

## 2.3 Gallery

### 2.3.1 Structural Calculation of Inspection Gallery

#### (1) Standard section

Inspection galleries are calculated with results of finite element method (FEM) about dam main body.

##### (a) Basic Condition

- (i) In case of structural calculation, inspection galleries are borne by rock mass. Therefore, it is regarded that upper side and bottom side beams of inspection galleries are fixed on rock mass. And they are calculated.
- (ii) Load affecting at bottom slab of gallery compares grout pressure and water pressure. And bigger pressure is adopted.
- (iii) Allowable compressive strength of concrete is  $225 \text{ kgf/cm}^2$ .
- (iv) Allowable tension strength of reinforcing bar is  $1,800 \text{ kgf/cm}^2$ . at Normal case
- (v) Minimum diameter of main reinforcing bar is D16 mm above.

##### (b) Cases to be Studied

Case 1 - Top crown elevation of gallery is EL. 80.00 m.

Case 2 - Top crown elevation of gallery is EL. 90.00 m.

Case 3 - Top crown elevation of gallery is EL. 115.00 m.

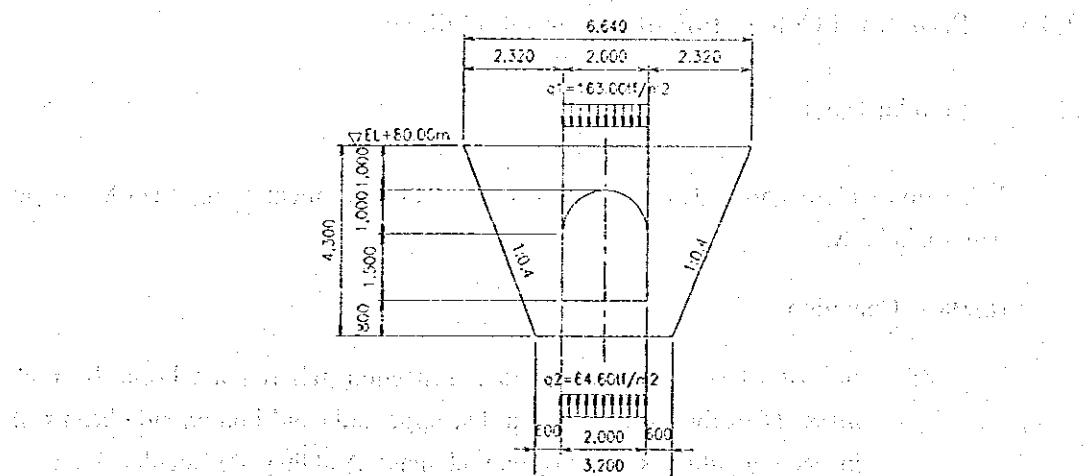
Case 4 - Top crown elevation of gallery is EL. 140.00 m.

Results of FEM method are shown in each case as follows.

Case No.	Surcharge Load ( $\text{tf/m}^2$ )
Case 1	163.0
Case 2	142.0
Case 3	89.0
Case 4	36.0

(c) Load calculation

a) Case 1 (EL+80.00 m)



(i) Upper side

Effective span  $L = 2.00 \text{ m}$

i) Moment at edge section (Mf)

$$M_f = -\frac{1}{12} \times 163.0 \times 2.00^2 = -54.33 \text{ tf-m}$$

ii) Moment at middle section (Mmax)

$$M_{\max} = \frac{1}{24} \times 163.0 \times 2.00^2 = 27.17 \text{ tf-m}$$

iii) Shearing stress at fulcrum (S)

$$S = \frac{1}{2} \times 163.0 \times 2.00 = 163.0 \text{ tf}$$

(ii) Bottom side

Grout pressure :  $q_g = 60.00 \text{ tf/m}^2$

$$\begin{aligned} \text{Water Pressure} &: q_w = (\text{EL} + 148.90 \text{ m} - \text{EL} + 80.00 \text{ m}) - 4.30 \text{ m} \\ &= 64.60 \text{ tf/m}^2 \end{aligned}$$

Therefore, water pressure as affecting load is adopted.

