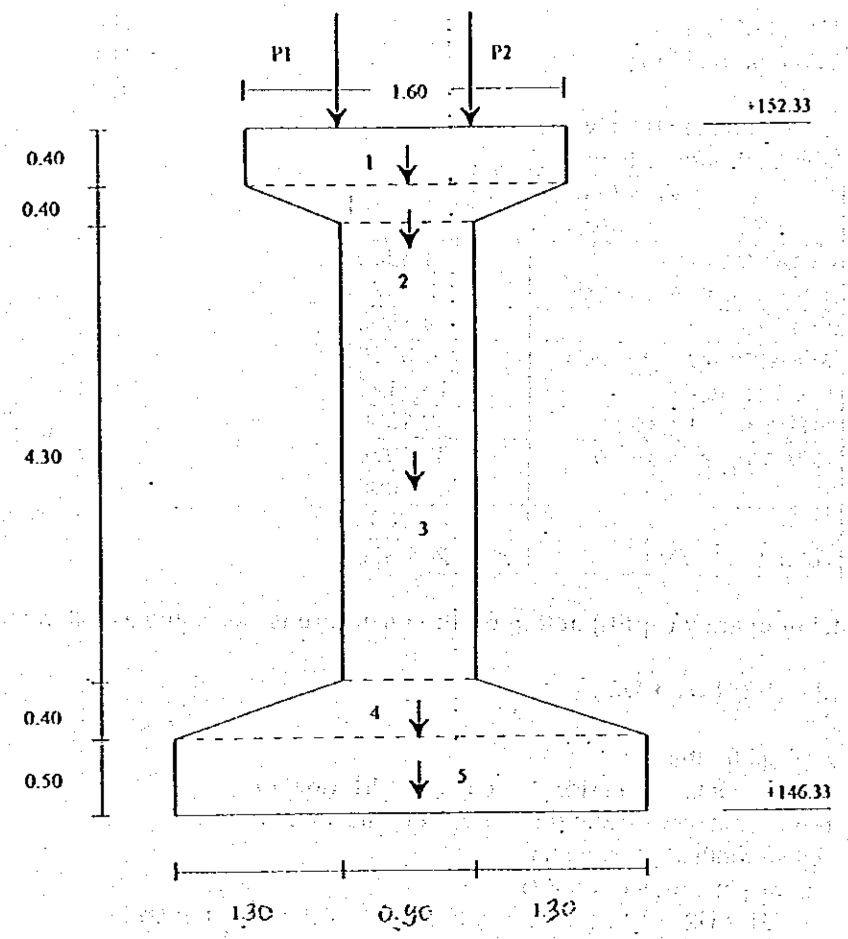
$Q_{max} = q_{max} * A =$ 139.970 ton

Checking the bearing capacity is :

Qmax = 139.97 ton < Qsafe = 3390.23 ton

OK

Name of Structure		Category of calculation		Page	25



DESIGN OF PIER – 1 (P-1)
Case I : water is empty + 146.33
(Normal Condition)

DESIGN OF PIER (P1)

File:PierII

Case II : Water is full at elevation MWL + 153.60 (NORMAL CONDITION).

Parameter of soil :

	$\phi' = 2/3\phi$ =	24 degree
	γsub =	1.0 t/m^3
	C'=2/3C =	12 t / m^2
Height of Pier	H =	6.0 m
Width of footing Pier	B =	3.5 m
	L =	3.5 m

Compute overturning stability :

Set up table and refer to figure : ....

part	Weight of part (ton)	
1	1.6*0.4*2.5*2.7 =	4.3200
2	(1.6+0.9)/2*0.4*2.5*(2.7+2)/2=	2.9375
3	0.7*4.3*2.5*2.0 =	19.3500
4	(3.5+0.9)/2*0.4*2.5*(3.5+2)/2=	6.0500
5	3.5*0.5*2.5*3.5 =	15.3125
6	((6.77+6.37)/2)*1.4*3.5*1.0	32.1930
7	((6.77+6.37)/2)*1.4*3.5*1.0	32.1930
8	P1	46.0000
9	P2	46.0000
	Total : Σ Fv =	204.356

The total buoyancy (uplift) acting on the structure is calculated as follows :

$$U = (1/2)*\{ U1 + U2 \} * B * \gamma w$$

where :

U = total uplift (ton /m)

U1 = buoyancy at upstream side $U1 = \gamma w * h1$ (ton/m)

U2 = buoyancy at downstream side $U2 = \gamma w * h2$ (ton/m)

B = bottom width of structure (m)

γw = unit weight of water (t/m^3)

U1 = U2 = 1,0 *(153.6-146.33) =	7.27	ton /m
U =	25.445	ton /m
U =	89.0575	ton

Total Vertical Force : $\Sigma Fv = \Sigma Fv' - U =$ 115.2985 ton

Checking of Bearing Capacity on soil :

$$Qu = A' * [\alpha * k * c * Nc + k * q * Nq + 0.5 * \gamma 1 * B' * \beta' * N\gamma$$

where :

Qu = ultimate bearing capacity

A' = effective loading area on footing

α, β = coefficient depending on shape of footing c = cohesion of foundation ground (ton/m^2)

q = ground surface surcharge (t/m^2) $q = \gamma * Df$

$\gamma 2$ = unit weight of soil on front of abutments (t/m^3) = 0.8 t/m^3

$\gamma 1$ = unit weight of soil of ground foundation (t/m^3) = 1.0 t/m^3

B',L' = width and length of effective loading area

e = distance from entrance of footing to acting point of resultant force on footing (m)

Df = depth from ground surface on front of abutment to bottom of footing (m)

Df' = height of toe (m) = 0.5 m

k = coefficient ⟶ k = (1 + 0,3 * Df' / B')

Nq , Nc , Nγ = bearing capacity factors

A' = L' * B' = (B - 2eb) * (L - 2el)

A' =(B - 2*eb) * (L - 2*el) =	12.25 m^2
α = (1 + 0,3B'/L') =	1.30
β = (1 - 4*B'/L') =	-3
q = γsub2 * Df =	2.936 t/m^2
k = (1 + 0,3 * (Df'/B')) =	1.0429
For tan θ =ΣFh/ ΣFv = 0	Nc= 50
ϕ = 36	Nq = 33
	Nγ = 40

Qu = 8629.74 ton

FS = 3

Qsafe = Qu / FS = 2876.58 ton

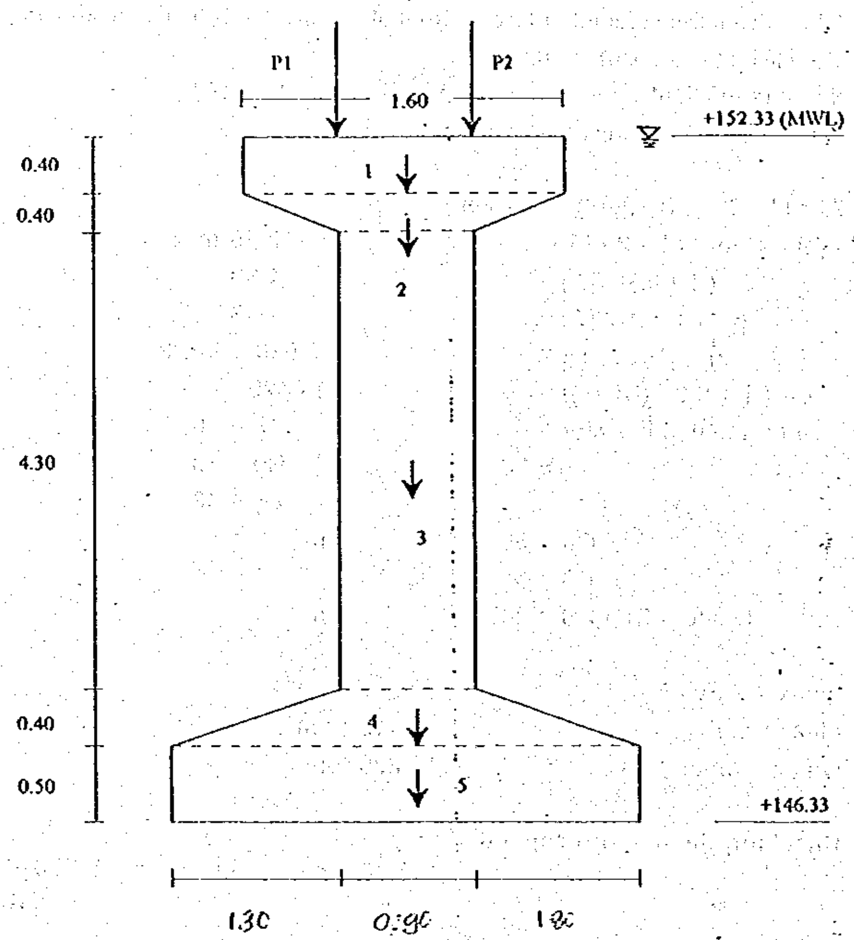
qmax = Σ Fv / B =	32.942 t / m'
qmax = Σ Fv / A =	9.412 t / m^2
Qmax = qmax * A =	115.299 ton

Checking the bearing capacity is :

Qmax = 115.30 ton < Qsafe = 2876.58 ton

OK

Name of Structure		Category of calculation		Page	28



DESIGN OF PIER – 1 (P-1)
Case II : water is full at elevation + 152.33
(Normal Condition)

DESIGN OF PIER (P1)

Case III : Water is full at elevation NWL + 148.90 (EARTHQUAKE CONDITION)

Parameter of soil :	ϕ' =2/3ϕ =	24	degree
	γsub =	1.0	t/m^3
	C'=2/3C =	12	t / m^2
Height of Pier	H =	6.0	m
Width of footing Pier	B =	3.5	m
	L =	3.5	m

Compute overturning stability :
Set up table and refer to figure : ....

part	Weight of part (ton)		Arm (m)	Moment (ton m)
1	1.6*0.4*2.5*2.7 =	4.320	1.750	7.560
2	(1.6+0.9)/2*0.4*2.5*(2.7+2)/2=	2.938	1.750	5.141
3	0.9*4.3*2.5*2.0 =	19.350	1.750	33.863
4	(3.5+0.9)/2*0.4*2.5*(3.5+2)/2=	6.050	1.750	10.588
5	3,5*0.5*2.5*3.5 =	15.313	1.750	26.797
6	((2.07+1.67)/2)*1.4*3.5*1.0	9.163	0.700	6.414
7	((2.07+1.67)/2)*1.4*3.5*1.0	9.163	2.800	25.656
8	P1	46.000	1.400	64.400
9	P2	46.000	2.100	96.600
	Total : Σ Fv =	158.296	Σ Mr =	277.018

The total buoyancy (uplift) acting on the structure is calculated as follows :

U = (1/2)*{ U1 + U2 } * B * γw

where :

U = total uplift (ton /m)
U1 = buoyancy at upstream side U1 = γw * h1 (ton/m)
U2 = buoyancy at downstream side U2 = γw * h2 (ton/m)
B = bottom width of structure (m)
γw = unit weight of water (t/m^3)

U1 = U2 = 1,0 *(148.9-146.33) =	2.57	ton /m
U =	8.995	ton /m
U =	31.4825	ton

Total Vertical Force : Σ Fv = Σ Fv' - U = 126.8135 ton

Structures surrounded by water, such as pier which suffer hydrodynamic force caused by earthquake is calculated by using following formulas :

P = (3/4)*Kh*Wo*Ao*h*(b/a)*[1-(b/4h)] in case b/h < 2.0

where :

P = *total hydrodynamic pressure during earthquake (ton)*
Kh=E = *design horizontal seismic coefficient* Kh =E = 0.15
h = *water depth (m)* h = 2.57 m
Wo = *unit weight of water (t/m^3)* Wo = 1.00 t/m^3
b = *column width perpendicular to the acting direction of hydrodynamic pressure during earthquake (m)* b = 2.00 m
a = *column width in acting direction of hydrodynamic pressure (m)* a = 0.9 m
Ao = *cross sectional area of a pier (m^2)* Ao = 1.8 m^2
hg = *hydrodynamic force acting depth from the bottom (m)* hg =3/7 h = 1.1014 m

P = (3/4)*Kh*Wo*Ao*h*(b/a)*[1-(b/4h)] = 0.93150 ton

The horizontal load (K) is determined using following formula :

P1 =	46.000	ton
P2 =	46.000	ton
W =	47.970	ton
KP = 0.15 * Ptotal =	13.800	ton
KW = 0.15 * W =	7.196	ton
Total horizontal force Σ Fh =	21.927	ton

Sum of Overturning Moments :

Σ Mo = P * hg + KP*h1+KW*h2 = 106.3785 ton m

Sum of Moments to Resist Overturning :

Σ Mr' = Σ Mr - U * B/2 = 221.9236 ton m

The Overturning safety factor is :

FS = Σ Mr' / Σ Mo = 2.086 > 1.2 OK

Compute Sliding Force : *Use base soil parameter*

Fr = C' *B*L + Σ Fv * tan ϕ' = Fr = 203.4612 ton

The sliding safety factor is :

FS = Fr / Σ Fh = 9.2790 > 1.2 Ok

Located the resultant on the base of footing. From rigid body static and moment summation can be taken at any location. Using the toe, as we already have most of the moments computed :

Δ M = Σ Mr' - Σ Mo = 115.545 ton m

x = Δ M / Σ Fv = 0.91114 m (*from toe*)

e = { B/2 } - x = 0.839 m

B / 3 = 1.167 m

→ e < (B/3) OK

0.839 < 1.167

OK

Compute soil pressure :

qmax = { Σ Fv / B } * { 1 + (6*e)/B } =	88.3362	ton / m
qmin = { Σ Fv / B } * { 1 - (6*e)/B } =	-15.8713	ton / m
Qmax = qmax * L =	309.177	ton
Qmin = qmin * L =	-55.550	ton

Checking of Bearing Capacity on soil :

$$Qu = A' * [\ \alpha * k * c * Nc\ +\ 0.143*k * q * Nq\ +\ 0.5 * \gamma_1 * B' * \beta' * N\gamma$$

where :

Qu = ultimate bearing capacity

A' = effective loading area on footing

α, β = coefficient depending on shape of footing

c = cohesion of foundation ground (ton/m^2)

q = ground surface surcharge (t/m^2) q = γ * Df

γ2 = unit weight of soil on front of abutments (t/m^3) = 0.8 t/m^3

$\gamma 1$ = unit weight of soil of ground foundation (t/m^3) = 1.0 t/m^3
B',L' = width and length of effective loading area
e = distance from entrance of footing to acting point of resultant force on footing (m)
Df = depth from ground surface on front of abutment to bottom of footing (m)
Df = height of toe (m) = 0.5 m
k = coefficient ⟶ k = (1 + 0,3 * Df / B')
Nq , Nc , Nγ = bearing capacity factors

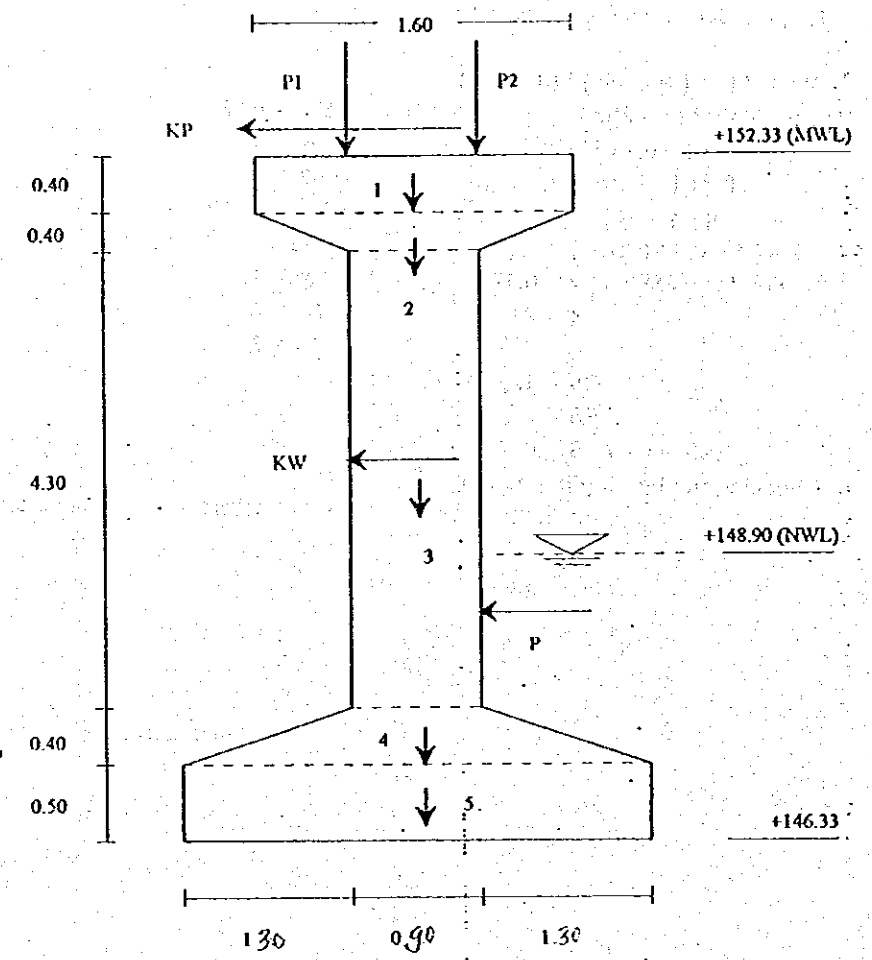
A' = L' * B' = (B - 2eb) * (L - 2el)

A' =(B - 2*eb) * (L - 2*el) =	6.378	m^2
α = (1 + 0,3B'/L') =	1.16	
β = (1 - 4*B'/L') =	-1.08	
q = γsub2 * Df =	2.936	t/m^2
k = (1 + 0,3 * (Df/B')) =	1.0823	
For tan θ =ΣFh/ ΣFv = 0.173	Nc= 13	
φ = 24	Nq = 7	
	Nγ = 3	

Qu = 1229.106 ton
FS = 2
Qsafe = Qu / FS = 614.553 ton

Checking the bearing capacity is :

Qmax = 309.18 ton < Qsafe = 614.55 ton
OK



DESIGN OF PIER – 1 (P-1)
Case III : water is full at elevation + 148.90 (NWL)
(Earthquake Condition)

DESIGN OF PIER (P1)

File:PierIV

Case IV : Water is full at elevation SWL + 151.80 (EARTHQUAKE CONDITION)

Parameter of soil :	$\phi' = 2/3\phi$ =	24	degree
	γsub =	1.0	t/m^3
	C'=2/3C =	12	t / m^2
Height of Pier	H =	6.0	m
Width of footing Pier	B =	3.5	m
	L =	3.5	m

Compute overturning stability :

Set up table and refer to figure : ....

part	Weight of part (ton)		Arm (m)	Moment (ton m)
1	1.6*0.4*2.5*2.7 =	4.320	1.75	7.560
2	(1.6+0.9)/2*0.4*2.5*(2.7+2)/2=	2.938	1.75	5.141
3	0.9*4.3*2.5*2.0 =	19.350	1.75	33.863
4	(3.5+0.9)/2*0.4*2.5*(3.5+2)/2=	6.050	1.75	10.588
5	3.5*0.5*2.5*3.5 =	15.313	1.75	26.797
6	((4.97+4.57)/2)*1.4*3.5*1.0	23.373	0.70	16.361
7	((4.97+4.57)/2)*1.4*3.5*1.0	23.373	2.80	65.444
8	P1	46.000	1.40	64.400
9	P2	46.000	2.10	96.600
	Total : Σ Fv =	186.716	Σ Mr =	326.753

The total buoyancy (uplift) acting on the structure is calculated as follows :

U = (1/2)*{ U1 + U2 } * B * γw

where :

U = total uplift (ton /m)

U1 = buoyancy at upstream side U1 = γw * h1 (ton/m)

U2 = buoyancy at downstream side U2 = γw * h2 (ton/m)

B = bottom width of structure (m)

γw = unit weight of water (t/m^3)

U1 = U2 = 1,0 *(151.8-146.33) = 5.47 ton /m

U = 19.145 ton /m

U = 67.008 ton

Structures surrounded by water, such as pier which suffer hydrodynamic force caused by earthquake is calculated by using following formulas :

P = (3/4)*Kh*Wo*Ao*h*(b/a)*[1-(b/4h)] in case b/h < 2.0

where :

P = *total hydrodynamic pressure during earthquake (ton)*

Kh =E = *design horizontal seismic coefficient* Kh =E = 0.15

h = *water depth (m)* h = 5.47 m

Wo = *unit weight of water (t/m^3)* Wo = 1.00 t/m^3

b = *column width perpendicular to the acting direction of hydrodynamic pressure during earthquake (m)* b = 2.00 m

a = *column width in acting direction of hydrodynamic pressure (m)* a = 0.9 m

Ao = *cross sectional area of a pier (m^2)* Ao = 1.8 m^2
hg = *hydrodynamic force acting depth from the bottom (m)* hg =3/7 h = 2.3443 m

P = (3/4)*Kh*Wo*Ao*h*(b/a)*[1-(b/4h)] = 2.23650 ton

The horizontal load (K) is determined using following formula :

P1 =	46.000	ton
P2 =	46.000	ton
W =	47.970	ton
KP = 0.15*Ptotal =	6.900	ton
KW = 0.15* W =	3.598	ton

Total horizontal force Σ Fh = 12.73425 ton
Total Vertical Force : Σ Fv = Σ Fv' - U = 119.7085 ton
Sum of Overturning Moments :
Σ Mo = P * hg + KP*h1+KW*h2 = 57.91925 ton m

Sum of Moments to Resist Overturning :
Σ Mr' = Σ Mr - U * B/2 = 209.4899 ton m

The Overturning safety factor is :
FS = Σ Mr' / Σ Mo = 3.617 > 1.2 OK

Compute Sliding Force : *Use base soil parameter*

Fr = C' * B*L + Σ Fv * tan ϕ' = Fr = 200.29782 ton

The sliding safety factor is :
FS = Fr / Σ Fh = 15.7291 > 1.2 Ok

Located the resultant on the base of footing. From rigid body static and moment summation can be taken at any location. Using the toe, as we already have most of the moments computed :

Δ M = Σ Mr' - Σ Mo = 151.57 ton m

x = Δ M / Σ Fv = 1.27 m (*from toe*)

e = { B/2 } - x = 0.4838 m

B / 3 = 1.1667 m

→ e < (B/3) OK
0.484 < 1.167 OK

Compute soil pressure :

qmax = { Σ Fv / B } * { 1 + (6*e)/B } = 62.5710 ton / m
qmin = { Σ Fv / B } * { 1 - (6*e)/B } = 5.8338 ton / m
Qmax = qmax * L = 218.99863 ton
Qmin = qmin * L = 20.418366 ton

Checking of Bearing Capacity on soil :

$$Qu = A' * [\alpha * k * c * Nc + 0.143 * k * q * Nq + 0.5 * \gamma_1 * B' * \beta' * N\gamma$$

where :

Qu = ultimate bearing capacity
A' = effective loading area on footing
α, β = coefficient depending on shape of footing
c = cohesion of foundation ground (ton/m^2)
q = ground surface surcharge (t/m^2) $q = \gamma * Df$
γ_2 = unit weight of soil on front of abutments (t/m^3) = 0.8 t/m^3
γ_1 = unit weight of soil of ground foundation (t/m^3) = 1.0 t/m^3
B',L' = width and length of effective loading area
e = distance from entrance of footing to acting point of resultant force on footing (m)
Df = depth from ground surface on front of abutment to bottom of footing (m)
Df' = height of toe (m) = 0.5 m
k = coefficient ⟶ $k = (1 + 0,3 * Df' / B')$
Nq , Nc , Nγ = bearing capacity factors

$A' = L' * B' = (B - 2eb) * (L - 2el)$

A' =(B - 2*eb) * (L - 2*el) =	8.8632 m^2
$\alpha = (1 + 0,3B'/L')$ =	1.22
$\beta = (1 - 4*B'/L')$ =	-1.89
q = γsub2 * Df =	2.936 t/m^2
k = (1 + 0,3 * (Df'/B')) =	1.0592
For tan 0 =ΣFh/ ΣFv = 0.106	Nc= 15
ϕ = 24	Nq = 8
	Nγ = 4

Qu = 1970.68 ton
FS = 2.00
Qsafe = Qu / FS = 985.34 ton

Checking the bearing capacity is :

Qmax = 219.00 ton < Qsafe = 985.34 ton
OK

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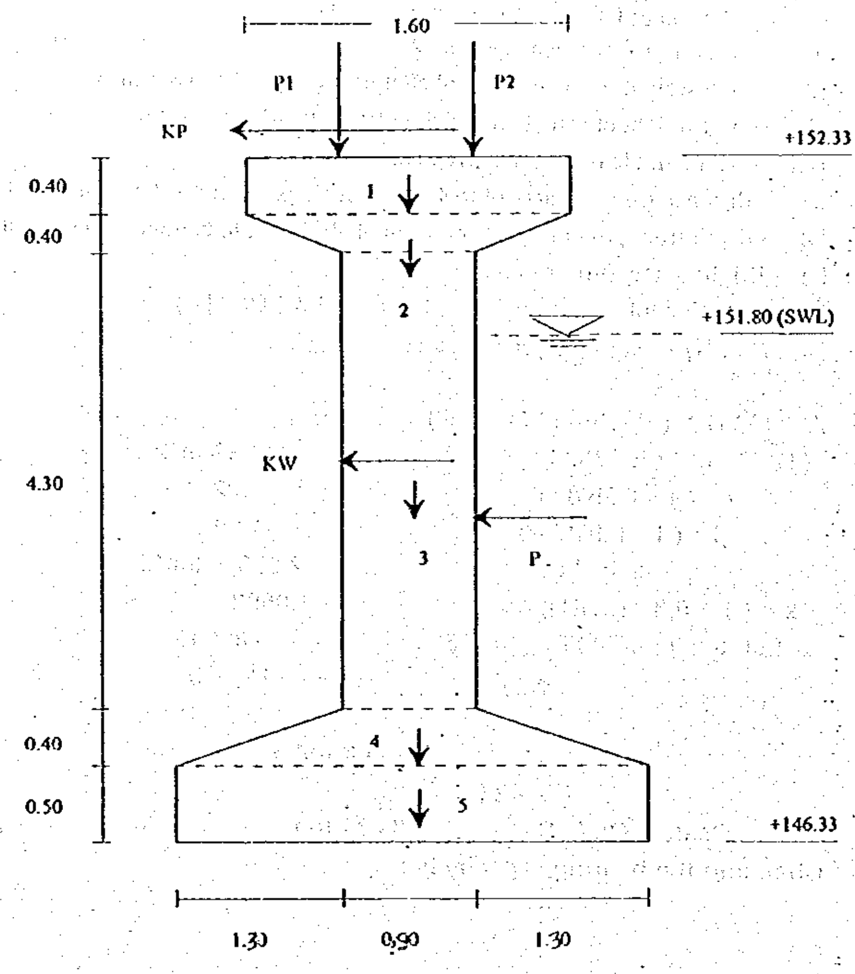


DESIGN OF PIER – 1 (P-1)
Case IV: water is full at elevation + 151.80 (SWL)
(Earthquake Condition)

DESIGN OF PIER (P1) File:PierV

Case V : Water is empty at elevation + 146.33 (EARTHQUAKE CONDITION)

Parameter of soil :	ϕ =	36	degree
	γ =	2.0	t/m^3
	C =	18	t / m^2
Height of Pier	H =	6.0	m
Width of footing Pier	B =	3.5	m
	L =	3.5	m

Compute overturning stability :

Set up table and refer to figure : ....

part	Weight of part *(ton)*		Arm *(m)*	Moment *(ton m)*
1	1.6*0.4*2.5*2.7 =	4.320	1.75	7.560
2	(1.6+0.9)/2*0.4*2.5*(2.7+2)/2=	2.938	1.75	5.141
3	0.9*4.3*2.5*2.0 =	19.350	1.75	33.863
4	(3.5+0.9)/2*0.4*2.5*(3.5+2)/2=	6.050	1.75	10.588
5	3.5*0.5*2.5*3.5 =	15.313	1.75	26.797
6	P1	46.000	1.40	64.400
7	P2	46.000	2.10	96.600
	Total : Σ Fv =	139.970	Σ Mr =	244.948

The horizontal load (K) is determined using following formula :

P1 = 46.000 ton

P2 = 46.000 ton

W = 47.970 ton

KP = 0.15*Ptotal = 13.800 ton

KW = 0.15 * W = 7.196 ton

Total horizontal force Σ Fh = 20.9955 ton

Total Vertical Force : Σ Fv = Σ Fv' = 139.9700 ton

Sum of Overturning Moments :