Effective span  $L = 2.00 \text{ m}$

i) Moment at edge section (Mf)

$$M_f = -\frac{1}{12} \times 64.60 \times 2.00^2 = -21.53 \text{ tf-m}$$

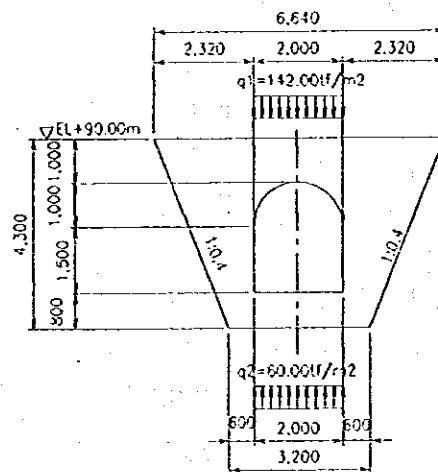
ii) Moment at middle section (Mmax)

$$M_{\max} = \frac{1}{24} \times 64.60 \times 2.00^2 = 10.77 \text{ tf-m}$$

iii) Shearing stress at fulcrum (S)

$$S = \frac{1}{2} \times 64.6 \times 2.00 = 64.60 \text{ tf}$$

b) Case 2 (EL+90.00 m)



(i) Upper side

Effective span  $L = 2.00 \text{ m}$

i) Moment at edge section (Mf)

$$M_f = -\frac{1}{12} \times 142.0 \times 2.00^2 = -47.33 \text{ tf-m}$$

ii) Moment at middle section (Mmax)

$$M_{\max} = \frac{1}{24} \times 142.0 \times 2.00^2 = 23.67 \text{ tf-m}$$

iii) Shearing stress at fulcrum (S)

$$S = \frac{1}{2} \times 142.0 \times 2.00 = 142.00 \text{ tf}$$

(ii) Bottom side

Grout pressure :  $q_g = 60.00 \text{ tf/m}^2$

Water Pressure :  $q_w = (\text{EL} + 148.90 \text{ m} - \text{EL} + 90.00 \text{ m}) - 4.30 \text{ m} = 54.60 \text{ tf/m}^2$

Therefore, grout pressure as affecting load is adopted.

Effective span  $L = 2.00 \text{ m}$

i) Moment at edge section (Mf)

$$M_f = -\frac{1}{12} \times 60.00 \times 2.00^2 = -20.00 \text{ tf-m}$$

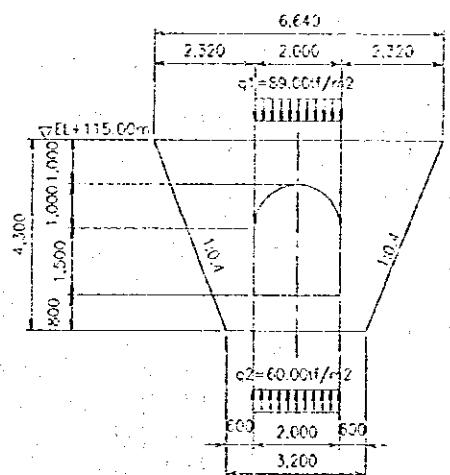
ii) Moment at middle section (Mmax)

$$M_{\max} = \frac{1}{24} \times 60.00 \times 2.00^2 = 10.00 \text{ tf-m}$$

iii) Shearing stress at fulcrum (S)

$$S = \frac{1}{2} \times 60.00 \times 2.00 = 60.00 \text{ tf}$$

c) Case 3 (EL+115.00 m)



(i) Upper side

Effective span      L = 2.00 m

i) Moment at edge section ( $M_f$ )

$$M_f = -\frac{1}{12} \times 89.0 \times 2.00^2 = -29.67 \text{ tf-m}$$

ii) Moment at middle section ( $M_{max}$ )

$$M_{\max} = \frac{1}{24} \times 89.0 \times 2.00^2 = 14.83 \text{ tf-m}$$

### iii) Shearing stress at fulcrum (S)

$$S = \frac{1}{2} \times 89.0 \times 2.00 = 89.00 \text{ tf}$$

(ii) Bottom side

Grout pressure :  $q_g = 60.00 \text{ tf/m}^2$

$$\text{Water Pressure} : q_w = (EL + 148.90 \text{ m} - EL + 115.00 \text{ m}) - 4.30 \text{ m} \\ = 29.60 \text{ t/m}^2$$

Therefore, grout pressure as affecting load is adopted.