Σ Mo = KP*h1+KW*h2 = 105.3525 ton m

Sum of Moments to Resist Overturning :

Σ Mr' = Σ Mr = 244.948 ton m

The Overturning safety factor is :

FS = Σ Mr' / Σ Mo = 2.325 > 1.2 OK

Compute Sliding Force : *Use base soil parameter*

Fr = C' * B*L + Σ Fv * tan ϕ' = Fr = 322.194 ton

The sliding safety factor is :

FS = Fr / Σ Fh = 15.346 > 1.2 Ok

Located the resultant on the base of footing. From rigid body static and moment summation can be taken at any location. Using the toe, as we already have most of the moments computed :

$\Delta M = \Sigma Mr' - \Sigma Mo =$ 139.60 ton m

$x = \Delta M / \Sigma Fv =$ 1.00 m (*from toe*)

$e = \{B/2\} - x =$ 0.7527 m

$B/3 =$ 1.1667 m

→ e < (B/3) OK
0.753 < 1.167
OK

Compute soil pressure :

$q_{max} = \{\Sigma Fv / B\} * \{1 + (6*e)/B\} =$ 91.5927 ton / m

$q_{min} = \{\Sigma Fv / B\} * \{1 - (6*e)/B\} =$ -11.6098 ton / m

$Q_{max} = q_{max} * L =$ 320.57429 ton

$Q_{min} = q_{min} * L =$ -40.63429 ton

Checking of Bearing Capacity on soil :

$$Qu = A' * [\ \alpha * k * c * Nc + 0.143 * k * q * Nq + 0.5 * \gamma_1 * B' * \beta' * N\gamma$$

where :

- Qu = ultimate bearing capacity
- A' = effective loading area on footing
- α, β = coefficient depending on shape of footing
- c = cohesion of foundation ground (ton/m^2)
- q = ground surface surcharge (t/m^2) $q = \gamma * Df$
- $\gamma 2$ = unit weight of soil on front of abutments (t/m^3) = 1.8 t/m^3
- $\gamma 1$ = unit weight of soil of ground foundation (t/m^3) = 2.0 t/m^3
- B',L' = width and length of effective loading area
- e = distance from entrance of footing to acting point of resultant force on footing (m)
- Df = depth from ground surface on front of abutment to bottom of footing (m)
- Df' = height of toe (m) = 0.5 m
- k = coefficient ⟶ $k = (1 + 0,3 * Df' / B')$
- Nq , Nc , Nγ = bearing capacity factors
- $A' = L' * B' = (B - 2eb) * (L - 2el)$

$A' = (B - 2*eb) * (L - 2*el) =$ 6.981 m^2

$\alpha = (1 + 0,3B'/L') =$ 1.17

$\beta = (1 - 4*B'/L') =$ -1.28

$q = \gamma sub2 * Df =$ 2.936 t/m^2

$k = (1 + 0,3 * (Df'/B')) =$ 1.0752

For $\tan \theta = \Sigma Fh / \Sigma Fv =$ 0.150 Nc= 32

$\phi = 36$ Nq = 25

Nγ = 21

Qu = 4485.00 ton

FS = 2.00

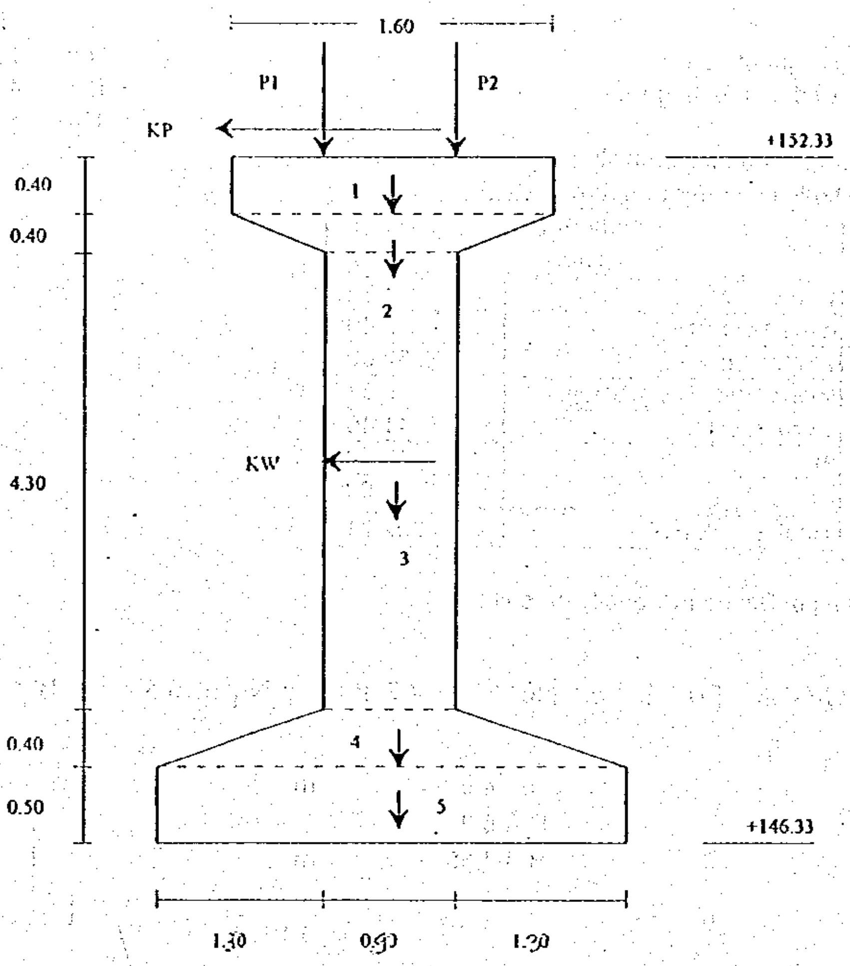
Qsafe = Qu / FS = 2242.50 ton

Checking the bearing capacity is :

Qmax = 320.57 ton < Qsafe = 2242.50 ton

OK

Name of Structure		Category of calculation		Page	39



DESIGN OF PIER – 1 (P-1)
Case V : water is empty at elevation + 146.33
(Earthquake Condition)

DESIGN OF PIER (P2)

File : PIER2-I

Case I : Water is empty + 142.33 (NORMAL CONDITION)

Parameter of soil :

ϕ =	36	degree
γ =	2.0	t/m^3
C =	18	t / m^2

Height of Pier	H =	10.0	m
Width of footing Pier	B =	4.55	m
	L =	4.55	m

Compute overturning stability :

Set up table and refer to figure : ....

part	Weight of part *(ton)*	
1	1.6*0.4*2.5*2.7 =	4.320
2	(1.6+1.3)/2*0.4*2.5*(2.7+2)/2=	3.408
3	1.3*8*2.5*2.0 =	52.000
4	(4.55+1.3)/2*0.4*2.5*(4.55+2)/2=	9.579
5	4.55*0.8*2.5*4.55 =	41.405
6	P1	46.000
7	P2	46.000
	Total : Σ Fv =	202.712

Checking of Bearing Capacity on soil :

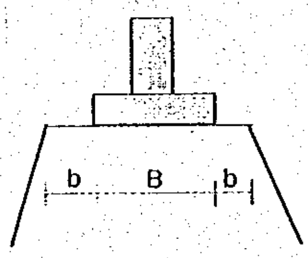
$$Qu = A' * [\ \alpha * k * c * Nc + 0.1667 * k * q * Nq + 0.5 * \gamma_1 * B' * \beta' * N\gamma$$

b= 4.5 m

R = 6.0

B = 4.55 m

$$\frac{b}{R \times B} = 0.1667$$



where :

Qu = ultimate bearing capacity

A' = effective loading area on footing

α, β = coefficient depending on shape of footing

c = cohesion of foundation ground (ton/m^2)

q = ground surface surcharge (t/m^2) $q = \gamma * Df$

γ_2 = unit weight of soil on front of abutments (t/m^3) = 1.8 t/m^3

γ_1 = unit weight of soil of ground foundation (t/m^3) = 2.0 t/m^3

B',L' = width and length of effective loading area

e = distance from entrance of footing to acting point of resultant force on footing (m)

Df = depth from ground surface on front of abutment to bottom of footing (m)

Df' = height of toe (m) = 0.8 m

k = coefficient ⟶ $k = (1 + 0,3 * Df / B')$

Nq , Nc , Nγ = bearing capacity factors

$A' = L' * B' = (B - 2eb) * (L - 2el)$

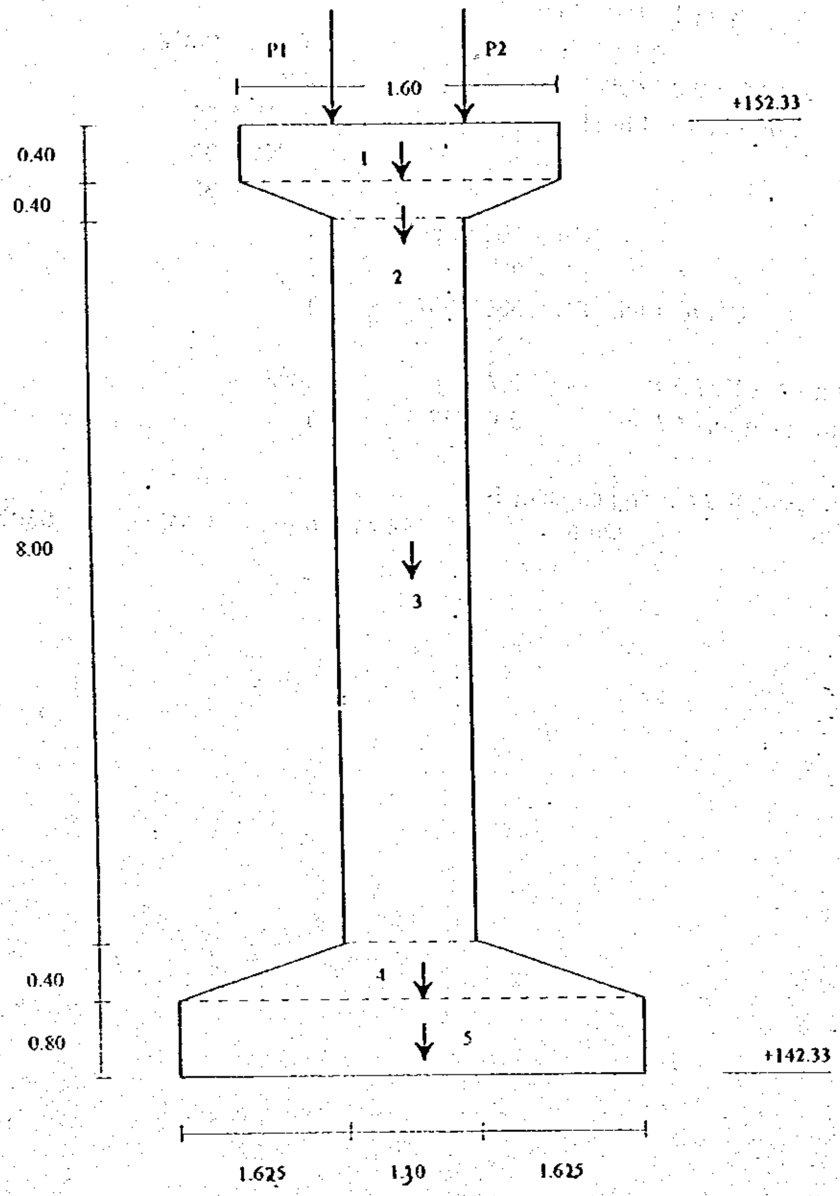
$A' = (B - 2*eb) * (L - 2*el) =$	20.7025	m^2
$\alpha = (1 + 0,3B'/L') =$	1.30	
$\beta = (1 - 4*B'/L') =$	-3	
$q = \gamma * Df =$	4.806	t/m^2
$k = (1 + 0,3 * (Df/B')) =$	1.0527	
For $\tan\theta = \Sigma Fh / \Sigma Fv = 0$	Nc= 50	
$\phi = 36$	Nq = 33	
	Nγ = 35	
Qu = 16178.587	ton	
FS = 3		
Qsafe = Qu / FS = 5392.862	ton	

$q_{max} = \Sigma Fv / A =$	9.792	t / m^2
$Q_{max} = q_{max} * A =$	202.712	ton

Checking the bearing capacity is :

Qmax = 202.71 ton < Qsafe = 5392.86 ton

OK



DESIGN OF PIER – 2 (P-2)
Case I : water is empty + 142.33
(Normal Condition)

DESIGN OF PIER (P2)

Case II : Water is full at elevation MWL + 153.60 (NORMAL CONDITION)

Parameter of soil :

φ' =2/3φ =	24	degree
γsub =	1.0	t/m^3
C'=2/3C =	12	t / m^2
Height of Pier H =	10.0	m
Width of footing Pier B =	4.55	m
L =	4.55	m

Compute overturning stability :

Set up table and refer to figure : ....

part	Weight of part (ton)	
1	1.6*0.4*2.5*2.7 =	4.320
2	(1.6+1.3)/2*0.4*2.5*(2.7+2)/2=	3.408
3	1.3*8*2.5*2.0 =	52.000
4	(4.55+1.3)/2*0.4*2.5*(4.55+2)/2=	9.579
5	4.55*0.8*2.5*4.55 =	41.405
6	(10.47+10.07)/2*1.675*4.55*1.0	78.270
7	(10.47+10.07)/2*1.675*4.55*1.0	78.270
8	P1	46.000
9	P2	46.000
	Total : Σ Fv =	359.252

The total buoyancy (uplift) acting on the structure is calculated as follows :

$$U = (1/2)*\{U1 + U2\} * B * \gamma w$$

where :

U = total uplift (ton /m)

U1 = buoyancy at upstream side   U1 = γw * h1 (ton/m)

U2 = buoyancy at downstream side   U2 = γw * h2 (ton/m)

B = bottom width of structure (m)

γw = unit weight of water (t/m^3)

U1 = U2 = 1,0 *(153.6-142.33) = 11.27 ton /m

U = 51.278 ton /m

U = 233.317 ton

Total Vertical Force : Σ Fv = Σ Fv' - U = 125.935 ton

Checking of Bearing Capacity on soil :

$$Qu = A' * [\, \alpha * k * c * Nc + 0.1667*k * q * Nq + 0.5 * \gamma_1 * B' * \beta' * N\gamma$$

Qu = ultimate bearing capacity

A' = effective loading area on footing

α, β = coefficient depending on shape of footing

c = cohesion of foundation ground (ton/m^2)

q = ground surface surcharge (t/m^2) $q = \gamma * Df$

γ2 = unit weight of soil on front of abutments (t/m^3) = 0.8 t/m^3

$\gamma 1$ = unit weight of soil of ground foundation (t/m^3) = 1.0 t/m^3
B',L' = width and length of effective loading area
e = distance from entrance of footing to acting point of resultant force on footing (m)
Df = depth from ground surface on front of abutment to bottom of footing (m)
Df' = height of toe (m) = 0.8 m
k = coefficient ⟶ k = (1 + 0,3 * Df' / B')
Nq , Nc , Nγ = bearing capacity factors

A' = L' * B' = (B - 2eb) * (L - 2el)

A' =(B - 2*eb) * (L - 2*el) =	20.7025 m^2
α = (1 + 0,3B'/L') =	1.30
β = (1 - 4*B'/L') =	-3
q = γsub2 * Df =	2.936 t/m^2
k = (1 + 0,3 * (Df'/B')) =	1.0527
For tan θ =ΣFh/ ΣFv = 0	Nc= 20
ϕ = 24	Nq = 8
	Nγ = 6

Qu =	6037.452 ton
FS = 3	
Qsafe = Qu / FS =	2012.484 ton

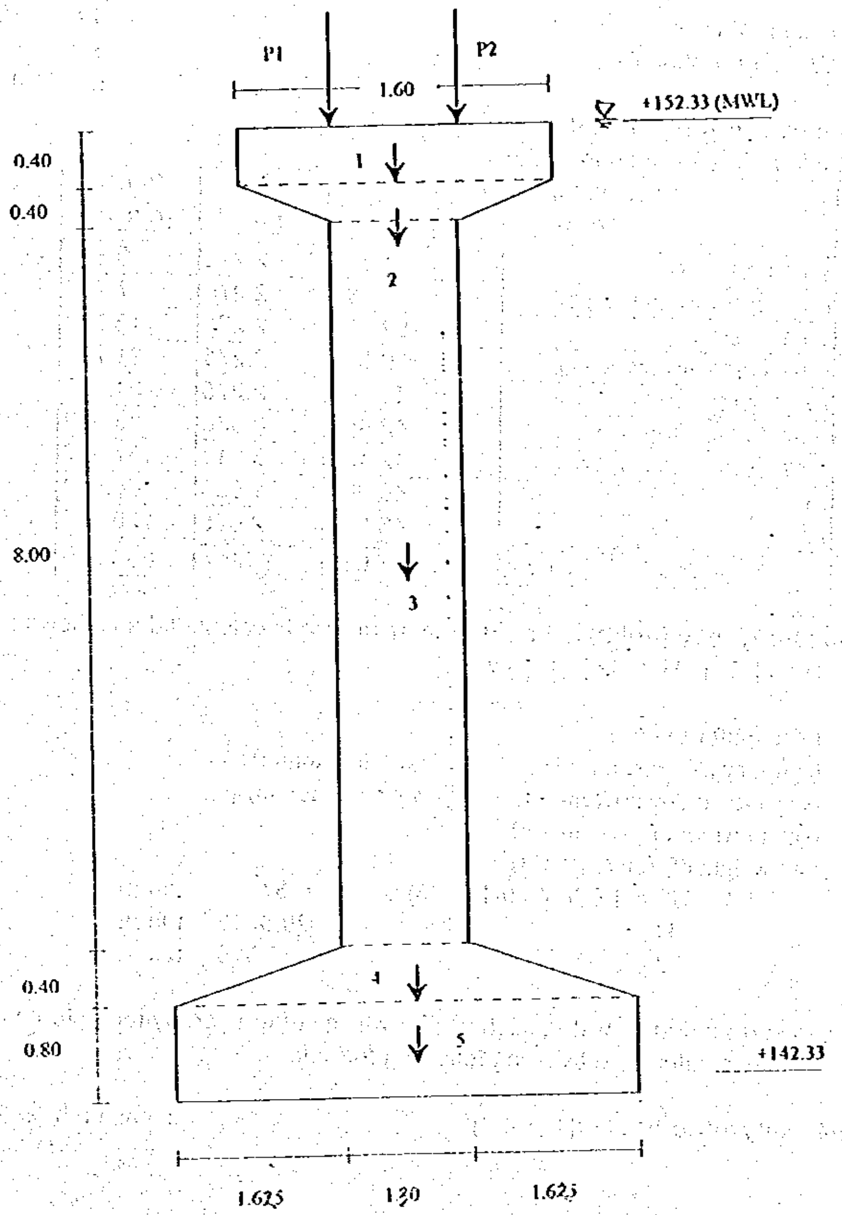
qmax = Σ Fv / A =	6.083 t / m^2
Qmax = qmax * A =	125.935 ton

Checking the bearing capacity is :

Qmax = 125.94 ton < Qsafe = 2012.48 ton

OK

Name of Structure		Category of calculation		Page	45



DESIGN OF PIER - 2 (P-2)
Case II : water is full at elevation + 152.33
(Normal Condition)

DESIGN OF PIER (P2)

Case III : Water is full at elevation NWL + 148.90 (EARTHQUAKE CONDITION)

Parameter of soil :

$\phi' = 2/3\phi$ =	24	degree
γsub =	1.0	t/m^3
C'=2/3C =	12	t / m^2
Height of Pier H =	10.0	m
Width of footing Pier B =	4.55	m
L =	4.55	m

Compute overturning stability :

Set up table and refer to figure : ....

part	Weight of part (ton)		Arm (m)	Moment (ton m)
1	1.6*0.4*2.5*2.70 =	4.320	2.275	9.828
2	(1.6+1.3)/2*0.4*2.5*(2.7+2)/2=	3.408	2.275	7.752
3	1.3*8.0*2.5*2.0 =	52.000	2.275	118.300
4	(4.55+1.3)/2*0.4*2.5*(4.55+2)/2=	9.579	2.275	21.793
5	4.55*0.8*2.5*4.55 =	41.405	2.275	94.196
6	(5.37+5.77)/2*1.70*4.55*1.0	42.450	0.838	35.552
7	(5.37+5.77)/2*1.70*4.55*1.0	42.450	3.713	157.597
8	P1	46.000	1.925	88.550
9	P2	46.000	2.625	120.750
	Total : Σ Fv =	287.613	Σ Mr =	654.319

The total buoyancy (uplift) acting on the structure is calculated as follows :

$U = (1/2)*\{ U1 + U2 \} * B * \gamma w$

where :

U = total uplift (ton /m)

U1 = buoyancy at upstream side $U1 = \gamma w * h1$ (ton/m)

U2 = buoyancy at downstream side $U2 = \gamma w * h2$ (ton/m)

B = bottom width of structure (m)

γw = unit weight of water (t/m^3)

U1 = U2 = 1,0 *(148.9-142.33) =	6.57	ton /m
U =	29.8935	ton /m
U =	136.015	ton

Structures surrounded by water, such as pier which suffer hydrodynamic force caused by earthquake is calculated by using following formulas :

$P = (3/4)*Kh*Wo*Ao*h*(b/a)*[1-(b/4h)]$ in case $b/h < 2.0$

where :

P = *total hydrodynamic pressure during earthquake (ton)*

Kh=E= *design horizontal seismic coefficient* Kh =E = 0.15

h = *water depth (m)* h = 6.57 m

Wo = *unit weight of water (t/m^3)* Wo = 1.00 t/m^3

b = *column width perpendicular to the acting direction of hydrodynamic pressure during earthquake (m)* b = 2.00 m

a = *column width in acting direction of hydrodynamic pressure (m)* a = 1.3 m
Ao = *cross sectional area of a pier (m^2)* Ao = 2.6 m^2
hg = *hydrodynamic force acting depth from the bottom (m)* hg =3/7 h = 2.8157 m

P = (3/4)*Kh*Wo*Ao*h*(b/a)*[1-(b/4h)] = 2.73150 ton

The horizontal load (K) is determined using following formula :

P1 = 46.00 ton
P2 = 46.00 ton
W = 110.71 ton
KP = 0.15*Ptotal = 13.80 ton
KW = 0.15* W = 16.61 ton

Total horizontal force Σ Fh = 33.13828 ton
Total Vertical Force : Σ Fv = Σ Fv' - U = 151.5972 ton
Sum of Overturning Moments :
Σ Mo = P * hg + KP*h1+KW*h2 = 226.3697 ton m

Sum of Moments to Resist Overturning :
Σ Mr' = Σ Mr - U * B/2 = 344.8836 ton m

The Overturning safety factor is :
FS = Σ Mr' / Σ Mo = 1.524 > 1.2 OK

Compute Sliding Force : *Use base soil parameter*

Fr = C' * B*L + Σ Fv * tan ϕ' = Fr = 258.59561 ton

The sliding safety factor is :
FS = Fr / Σ Fh = 7.8035 > 1.2 Ok

Located the resultant on the base of footing. From rigid body static and moment summation can be taken at any location. Using the toe, as we already have most of the moments computed :

Δ M = Σ Mr - Σ Mo = 118.514 ton m

x = Δ M / Σ Fv = 0.7818 m (*from toe*)

e = { B/2 } - x = 1.493 m

B / 3 = 1.517 m

=> e < (B/3) OK
1.493 < 1.517
OK

Compute soil pressure :

qmax = { Σ Fv / B } * { 1 + (6*e)/B } = 98.9245 ton / m
qmin = { Σ Fv / B } * { 1 - (6*e)/B } = -32.2884 ton / m
Qmax = qmax * L = 450.10663 ton
Qmin = qmin * L = -146.9123 ton

Checking of Bearing Capacity on soil :

$$Qu = A' * [\alpha * k * c * Nc + 0.1667*k * q * Nq + 0.5 * \gamma_1 * B' * \beta' * N\gamma$$

where :

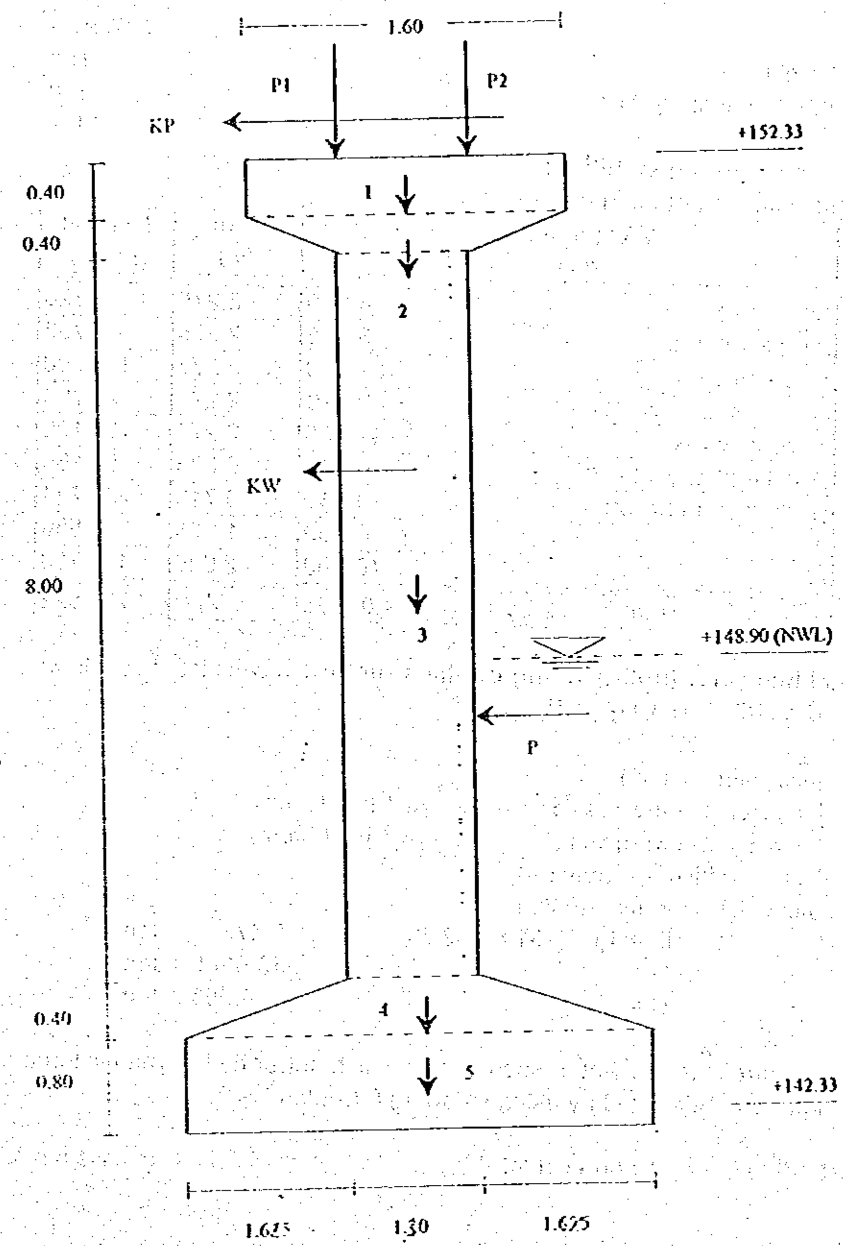
Qu = ultimate bearing capacity
A' = effective loading area on footing
α, β = coefficient depending on shape of footing
c = cohesion of foundation ground (ton/m^2)
q = ground surface surcharge (t/m^2) q = γ * Df
γ_2 = unit weight of soil on front of abutments (t/m^3) = 0.8 t/m^3
γ_1 = unit weight of soil of ground foundation (t/m^3) = 1.0 t/m^3
B',L' = width and length of effective loading area
e = distance from entrance of footing to acting point of resultant force on footing (m)
Df = depth from ground surface on front of abutment to bottom of footing (m)
Df' = height of toe (m) = 0.8 m
k = coefficient ⟶ k = (1 + 0,3 * Df' / B')
Nq , Nc , Nγ = bearing capacity factors

A' = L' * B' = (B - 2eb) * (L - 2el)
A' =(B - 2*eb) * (L - 2*el) = 7.114 m^2
α = (1 + 0.3B'/L') = 1.103
β = (1 - 4*B'/L') = -0.375
q = γsub2 * Df = 2.936 t/m^2
k = (1 + 0,3 * (Df'/B')) = 1.1535
For tan θ =ΣFh/ ΣFv = 0.219 Nc= 17
ϕ = 24 Nq = 7
Nγ = 4