Effective span      L = 2.00 m

i) Moment at edge section ( $M_f$ )

$$M_f = -\frac{1}{12} \times 60.00 \times 2.00^2 = -20.00 \text{ tf-m}$$

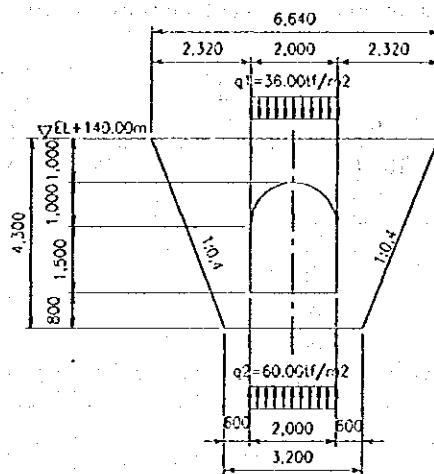
ii) Moment at middle section ( $M_{max}$ )

$$M_{max} = \frac{1}{24} \times 60.00 \times 2.00^2 = 10.00 \text{ tf-m}$$

### iii) Shearing stress at fulcrum (S)

$$S = \frac{1}{2} \times 60.00 \times 2.00 = 60.00 \text{ tf}$$

d) Case 4 (EL+140.00 m)



(i) Upper side

Effective span  $L = 2.00 \text{ m}$

i) Moment at edge section ( $M_f$ )

$$M_f = -\frac{1}{12} \times 36.0 \times 2.00^2 = -12.00 \text{ tf-m}$$

ii) Moment at middle section ( $M_{max}$ )

$$M_{max} = \frac{1}{24} \times 36.0 \times 2.00^2 = 6.00 \text{ tf-m}$$

iii) Shearing stress at fulcrum ( $S$ )

$$S = \frac{1}{2} \times 36.0 \times 2.00 = 36.00 \text{ tf}$$

(ii) Bottom side

Grout pressure :  $q_g = 60.00 \text{ tf/m}^2$

Water Pressure :  $q_w = (\text{EL}+148.90 \text{ m} - \text{EL}+140.00 \text{ m}) - 4.30 \text{ m}$   
 $= 4.60 \text{ tf/m}^2$

Therefore, grout pressure as affecting load is adopted.

Effective span  $L = 2.00 \text{ m}$

i) Moment at edge section ( $M_f$ )

$$M_f = -\frac{1}{12} \times 60.00 \times 2.00^2 = -20.00 \text{ tf-m}$$

ii) Moment at middle section ( $M_{max}$ )

$$M_{max} = \frac{1}{24} \times 60.00 \times 2.00^2 = 10.00 \text{ tf-m}$$

iii) Shearing stress at fulcrum ( $S$ )

$$S = \frac{1}{2} \times 60.00 \times 2.00 = 60.00 \text{ tf}$$

(d) Structural calculation

Results of structural calculation on each case are shown as follows.

[Case-1]

Member of shape		Top slab		Bottom slab	
		Inside Rectangle		Inside Rectangle	Outside Rectangle
M	tf-m	27.17		10.77	-21.53
N	tf	0.00		0.00	0.00
S	tf	0.00		0.00	64.60
B	cm	100.00		100.00	100.00
D	cm	90.00		70.00	70.00
Ac	cm <sup>2</sup>	9000.00		7000.00	7000.00
As	cm <sup>2</sup>	18.08		9.09	18.61
P=As/(B×D)		0.00201		0.0013	0.00266
N=E <sub>s</sub> /E <sub>c</sub>		15		15	15
X <sub>0</sub>	cm	19.50		12.50	17.20
K=X <sub>0</sub> /D		0.217		0.179	0.245
M/(B×D <sup>2</sup> )	kgf/cm <sup>2</sup>	3.354		2.198	4.394
S/(B×D)	kgf/cm <sup>2</sup>	0.000		0.000	9.229
(C)		9.927		11.891	8.878
(S)		35.775		54.596	27.311
(Z)		1.078		1.063	1.089
σ <sub>c</sub>	kgf/cm <sup>2</sup>	33.30		26.10	39.00
σ <sub>s</sub>	kgf/cm <sup>2</sup>	1800.00		1800.00	1800.00
τ	kgf/cm <sup>2</sup>	0.00		0.00	
σ <sub>ca</sub>	kgf/cm <sup>2</sup>	75.00		75.00	75.00
σ <sub>sa</sub>	kgf/cm <sup>2</sup>	1800.00		1800.00	1800.00
τ <sub>a</sub>	kgf/cm <sup>2</sup>	6.50		6.50	