Qu = 1847.081 ton
FS = 2
Qsafe = Qu / FS = 923.541 ton

Checking the bearing capacity is :
Qmax = 450.11 ton < Qsafe = 923.54 ton
OK

Name of Structure		Category of calculation		Page	49



DESIGN OF PIER – 2 (P-2)
Case III : water is full at elevation + 148.90 (NWL)
(Earthquake Condition)

DESIGN OF PIER (P2)

Case IV : Water is full at elevation SWL + 151.80 (EARTHQUAKE CONDITION)

Parameter of soil :

	$\phi' = 2/3\phi$ =	24	degree
	γsub =	1.0	t/m^3
	C'=2/3C =	12	t / m^2
Height of Pier	H =	10.0	m
Width of footing Pier	B =	4.55	m
	L =	4.55	m

Compute overturning stability :

Set up table and refer to figure : ....

part	Weight of part (ton)		Arm (m)	Moment (ton m)
1	1.6*0.4*2.5*2.7 =	4.320	2.275	9.828
2	(1.6+1.3)/2*0.4*2.5*(2.7+2)/2=	3.408	2.275	7.752
3	1.3*8.0*2.5*2.0 =	52.000	2.275	118.300
4	(4.55+1.3)/2*0.4*2.5*(4.55+2)/2=	9.579	2.275	21.793
5	4.55*0.8*2.5*4.55 =	41.405	2.275	94.196
6	(9.47+9.07)/2*1.70*4.55*1.0	70.649	0.838	59.169
7	(9.47+9.07)/2*1.70*4.55*1.0	70.649	3.713	262.284
8	P1	46.000	1.925	88.550
9	P2	46.000	2.625	120.750
	Total : Σ Fv =	344.00985	Σ Mr =	782.622

The total buoyancy (uplift) acting on the structure is calculated as follows :

$U = (1/2)*\{ U1 + U2 \} * B * \gamma w$

where :

U = total uplift (ton /m)

U1 = buoyancy at upstream side $U1 = \gamma w * h1$ (ton/m)

U2 = buoyancy at downstream side $U2 = \gamma w * h2$ (ton/m)

B = bottom width of structure (m)

γw = unit weight of water (t/m^3)

U1 = U2 = 1,0 *(151.8-142.33) =	9.47	ton /m
U =	43.0885	ton /m
U =	196.053	ton

Structures surrounded by water, such as pier which suffer hydrodynamic force caused by earthquake is calculated by using following formulas :

P = (3/4)*Kh*Wo*Ao*h*(b/a)*[1-(b/4h)] in case b/h < 2.0

where :

P = *total hydrodynamic pressure during earthquake (ton)*

Kh=E= *design horizontal seismic coefficient* Kh =E = 0.15

h = *water depth (m)* h = 9.47 m

Wo = *unit weight of water (t/m^3)* Wo = 1.00 t/m^3

b = *column width perpendicular to the acting direction of hydrodynamic pressure during earthquake (m)* b = 2.00 m

a = *column width in acting direction of hydrodynamic pressure (m)* a = 1.3 m

Ao = *cross sectional area of a pier (m^2)* Ao = 2.6 m^2

hg = *hydrodynamic force acting depth from the bottom (m)* hg =3/7 h = 4.0586 m

P = (3/4)*Kh*Wo*Ao*h*(b/a)*[1-(b/4h)] = 4.03650 ton

The horizontal load (K) is determined using following formula :

P1 = 46.00 ton

P2 = 46.00 ton

W = 110.71 ton

KP = 0.15*Ptotal = 13.80 ton

KW = 0.15* W = 16.61 ton

Total horizontal force Σ Fh = 34.443 ton

Total Vertical Force : Σ Fv = Σ Fv' - U = 147.957 ton

Sum of Overturning Moments :

Σ Mo = P * hg + KP*h1+KW*h2 = 235.061 ton m

Sum of Moments to Resist Overturning :

Σ Mr' = Σ Mr - U * B/2 = 336.6026 ton m

The Overturning safety factor is :

FS = Σ Mr' / Σ Mo = 1.432 > 1.2 OK

Compute Sliding Force : *Use base soil parameter*

Fr = C' * B*L + Σ Fv * tan ϕ' = Fr = 256.975 ton

The sliding safety factor is :

FS = Fr / Σ Fh = 7.4608 > 1.2 Ok

Located the resultant on the base of footing. From rigid body static and moment summation can be taken at any location. Using the toe, as we already have most of the moments computed :

Δ M = Σ Mr - Σ Mo = 101.542 ton m

x = Δ M / Σ Fv = 0.6863 m (*from toe*)

e = { B/2 } - x = 1.5087 m

B / 3 = 1.5167 m

=> e < (B/3) OK

1.5087 < 1.5167

OK

Compute soil pressure :

qmax = { Σ Fv / B } * { 1 + (6*e)/B } = 97.2126 ton / m

qmin = { Σ Fv / B } * { 1 - (6*e)/B } = -32.1764 ton / m

Qmax = qmax * L = 442.31716 ton

Qmin = qmin * L = -146.4028 ton

Checking of Bearing Capacity on soil :

$$Q_u = A' * [\alpha * k * c * N_c + 0.1667*k * q * N_q + 0.5 * \gamma_1 * B' * \beta' * N_\gamma$$

where :

Qu = ultimate bearing capacity
A' = effective loading area on footing
α, β = coefficient depending on shape of footing
c = cohesion of foundation ground (ton/m^2)
q = ground surface surcharge (t/m^2) $q = \gamma * Df$
γ2 = unit weight of soil on front of abutments (t/m^3) = 0.8 t/m^3
γ1 = unit weight of soil of ground foundation (t/m^3) = 1.0 t/m^3
B',L' = width and length of effective loading area
e = distance from entrance of footing to acting point of resultant force on footing (m)
Df = depth from ground surface on front of abutment to bottom of footing (m)
Df' = height of toe (m) = 0.8 m
k = coefficient ⟶ k = (1 + 0,3 * Df' / B')
Nq , Nc , Nγ = bearing capacity factors

A' = L' * B' = (B - 2eb) * (L - 2el)

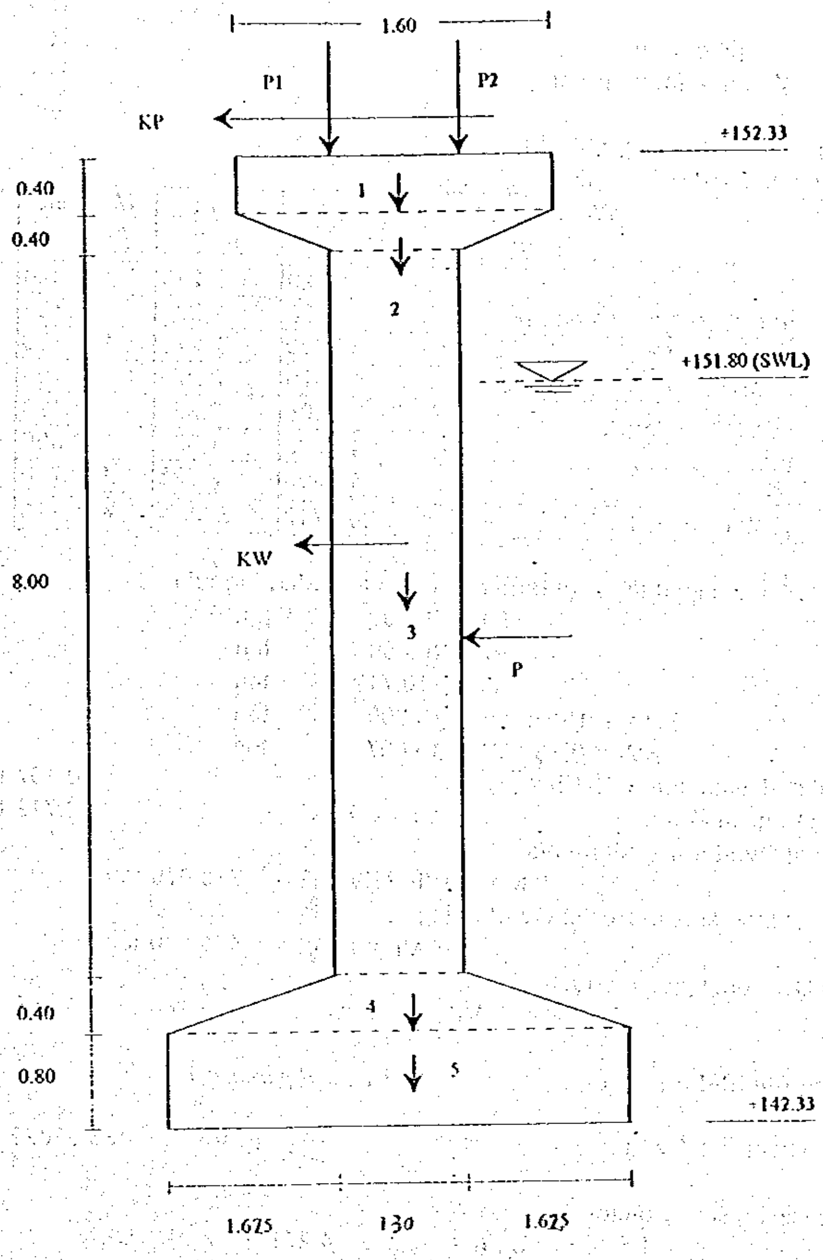
A' =(B - 2*eb) * (L - 2*el) =	4.804	m^2
α = (1 + 0.3B'/L') =	1.118	
β = (1 - 4*B'/L') =	-0.569	
q = γsub2 * Df =	2.936	t/m^2
k = (1 + 0,3 * (Df'/B')) =	1.1749	
For tan θ =ΣFh/ ΣFv = 0.233	Nc= 15	
ϕ = 24	Nq = 7	
	Nγ = 2.5	

Qu = 1139.248 ton
FS = 2
Qsafe = Qu / FS = 569.624 ton

Checking the bearing capacity is :

Qmax = 457.93 ton < Qsafe = 569.62 ton
OK

Name of Structure		Category of calculation		Page	73



DESIGN OF PIER – 2 (P-2)
Case IV : water is full at elevation + 151.80 (SWL)
(Earthquake Condition)

DESIGN OF PIER (P2)

File:Pier2-V

Case V : Water is empty + 146.33 (EARTHQUAKE CONDITION)

Parameter of soil :

	ϕ =	36	degree
	γ =	2.0	t/m^3
	C =	18	t / m^2
Height of Pier	H =	10.0	m
Width of footing Pier	B =	4.55	m
	L =	4.55	m

Compute overturning stability :

Set up table and refer to figure : ....

part	Weight of part *(ton)*		Arm *(m)*	Moment *(ton m)*
1	1.6*0.4*2.5*2.7 =	4.320	2.275	9.828
2	(1.6+1.3)/2*0.4*2.5*(2.7+2)/2=	3.408	2.275	7.752
3	1.3*8*2.5*2.0 =	52.000	2.275	118.300
4	(4.55+1.2)/2*0.4*2.5*(4.55+2)/2=	9.579	2.275	21.793
5	4.55*0.8*2.5*4.55 =	41.405	2.275	94.196
6	P1	46.000	1.925	88.550
7	P2	46.000	2.625	120.750
	Total : Σ Fv =	202.712	Σ Mr =	461.170

The horizontal load (K) is determined using following formula :

P1 =	46.000	ton
P2 =	46.000	ton
W =	110.712	ton
KP = 0.15*Ptotal =	13.800	ton
KW = 0.15 * W =	16.607	ton

Total horizontal force Σ Fh = 30.407 ton

Total Vertical Force : Σ Fv = Σ Fv' = 202.712 ton

Sum of Overturning Moments :

Σ Mo =KP*h1+KW*h2 = 218.679 ton m

Sum of Moments to Resist Overturning :

Σ Mr' = Σ Mr = 461.170 ton m

The Overturning safety factor is :

FS = Σ Mr' / Σ Mo = 2.109 > 1.2 OK

Compute Sliding Force : *Use base soil parameter*

Fr = C*B*L + Σ Fv * tan ϕ = Fr = 433.92829 ton

The sliding safety factor is :

FS = Fr / Σ Fh = 14.271 > 1.2 Ok

Located the resultant on the base of footing. From rigid body static and moment summation can be taken at any location. Using the toe, as we already have most of the moments computed :

Δ M = Σ Mr - Σ Mo = 242.491 ton m

$x = \Delta M / \Sigma Fv =$ 1.19623 m (*from toe*)

$e = \{B/2\} - x =$ 1.079 m

$B/3 =$ 1.517 m

→ e < (B/3) OK

1.079 < 1.517 OK

Compute soil pressure :

$q_{max} = \{\Sigma Fv / B\} * \{1 + (6*e)/B\} =$ 107.929 ton / m

$q_{min} = \{\Sigma Fv / B\} * \{1 - (6*e)/B\} =$ -18.825 ton / m

$Q_{max} = q_{max} * L =$ 491.079 ton

$Q_{min} = q_{min} * L =$ -85.655 ton

Checking of Bearing Capacity on soil :

$$Qu = A' * [\alpha * k * c * Nc + 0.1667 * k * q * Nq + 0.5 * \gamma_1 * B' * \beta' * N\gamma$$

where :

- Qu = ultimate bearing capacity
- A' = effective loading area on footing
- α, β = coefficient depending on shape of footing
- c = cohesion of foundation ground (ton/m^2)
- q = ground surface surcharge (t/m^2) — $q = \gamma * Df$
- γ2 = unit weight of soil on front of abutments (t/m^3) = 1.8 t/m^3
- γ1 = unit weight of soil of ground foundation (t/m^3) = 2.0 t/m^3
- B',L' = width and length of effective loading area
- e = distance from entrance of footing to acting point of resultant force on footing (m)
- Df = depth from ground surface on front of abutment to bottom of footing (m)
- Df' = height of toe (m) = 0.8 m
- k = coefficient ⟶ $k = (1 + 0{,}3 * Df' / B')$
- Nq , Nc , Nγ = bearing capacity factors