Result of FEM method is adopted at outside of top slab. (refer to stress – strain analysis)

Result of FEM method around top slab

$$\text{Tension stress} = 117.90 + 51.80 = 169.70 \text{ tf/m}^2$$

Necessary reinforcing bar section area

$$A_s = 1677 \text{ kgf/cm}^2 \times 20 \text{ cm} / 1800 \text{ kgf/cm}^2 = 18.63 \text{ cm}^2$$

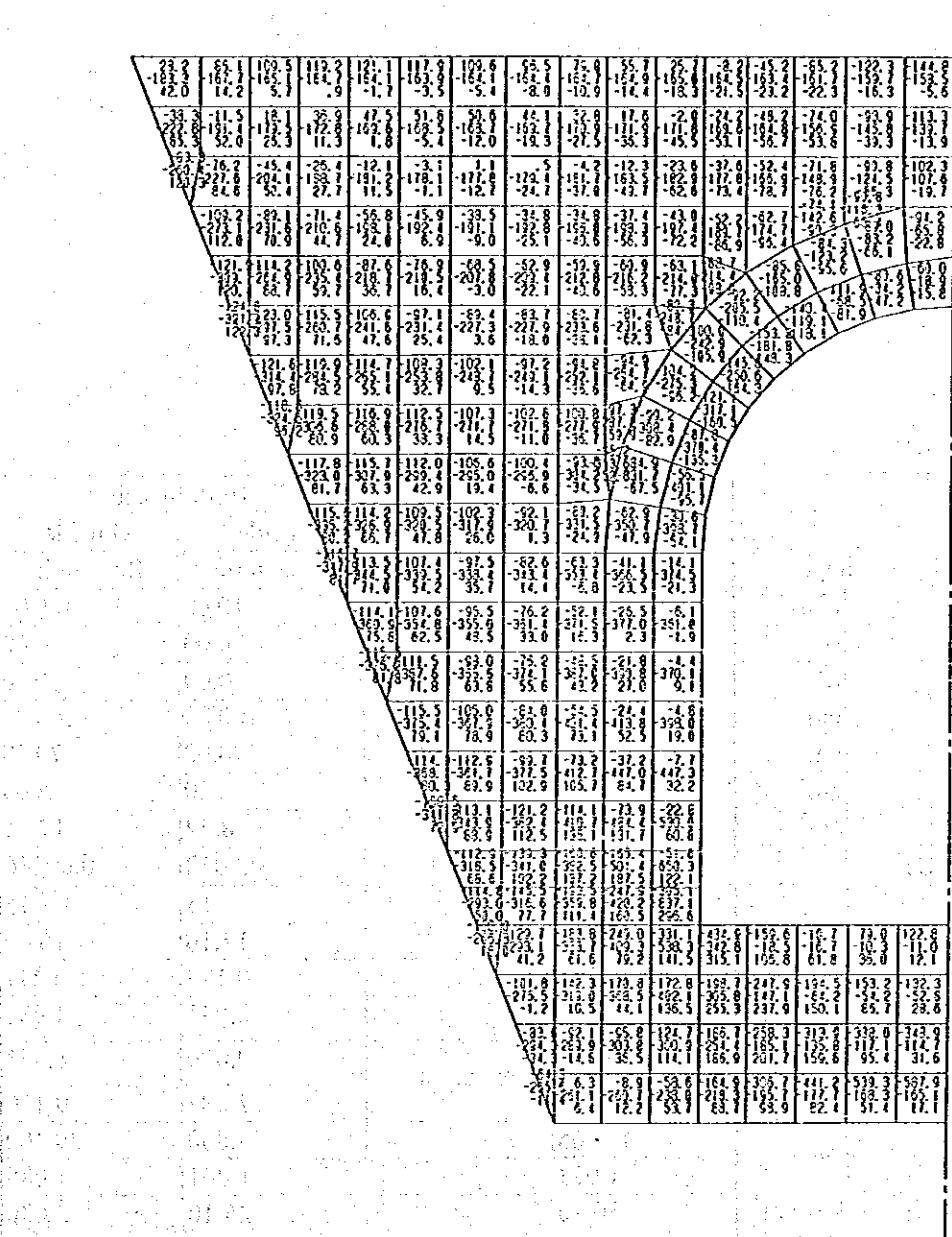
Area of reinforcement

- i) Inside of top slab  
 $A_s = 18.08 \text{ cm}^2 \leq 19.00 \text{ cm}^2 (\text{D22@200}) \dots \text{O.K}$
- ii) Out side of top slab  
 $A_s = 18.63 \text{ cm}^2 \leq 19.00 \text{ cm}^2 (\text{D22@200}) \dots \text{O.K}$
- iii) Inside of bottom slab  
 $A_s = 9.09 \text{ cm}^2 \leq 10.05 \text{ cm}^2 (\text{D16@200}) \dots \text{O.K}$
- iv) Outside of bottom slab  
 $A_s = 18.61 \text{ cm}^2 \leq 19.00 \text{ cm}^2 (\text{D22@200}) \dots \text{O.K}$

## STRESS – STRAIN ANALYSIS CASE 1

### Value of Stress

D. C.

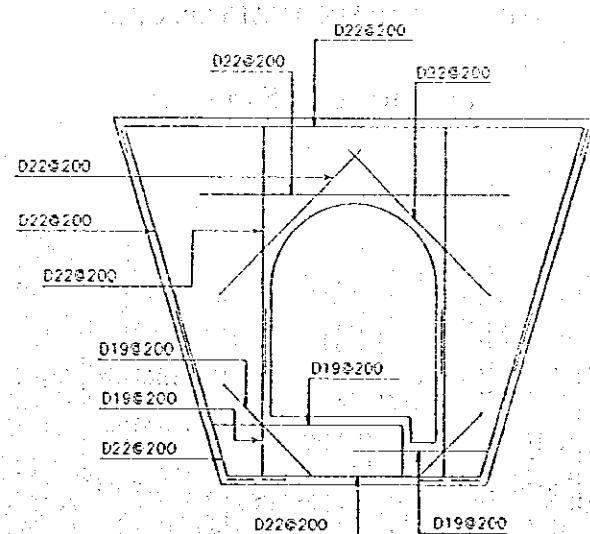


Up : σ x  
Mid : σ y  
Low : τ xy

GEO. SCALE (□)  
3.0000E-1

**UNIT (t/m<sup>2</sup>)**

Figure of main reinforcing bar is shown as follows.



[Case-2]

Member of shape	Top slab		Bottom slab	
	Inside	Outside	Inside	Outside
M	tf-m	23.67	10.00	-20.00
N	tf	0.00	0.00	0.00
S	tf	0.00	0.00	60.00
B	cm	100.00	100.00	100.00
D	cm	90.00	70.00	70.00
Ac	cm <sup>2</sup>	9000	7000	7000
As	cm <sup>2</sup>	15.68	8.42	17.24
P=As/(B×D)		0.00174	0.0012	0.00246
N=Es/Ec		15	15	15
X0	cm	18.40	12.10	16.60
K=X0/D		0.204	0.173	0.237
M/(B×D <sup>2</sup> )	kgf/cm <sup>2</sup>	2.922	2.041	4.082
S/(B×D)	kgf/cm <sup>2</sup>	0.000	0.000	8.571
(C)		10.521	12.282	9.150
(S)		41.065	58.800	29.400
(Z)		1.073	1.061	1.086
$\sigma_c$	kgf/cm <sup>2</sup>	30.70	25.10	37.30
$\sigma_s$	kgf/cm <sup>2</sup>	1800.00	1800.00	1800.00
$\tau$	kgf/cm <sup>2</sup>	0.00	0.00	
$\sigma_{ca}$	kgf/cm <sup>2</sup>	75.00	75.00	75.00
$\sigma_{sa}$	kgf/cm <sup>2</sup>	1800.00	1800.00	1800.00
$\tau_a$	kgf/cm <sup>2</sup>	6.50	6.50	

Result of FEM method is adopted at outside of top slab. (refer to

stress – strain analysis)

#### Result of FEM method around top slab

$$\text{Tension stress} = 111.00 + 51.80 = 162.80 \text{ t/m}^2$$

#### Necessary reinforcing bar section area

$$As = 1628 \text{ kgf/cm}^2 \times 20 \text{ cm} / 1800 \text{ kgf/cm}^2 = 18.09 \text{ cm}^2$$