$A' = L' * B' = (B - 2eb) * (L - 2el)$

$A' = (B - 2*eb) * (L - 2*el) =$ 10.8857 m^2

$\alpha = (1 + 0{,}3B'/L') =$ 1.16

$\beta = (1 - 4*B'/L') =$ -1.10327

$q = \gamma sub2 * Df =$ 6.606 t/m^2

$k = (1 + 0{,}3 * (Df'/B')) =$ 1.1003

For $\tan\theta = \Sigma Fh / \Sigma Fv =$ 0.150 — Nc= 30

$\phi = 36$ — Nq = 15

Nγ = 20

Qu = 6593.22 ton

FS = 2

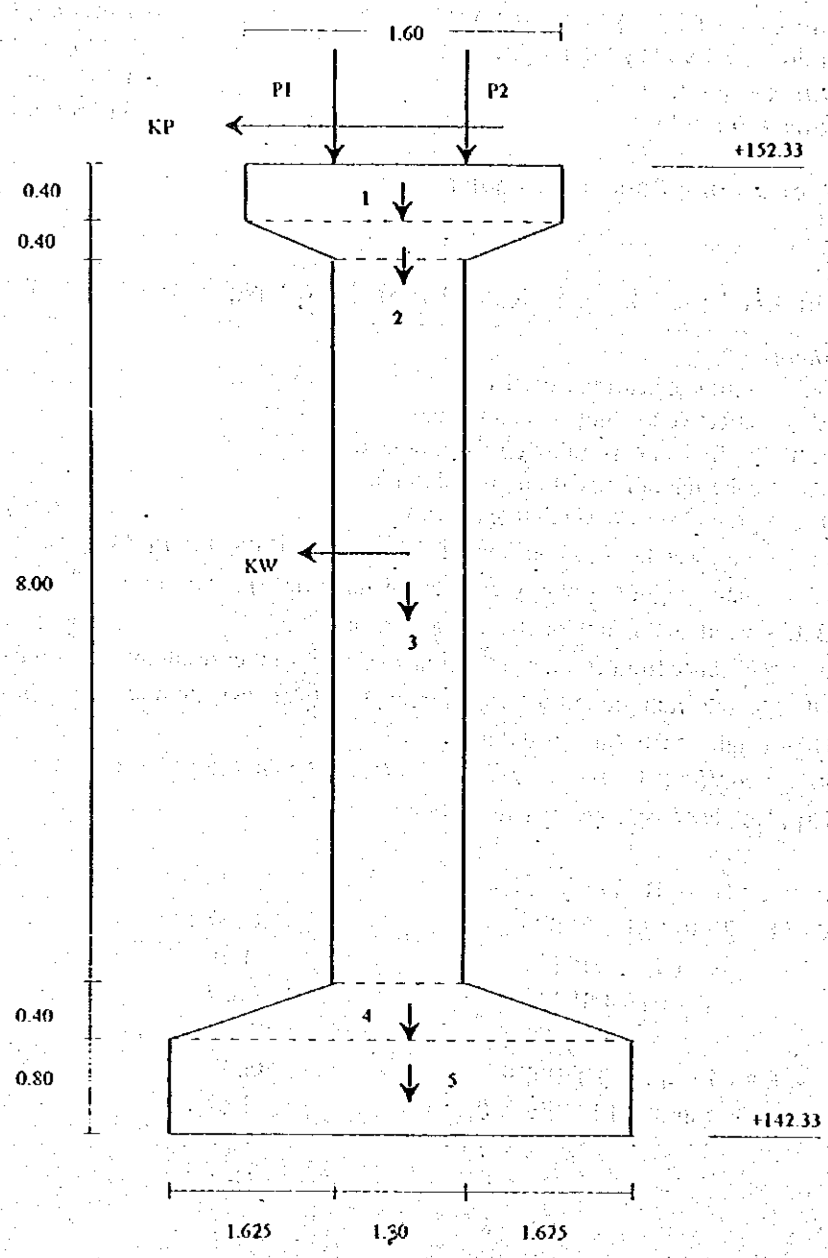
Qsafe = Qu / FS = 3296.61 ton

Checking the bearing capacity is :

Qmax = 491.08 ton < Qsafe = 3296.61 ton

OK

Name of Structure		Category of calculation		Page	√6



DESIGN OF PIER – 2 (P-2)
Case V : water is empty at elevation + 142.33
(Earthquake Condition)

DESIGN OF PIER (P3)

File : PIER3-I

Case I : Water is empty + 144.33 (NORMAL CONDITION)

Parameter of soil :

ϕ =	36	degree
γ =	2.0	t/m^3
C =	18	t / m^2
H =	8.0	m
B =	4.0	m
L =	4.0	m

Height of Pier
Width of footing Pier

Compute overturning stability :
Set up table and refer to figure : ....

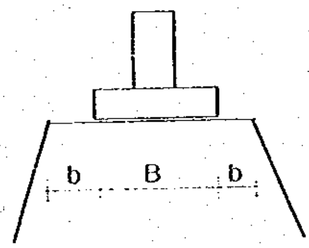
part	Weight of part (ton)	
1	1.6*0.4*2.5*2.7 =	4.320
2	(1.6+1.1)/2*0.4*2.5*(2.7+2)/2=	3.055
3	1.1*6.1*2.5*2.0 =	33.550
4	(4+1.1)/2*0.4*2.5*(4+2)/2=	7.650
5	4*0.7*2.5*4.0 =	28.000
6	P1	46.000
7	P2	46.000
	Total : Σ Fv =	168.575

Checking of Bearing Capacity on soil :

$$Qu = A' * [\alpha * k * c * Nc + 0.167*k * q * Nq + 0.5 * \gamma_1 * B' * \beta' * N\gamma$$

b= 4.0 m
R = 6.0
B = 4.0 m

$$\frac{b}{R \times B} = 0.167$$



where :

Qu = ultimate bearing capacity
A' = effective loading area on footing
α, β = coefficient depending on shape of footing
c = cohesion of foundation ground (ton/m^2)
q = ground surface surcharge (t/m^2) q = γ * Df
$\gamma 2$ = unit weight of soil on front of abutments (t/m^3) = 1.8 t/m^3
$\gamma 1$ = unit weight of soil of ground foundation (t/m^3) = 2.0 t/m^3
B',L' = width and length of effective loading area
e = distance from entrance of footing to acting point of resultant force on footing (m)
Df = depth from ground surface on front of abutment to bottom of footing (m)
Df' = height of toe (m) = 0.7 m

k = coefficient ⟶ k = (1 + 0,3 * Df / B')

Nq , Nc , Nγ = bearing capacity factors

A' = L' * B' = (B - 2eb) * (L - 2el)

A' =(B - 2*eb) * (L - 2*el) =	16	m^2
α = (1 + 0,3B'/L') =	1.30	
β = (1 - 4*B'/L') =	-3	
q = γ * Df =	6.606	t/m^2
k = (1 + 0,3 * (Df/B')) =	1.0525	
For tan θ =ΣFh/ ΣFv = 0	Nc= 50	
φ = 36	Nq = 33	
	Nγ = 40	
Qu = 12635.87	ton	
FS = 3		
Qsafe = Qu / FS = 4211.96	ton	

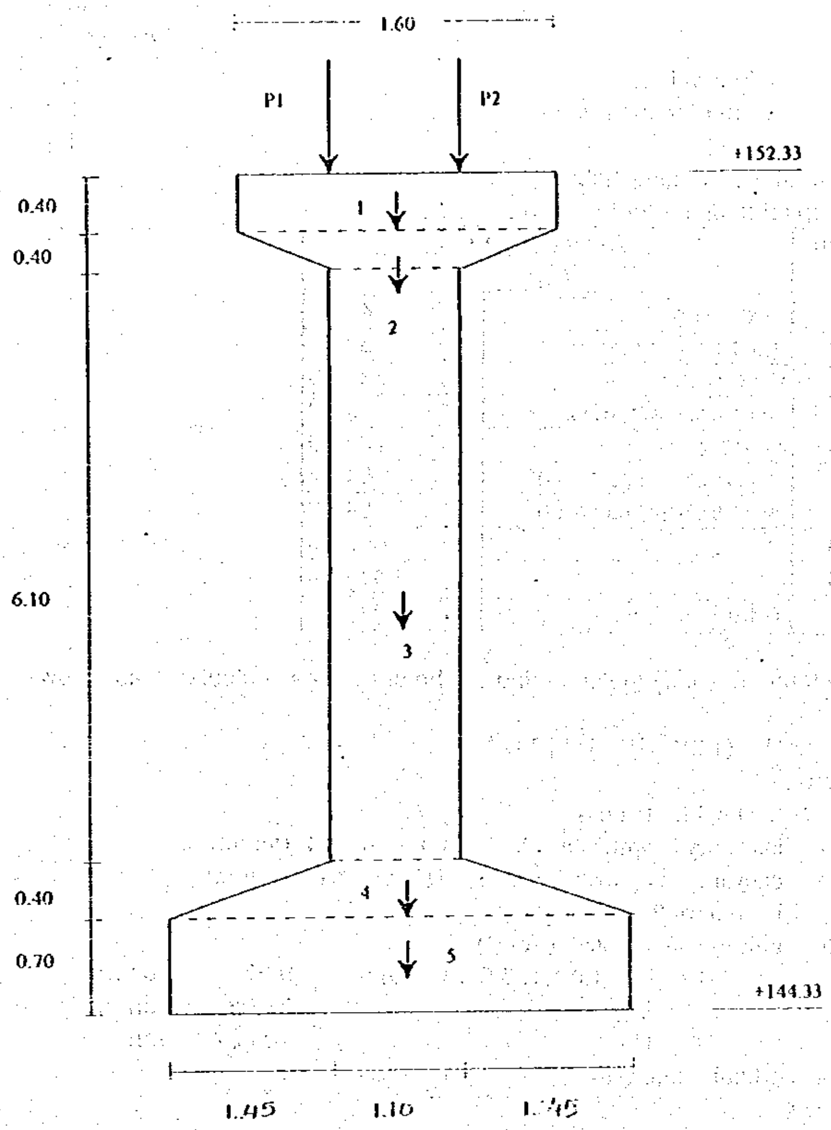
qmax = Σ Fv / A =	10.536	t / m^2
Qmax = qmax * A =	168.575	ton

Checking the bearing capacity is :

Qmax = 168.575 ton < Qsafe = 4211.96 ton

OK

Name of Structure.		Category of calculation		Page	√ℐ.



DESIGN OF PIER – 3 (P-3)
Case I : water is empty + 144.33
(Normal Condition)

DESIGN OF PIER (P3)

File:Pier3-II

Case II : Water is full at elevation MWL + 153.60 (NORMAL CONDITION)

Parameter of soil :	$\phi' = 2/3\phi$ =	24	degree
	γsub =	1.0	t/m^3
	C'=2/3C =	12	t / m^2
Height of Pier	H =	8.0	m
Width of footing Pier	B =	4.0	m
	L =	4.0	m

Compute overturning stability :

Set up table and refer to figure : ....

part	Weight of part (ton)	
1	1.6*0.4*2.5*2.7 =	4.320
2	(1.6+1.1)/2*0.4*2.5*(2.7+2)/2=	3.055
3	1.1*6.1*2.5*2.0 =	33.550
4	(4+1.1)/2*0.4*2.5*(4+2)/2=	7.650
5	4*0.7*2.5*4.0 =	28.000
6	((9.27+8.87)/2)*1.50*4.0*1.0	54.42
7	((9.27+8.87)/2)*1.50*4.0*1.0	54.42
8	P1	46.000
9	P2	46.000
	Total : Σ Fv =	277.415

The total buoyancy (uplift) acting on the structure is calculated as follows :

$U = (1/2)*\{ U1 + U2 \} * B * \gamma w$

where :

U = total uplift (ton /m)

U1 = buoyancy at upstream side $U1 = \gamma w * h1$ (ton/m)

U2 = buoyancy at downstream side $U2 = \gamma w * h2$ (ton/m)

B = bottom width of structure (m)

γw = unit weight of water (t/m^3)

U1 = U2 = 1,0 *(153.6-142.33) =	9.27	ton /m
U =	37.08	ton /m
U =	148.32	ton

Total Vertical Force : Σ Fv = Σ Fv' - U = 129.095 ton

Checking of Bearing Capacity on soil :

$$Qu = A' * [\alpha * k * c * Nc + 0.167*k * q * Nq + 0.5 * \gamma_1 * B' * \beta' * N\gamma$$

Qu = ultimate bearing capacity

A' = effective loading area on footing

α, β = coefficient depending on shape of footing

c = cohesion of foundation ground (ton/m^2)

q = ground surface surcharge (t/m^2) $q = \gamma * Df$

$\gamma 2$ = unit weight of soil on front of abutments (t/m^3) = 0.8 t/m^3

$\gamma 1$ = unit weight of soil of ground foundation (t/m^3) = 1.0 t/m^3

B',L' = width and length of effective loading area

e = distance from entrance of footing to acting point of resultant force on footing (m)

Df = depth from ground surface on front of abutment to bottom of footing (m)

Df' = height of toe (m) = 0.7 m

k = coefficient ⟶ k = (1 + 0,3 * Df' / B')

Nq , Nc , Nγ = bearing capacity factors

A' = L' * B' = (B - 2eb) * (L - 2el)

A' =(B - 2*eb) * (L - 2*el) =	16 m^2
α = (1 + 0,3B'/L') =	1.30
β = (1 - 4*B'/L') =	-3
q = γsub2 * Df =	2.936 t/m^2
k = (1 + 0,3 * (Df'/B')) =	1.0525
For tan θ =ΣFh/ ΣFv = 0	Nc= 18
φ = 24	Nq = 9
	Nγ = 6