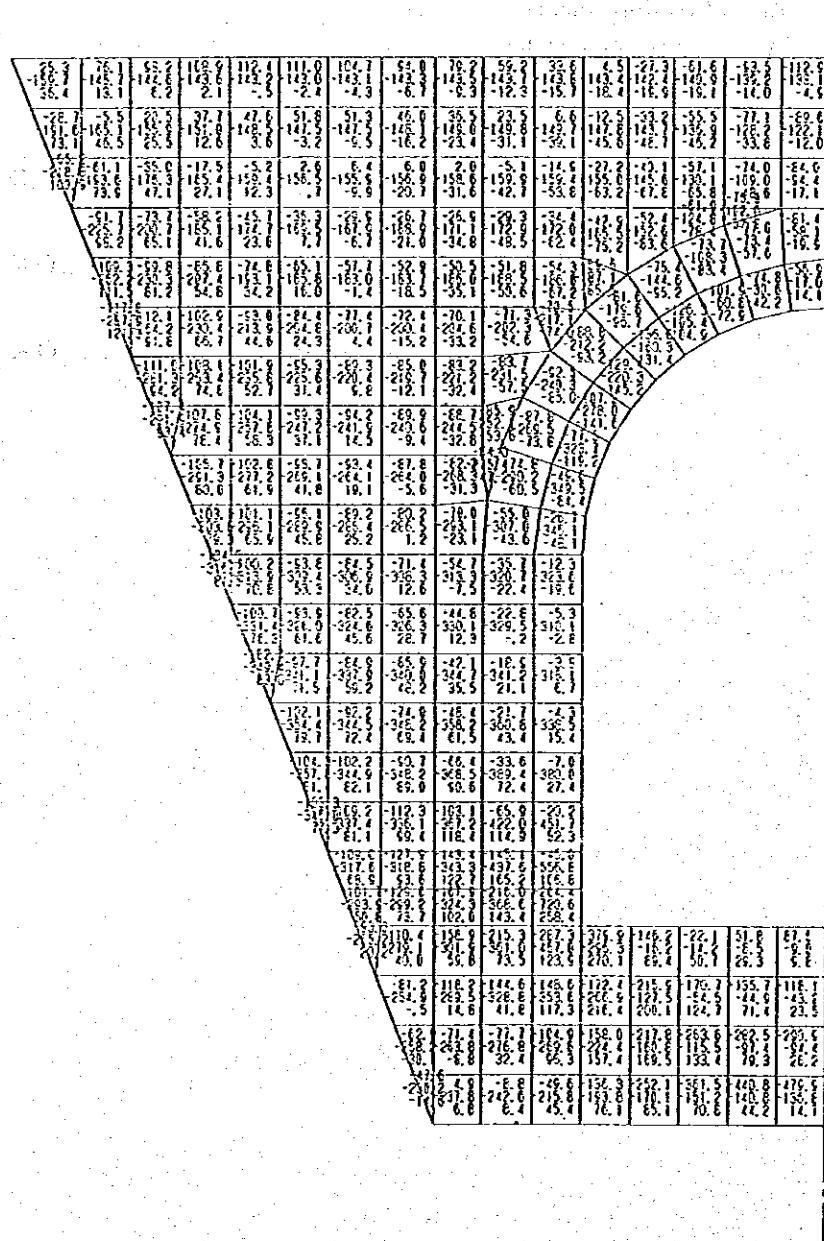
#### Area of reinforcement

- i) Inside of top slab  
 $As = 15.68 \text{ cm}^2 \leq 19.00 \text{ cm}^2 (\text{D22@200})$  ..... O.K.
  - ii) Out side of top slab  
 $As = 18.09 \text{ cm}^2 \leq 19.00 \text{ cm}^2 (\text{D22@200})$  ..... O.K.
  - iii) Inside of bottom slab  
 $As = 8.42 \text{ cm}^2 \leq 10.05 \text{ cm}^2 (\text{D16@200})$  ..... O.K.
  - iv) Outside of bottom slab  
 $As = 17.24 \text{ cm}^2 \leq 19.00 \text{ cm}^2 (\text{D22@200})$  ..... O.K.

## STRESS - STRAIN ANALYSIS CASE 2

### Value of Stress

D. C.



Up :  $\sigma_x$

Mid :  $\sigma_y$

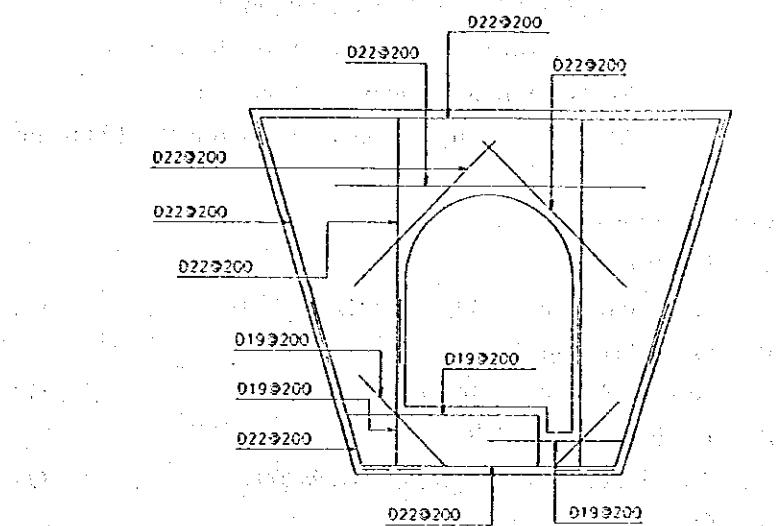
Low :  $\sigma_{xy}$

GEO. SCALE (m)

3.0000E-1

UNIT ( $t/m^2$ )

Figure of main reinforcing bar is shown as follows.



[Case-3]

Member of shape	Top slab		Bottom slab	
	Inside	Rectangle	Inside	Outside
M	tf-m	14.83	10.00	-20.00
N	tf	0.00	0.00	0.00
S	tf	0.00	0.00	60.00
B	cm	100.00	100.00	100.00
D	cm	90.00	70.00	70.00
A <sub>c</sub>	cm <sup>2</sup>	9000	7000	7000
A <sub>s</sub>	cm <sup>2</sup>	10.65	8.42	17.24
P=As/(B×D)		0.00108	0.0012	0.00246
N=E <sub>s</sub> /E <sub>c</sub>		15	15	15
X <sub>0</sub>	cm	14.800	12.100	16.600
K=X <sub>0</sub> /D		0.164	0.173	0.237
M/(B×D <sup>2</sup> )	kgf/cm <sup>2</sup>	1.831	2.041	4.082
S/(B×D)	kgf/cm <sup>2</sup>	0.000	0.000	8.571
(C)		12.882	12.282	9.150
(S)		65.543	58.800	29.400
(Z)		1.058	1.061	1.086
σ <sub>c</sub>	kgf/cm <sup>2</sup>	23.60	25.10	37.30
σ <sub>s</sub>	kgf/cm <sup>2</sup>	1800.00	1800.00	1800.00
τ	kgf/cm <sup>2</sup>	0.00	0.00	
σ <sub>ca</sub>	kgf/cm <sup>2</sup>	75.00	75.00	75.00
σ <sub>sa</sub>	kgf/cm <sup>2</sup>	1800.00	1800.00	1800.00
τ <sub>a</sub>	kgf/cm <sup>2</sup>	6.50	6.50	

Result of FEM method is adopted at outside of top slab. (refer to

stress - strain analysis)

Result of FEM method around top slab

$$\text{Tension stress} = 67.40 + 30.30 = 97.70 \text{ tf/m}^2$$

Necessary reinforcing bar section area

$$A_s = 977 \text{ kgf/cm}^2 \times 20 \text{ cm} / 1800 \text{ kgf/cm}^2 = 10.86 \text{ cm}^2$$

#### Area of reinforcement

- i) Inside of top slab

$$A_s = 10.65 \text{ cm}^2 \leq 14.20 \text{ cm}^2 (\text{D19@200}) \dots \text{O.K}$$

- ii) Out side of top slab

$$A_s = 10.86 \text{ cm}^2 \leq 14.20 \text{ cm}^2 (\text{D19@200}) \dots \text{O.K}$$

- iii) Inside of bottom slab

$$A_s = 8.42 \text{ cm}^2 \leq 10.05 \text{ cm}^2 (\text{D16@200}) \dots \text{O.K}$$

- iv) Outside of bottom slab

$$A_s = 17.24 \text{ cm}^2 \leq 19.00 \text{ cm}^2 (\text{D22@200}) \dots \text{O.K}$$