Qu = 4226.98 ton

FS = 3

Qsafe = Qu / FS = 1408.99 ton

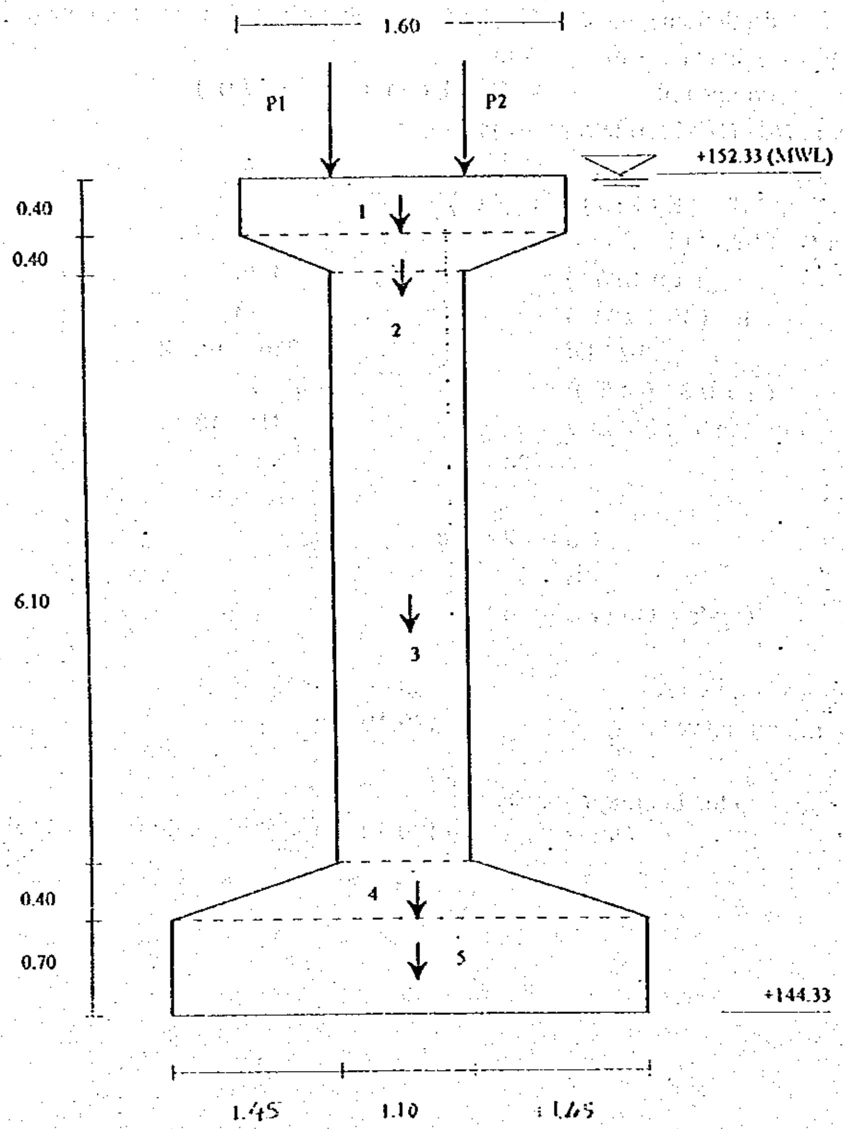
qmax = Σ Fv / A = 8.068 t / m^2

Qmax = qmax * A = 129.10 ton

Checking the bearing capacity is :

Qmax = 129.10 ton < Qsafe = 1408.99 ton

OK



DESIGN OF PIER – 3 (P-3)
Case II : water is full at elevation + 152.33 (MWL)
(Normal Condition)

DESIGN OF PIER (P3)

File:Pier3-III

Case III : Water is full at elevation NWL + 148.90 (EARTHQUAKE CONDITION)

Parameter of soil :			
	φ' =2/3φ =	24	degree
	γsub =	1.0	t/m^3
	C'=2/3C =	12	t / m^2
Height of Pier	H =	8.0	m
Width of footing Pier	B =	4.0	m
	L =	4.0	m

Compute overturning stability :
Set up table and refer to figure : ....

part	Weight of part (ton)		Arm (m)	Moment (ton m)
1	1.6*0.4*2.5*2.7 =	4.320	2.00	8.640
2	(1.6+1.1)/2*0.4*2.5*(2.7+2)/2=	3.055	2.00	6.110
3	1.1*6.1*2.5*2.0 =	33.550	2.00	67.100
4	(4+1.1)/2*0.4*2.5*(4+2)/2=	7.650	2.00	15.300
5	4*0.7*2.5*4.0 =	28.000	2.00	56.000
6	((3.87+3.47)/2)*1.5*4*1.0	22.02	0.75	16.515
7	((3.87+3.47)/2)*1.5*4.0*1.0	22.02	3.25	71.565
8	P1	46.000	1.65	75.900
9	P2	46.000	2.35	108.100
	Total : Σ Fv =	212.615	Σ Mr =	425.230

The total buoyancy (uplift) acting on the structure is calculated as follows :

U = (1/2)*{ U1 + U2 } * B * γw

where :

U = total uplift (ton /m)
U1 = buoyancy at upstream side U1 = γw * h1 (ton/m)
U2 = buoyancy at downstream side U2 = γw * h2 (ton/m)
B = bottom width of structure (m)
γw = unit weight of water (t/m^3)

U1 = U2 = 1,0 *(148.9-144.33) =	4.57	ton /m
U =	18.28	ton /m
U =	73.12	ton

Total Vertical Force : Σ Fv = Σ Fv' - U = 139.4950 ton

Structures surrounded by water, such as pier which suffer hydrodynamic force caused by earthquake is calculated by using following formulas :

P = (3/4)*Kh*Wo*Ao*h*(b/a)*[1-(b/4h)] in case b/h < 2.0

where :

P = *total hydrodynamic pressure during earthquake (ton)*
Kh=E= *design horizontal seismic coefficient* Kh =E = 0.15
h = *water depth (m)* h = 4.57 m
Wo = *unit weight of water (t/m^3)* Wo = 1.00 t/m^3
b = *column width perpendicular to the acting* b = 2.00 m

direction of hydrodynamic pressure during earthquake (m)

a = *column width in acting direction of hydrodynamic pressure (m)a =* 1.1 m

Ao = *cross sectional area of a pier (m^2)* Ao = 2.2 m^2

hg = *hydrodynamic force acting depth from the bottom (m)* hg =3/7 h = 1.9586 m

P = (3/4)*Kh*Wo*Ao*h*(b/a)*[1-(b/4h)] = 1.83150 ton

The horizontal load (K) is determined using following formula :

P1 =	46.000	ton
P2 =	46.000	ton
W =	76.575	ton
KP = 0.15 * Ptotal =	13.800	ton
KW = 0.15 * W =	11.486	ton
Total horizontal force Σ Fh =	27.118	ton

Sum of Overturning Moments :

Σ Mo = P * hg + KP*h1+KW*h2 = 160.8981 ton m

Sum of Moments to Resist Overturning :

Σ Mr' = Σ Mr - U * B/2 = 278.99 ton m

The Overturning safety factor is :

FS = Σ Mr' / Σ Mo = 1.734 > 1.2 OK

Compute Sliding Force : *Use base soil parameter*

Fr = C' *B*L + Σ Fv * tan φ' = Fr = 230.10736 ton

The sliding safety factor is :

FS = Fr / Σ Fh = 8.4855 > 1.2 Ok

Located the resultant on the base of footing. From rigid body static and moment summation can be taken at any location. Using the toe, as we already have most of the moments computed :

Δ M = Σ Mr - Σ Mo = 118.092 ton m

x = Δ M / Σ Fv = 0.847 m (*from toe*)

e = { B/2 } - x = 1.153 m

B / 3 = 1.333 m

→ e < (B/3) OK
1.153 > 1.333
OK

Compute soil pressure :

qmax = { Σ Fv / B } * { 1 + (6*e)/B } = 95.2105 ton / m

qmin = { Σ Fv / B } * { 1 - (6*e)/B } = -25.4630 ton / m

Qmax = qmax * L = 333.23691 ton

Qmin = qmin * L = -89.12066 ton

Checking of Bearing Capacity on soil :

$$Qu = A' * [\alpha * k * c * Nc + 0.167*k * q * Nq + 0.5 * \gamma 1 * B' * \beta' * N\gamma$$

where :

Qu = ultimate bearing capacity

A' = effective loading area on footing

α, β = coefficient depending on shape of footing

c = cohesion of foundation ground (ton/m^2)

q = ground surface surcharge (t/m^2) $q = \gamma * Df$

γ2 = unit weight of soil on front of abutments (t/m^3) = 0.8 t/m^3

γ1 = unit weight of soil of ground foundation (t/m^3) = 1.0 t/m^3

B',L' = width and length of effective loading area

e = distance from entrance of footing to acting point of resultant force on footing (m)

Df = depth from ground surface on front of abutment to bottom of footing (m)

Df' = height of toe (m) = 0.7 m

k = coefficient ⟶ $k = (1 + 0,3 * Df' / B')$

Nq , Nc , Nγ = bearing capacity factors

$A' = L' * B' = (B - 2eb) * (L - 2el)$

A' =(B - 2*eb) * (L - 2*el) =	6.773	m^2
α = (1 + 0.3B'/L') =	1.13	
β = (1 - 4*B'/L') =	-0.69313	
q = γsub2 * Df =	2.936	t/m^2
k = (1 + 0,3 * (Df'/B')) =	1.1240	

For tan θ = ΣFh/ ΣFv = 0.194 Nc= 14

ϕ = 24 Nq = 6.5

Nγ = 2.5

Qu = 1442.10 ton

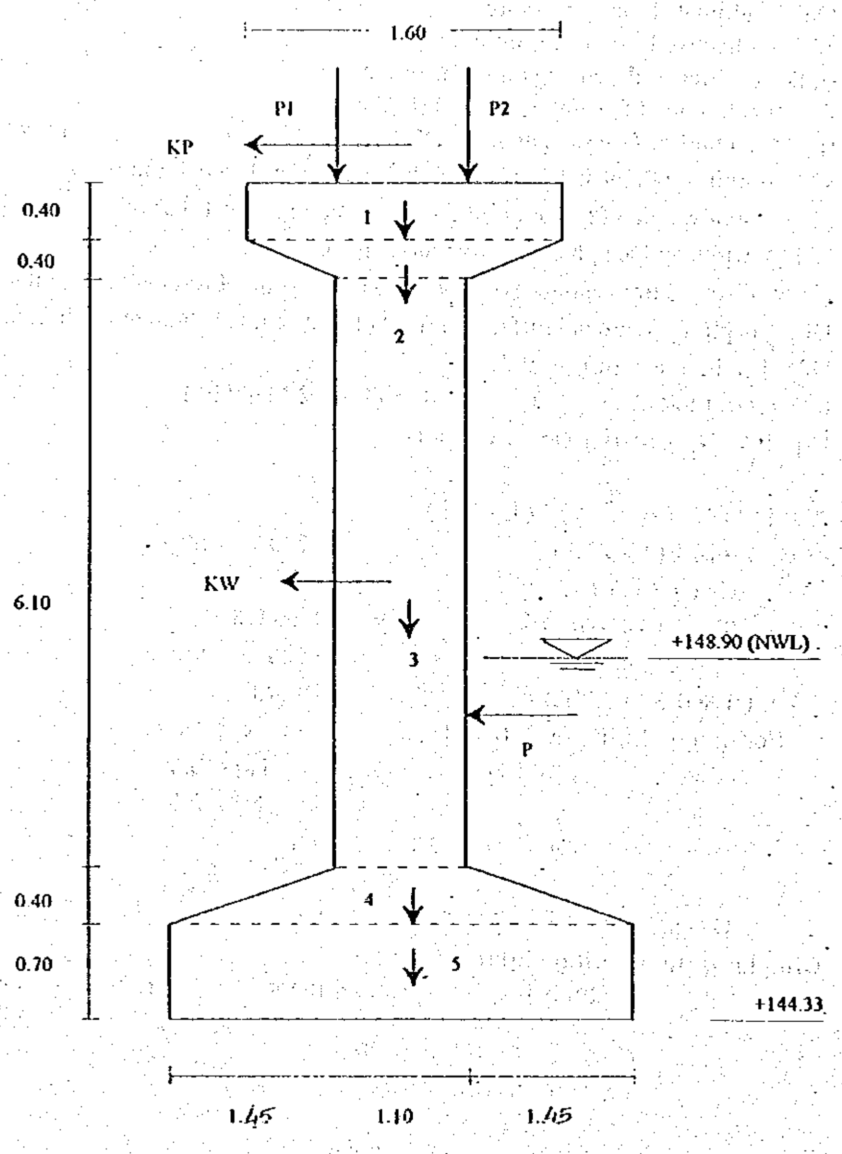
FS = 2

Qsafe = Qu / FS = 721.05 ton

Checking the bearing capacity is :

Qmax = 333.24 ton < Qsafe = 721.05 ton

OK



DESIGN OF PIER – 3 (P-3)
Case III : water is full at elevation + 148.90 (NWL)
(Earthquake Condition)

DESIGN OF PIER (P3)

Case IV : Water is full at elevation SWL + 151.80 (EARTHQUAKE CONDITION)

Parameter of soil :

	$\phi' = 2/3\phi$ =	24	degree
	γsub =	1.0	t/m^3
	C'=2/3C =	12	t / m^2
Height of Pier	H =	8.0	m
Width of footing Pier	B =	4.0	m
	L =	4.0	m

Compute overturning stability :

Set up table and refer to figure : ....

part	Weight of part (ton)		Arm (m)	Moment (ton m)
1	1.6*0.4*2.5*2.7 =	4.320	2.000	8.640
2	(1.6+1.1)/2*0.4*2.5*(2.7+2)/2=	3.055	2.000	6.110
3	1.1*6.1*2.5*2.0 =	33.550	2.000	67.100
4	(4+1.1)/2*0.4*2.5*(4+2)/2=	7.650	2.000	15.300
5	4*0.7*2.5*4.0 =	28.000	2.000	56.000
6	((6.77+6.37)/2)*1.5*4.0*1.0	39.42	0.750	29.565
7	((6.77+6.37)/2)*1.5*4.0*1.0	39.42	3.250	128.115
8	P1	46.000	1.650	75.900
9	P2	46.000	2.350	108.100
	Total : Σ Fv =	247.415	Σ Mr =	494.830

The total buoyancy (uplift) acting on the structure is calculated as follows :

$$U = (1/2)*\{ U1 + U2 \} * B * \gamma w$$

where :

U = total uplift (ton /m)

U1 = buoyancy at upstream side $U1 = \gamma w * h1$ (ton/m)

U2 = buoyancy at downstream side $U2 = \gamma w * h2$ (ton/m)

B = bottom width of structure (m)

γw = unit weight of water (t/m^3)

U1 = U2 = 1,0 *(151.8-144.33) = 7.47 ton /m

U = 29.88 ton /m

U = 119.520 ton

Structures surrounded by water, such as pier which suffer hydrodynamic force caused by earthquake is calculated by using following formulas :

$$P = (3/4)*Kh*Wo*Ao*h*(b/a)*[1-(b/4h)]$$ in case b/h < 2.0

where :

P = *total hydrodynamic pressure during earthquake (ton)*

Kh =E = *design horizontal seismic coefficient* Kh =E = 0.15

h = *water depth (m)* h = 7.47 m

Wo = *unit weight of water (t/m^3)* Wo = 1.00 t/m^3

b = *column width perpendicular to the acting direction of hydrodynamic pressure during earthquake (m)* b = 2.00 m

a = *column width in acting direction of hydrodynamic pressure (m)* a = 1.1 m

Ao = *cross sectional area of a pier (m^2)* Ao = 2.2 m^2

hg = *hydrodynamic force acting depth from the bottom (m)* hg =3/7 h = 3.2014 m

P = (3/4)*Kh*Wo*Ao*h*(b/a)*[1-(b/4h)] = 3.13650 ton

The horizontal load (K) is determined using following formula :

P1 =	46	ton
P2 =	46	ton
W =	76.575	ton
KP = 0.15*0.5*Ptotal =	6.9	ton
KW = 0.15*0.5* W =	5.743	ton

Total horizontal force Σ Fh = 15.780 ton

Total Vertical Force : Σ Fv = Σ Fv' - U = 127.895 ton

Sum of Overturning Moments :

Σ Mo = P * hg + KP*h1+KW*h2 = 88.697 ton m

Sum of Moments to Resist Overturning :

Σ Mr' = Σ Mr - U * B/2 = 255.790 ton m

The Overturning safety factor is :

FS = Σ Mr' / Σ Mo = 2.884 > 1.2 OK

Compute Sliding Force : *Use base soil parameter*

Fr = C' * B*L + Σ Fv * tan ϕ' = Fr = 224.943 ton

The sliding safety factor is :

FS = Fr / Σ Fh = 14.255 > 1.2 Ok

Located the resultant on the base of footing. From rigid body static and moment summation can be taken at any location. Using the toe, as we already have most of the moments computed :

Δ M = Σ Mr - Σ Mo = 167.093 ton m

x = Δ M / Σ Fv = 1.306 m (*from toe*)

e = { B/2 } - x = 0.694 m

B / 3 = 1.333 m

→ e < (B/3) OK

0.694 < 1.333 OK

Compute soil pressure :

qmax = { Σ Fv / B } * { 1 + (6*e)/B } = 65.2350 ton / m

qmin = { Σ Fv / B } * { 1 - (6*e)/B } = -1.2875 ton / m

Qmax = qmax * L = 260.94017 ton

Qmin = qmin * L = -5.150171 ton

Checking of Bearing Capacity on soil :

$$Qu = A' * [\ \alpha * k * c * Nc + 0.167*k * q * Nq + 0.5 * \gamma_1 * B' * \beta' * N\gamma$$

where :

Qu = ultimate bearing capacity

A' = effective loading area on footing

α, β = coefficient depending on shape of footing

c = cohesion of foundation ground (ton/m^2)

q = ground surface surcharge (t/m^2) $q = \gamma * Df$

γ2 = unit weight of soil on front of abutments (t/m^3) = 0.8 t/m^3

γ1 = unit weight of soil of ground foundation (t/m^3) = 1.0 t/m^3

B',L' = width and length of effective loading area

e = distance from entrance of footing to acting point of resultant force on footing (m)

Df = depth from ground surface on front of abutment to bottom of footing (m)

Df' = height of toe (m) = 0.7 m

k = coefficient ⟶ $k = (1 + 0,3 * Df' / B')$

Nq , Nc , Nγ = bearing capacity factors

$A' = L' * B' = (B - 2eb) * (L - 2el)$

A' =(B - 2*eb) * (L - 2*el) =	10.4519 m^2
α = (1 + 0.3B'/L') =	1.20
β = (1 - 4*B'/L') =	-1.613
q = γsub2 * Df =	2.936 t/m^2
k = (1 + 0,3 * (Df'/B')) =	1.0804
For tan θ =ΣFh/ ΣFv = 0.123	Nc= 15
φ = 24	Nq = 8
	Nγ = 4

Qu = 2340.289 ton

FS = 2

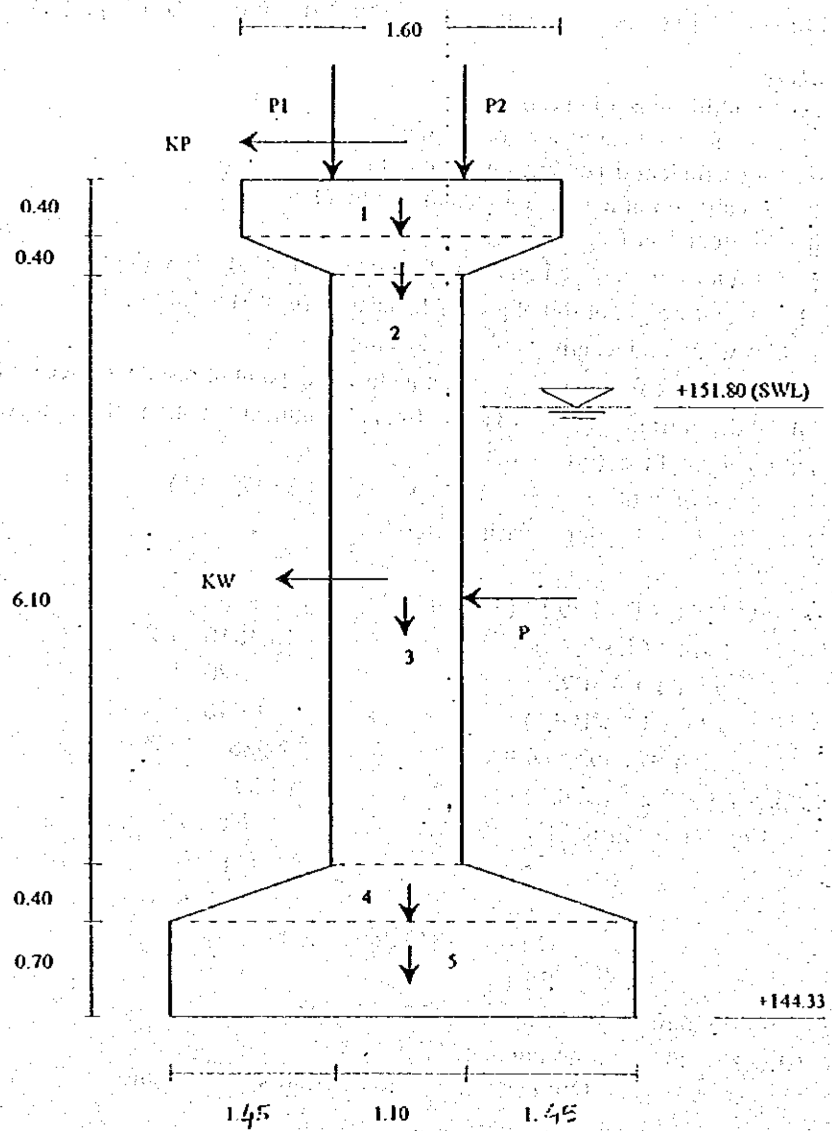
Qsafe = Qu / FS = 1170.144 ton

Checking the bearing capacity is :

Qmax = 260.94 ton < Qsafe = 1170.14 ton

OK

Name of Structure		Category of calculation		Page	



DESIGN OF PIER – 3 (P-3)
Case IV : water is full at elevation + 151.80 (SWL)
(Earthquake Condition)

DESIGN OF PIER (P3)

Case V : Water is empty + 144.33 (EARTHQUAKE CONDITION)

Parameter of soil :

	ϕ =	36	degree
	γ =	2.0	t/m^3
	C =	18	t / m^2
Height of Pier	H =	8.0	m
Width of footing Pier	B =	4.0	m
	L =	4.0	m

Compute overturning stability :

Set up table and refer to figure : ....

part	Weight of part (ton)		Arm (m)	Moment (ton m)
1	1.6*0.4*2.5*2.7 =	4.320	2.00	8.640
2	(1.6+1.1)/2*0.4*2.5*(2.7+2)/2=	3.055	2.00	6.110
3	1.1*6.1*2.5*2.0 =	33.550	2.00	67.100
4	(4+1.1)/2*0.4*2.5*(4+2)/2=	7.650	2.00	15.300
5	4*0.7*2.5*4.0 =	28.000	2.00	56.000
6	P1	46.000	1.65	75.900
7	P2	46.000	2.35	108.100
	Total : Σ Fv =	168.575	Σ Mr =	337.150

The horizontal load (K) is determined using following formula :

P1 = 46 ton
P2 = 46 ton
W = 76.575 ton
KP = 0.15*Ptotal = 13.8 ton
KW = 0.15 * W = 11.48625 ton

Total horizontal force Σ Fh = 25.286 ton

Total Vertical Force : Σ Fv = Σ Fv' = 168.575 ton

Sum of Overturning Moments :

Σ Mo =KP*h1+KW*h2 = 157.311 ton m

Sum of Moments to Resist Overturning :

Σ Mr' = Σ Mr = 337.150 ton m

The Overturning safety factor is :

FS = Σ Mr' / Σ Mo = 2.143 > 1.2 OK

Compute Sliding Force : *Use base soil parameter*

Fr = C*B*L + Σ Fv * tan ϕ = Fr = 374.476 ton

The sliding safety factor is :

FS = Fr / Σ Fh = 14.81 > 1.2 Ok

Located the resultant on the base of footing. From rigid body static and moment summation can be taken at any location. Using the toe, as we already have most of the moments computed :

Δ M = Σ Mr - Σ Mo = 179.839 ton m

$x = \Delta M / \Sigma Fv =$ 1.067 m (*from toe*)

$e = \{B/2\} - x =$ 0.933 m

$B / 3 =$ 1.333 m

→ e < (B/3) OK

0.933 < 1.333

OK

Compute soil pressure :

$q_{max} = \{\Sigma Fv / B\} * \{1 + (6*e)/B\} =$ 101.1354 ton / m

$q_{min} = \{\Sigma Fv / B\} * \{1 - (6*e)/B\} =$ -16.8479 ton / m

$Q_{max} = q_{max} * L =$ 353.97381 ton

$Q_{min} = q_{min} * L =$ -58.96756 ton

Checking of Bearing Capacity on soil :

$$Qu = A' * [\alpha * k * c * Nc + 0.167*k * q * Nq + 0.5 * \gamma_1 * B' * \beta' * N\gamma$$

where :

Qu = ultimate bearing capacity

A' = effective loading area on footing

α, β = coefficient depending on shape of footing

c = cohesion of foundation ground (ton/m^2)

q = ground surface surcharge (t/m^2) $q = \gamma * Df$

γ2 = unit weight of soil on front of abutments (t/m^3) = 1.8 t/m^3

γ1 = unit weight of soil of ground foundation (t/m^3) = 2.0 t/m^3

B',L' = width and length of effective loading area

e = distance from entrance of footing to acting point of resultant force on footing (m)

Df = depth from ground surface on front of abutment to bottom of footing (m)

Df' = height of toe (m) = 0.7 m

k = coefficient ⟶ $k = (1 + 0,3 * Df' / B')$

Nq , Nc , Nγ = bearing capacity factors

$A' = L' * B' = (B - 2eb) * (L - 2el)$

$A' = (B - 2*eb) * (L - 2*el) =$ 8.535 m^2

$\alpha = (1 + 0.3B'/L') =$ 1.16

$\beta = (1 - 4*B'/L') =$ -1.134

$q = \gamma * Df =$ 6.606 t/m^2

$k = (1 + 0,3 * (Df'/B')) =$ 1.0984

For $\tan\theta = \Sigma Fh / \Sigma Fv =$ 0.150 Nc= 32

$\phi = 36$ Nq = 24

Nγ = 22

Qu = 5660.624 ton

FS = 2

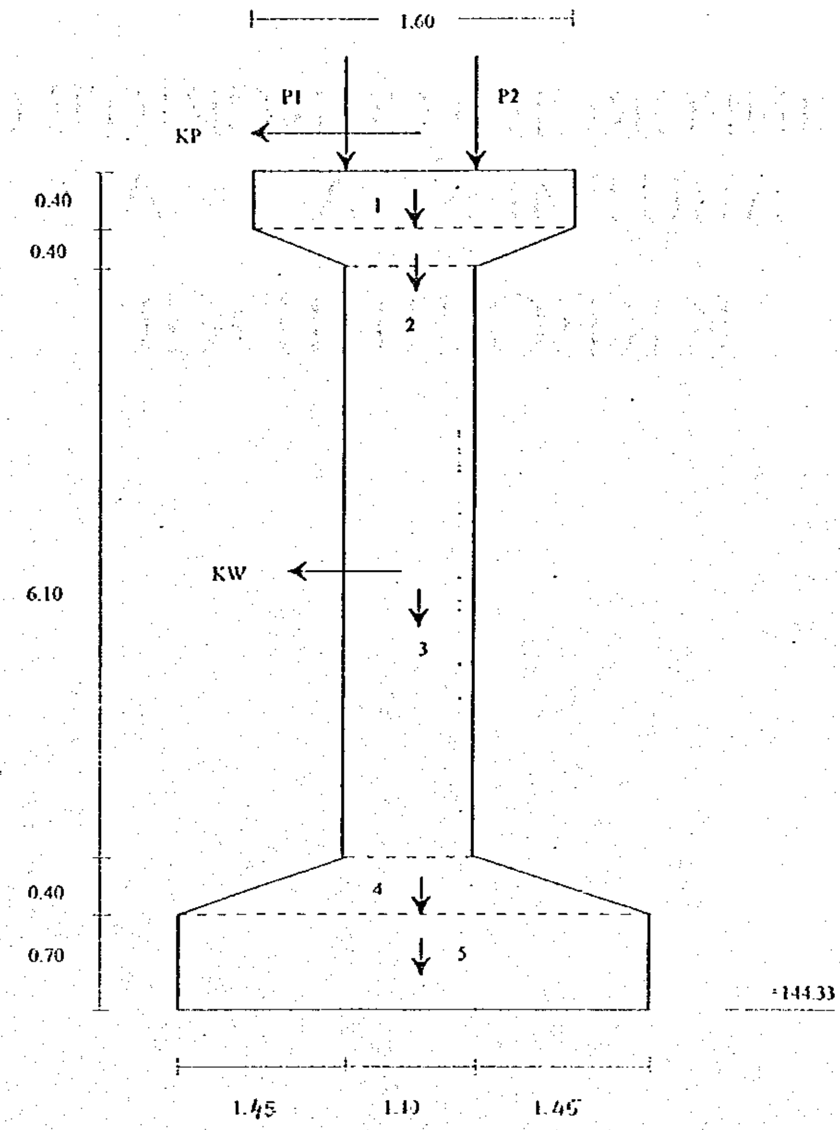
Qsafe = Qu / FS = 2830.312 ton

Checking the bearing capacity is :

Qmax = 353.97 ton < Qsafe = 2830.31 ton

OK

Name of Structure		Category of calculation		Page	



DESIGN OF PIER – 3 (P-3)
Case V : water is empty at elevation + 144.33
(Earthquake Condition)