### STRESS - STRAIN ANALYSIS CASE 3

#### Value of Stress

D. C.

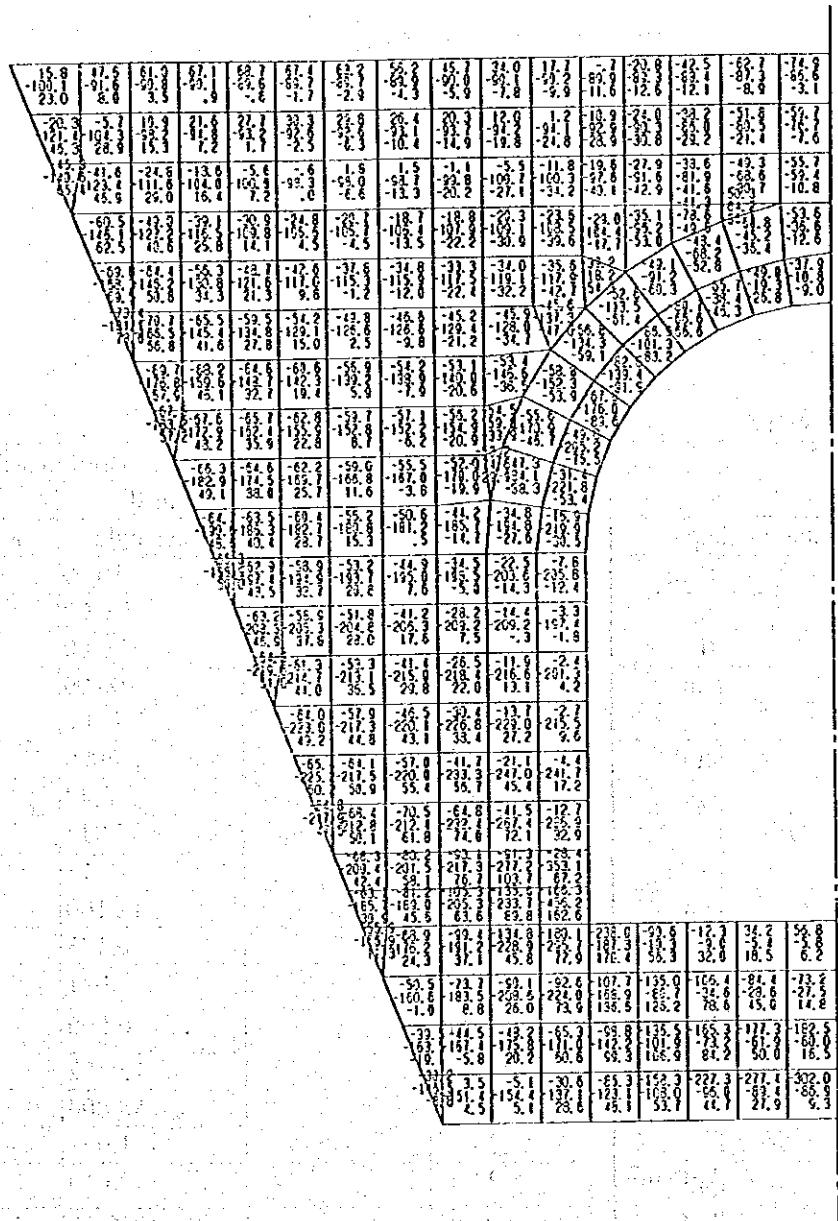
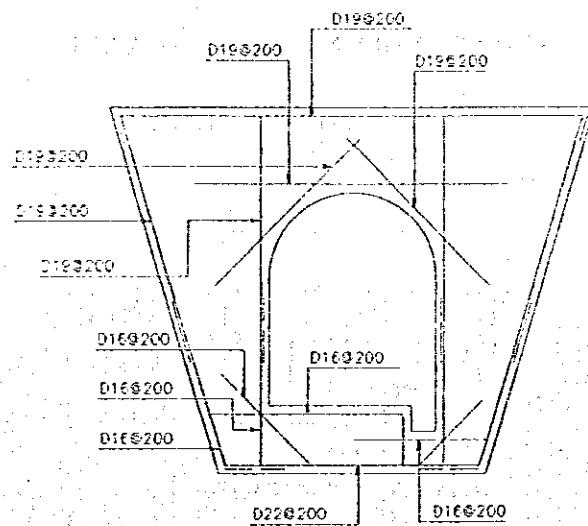


Figure of main reinforcing bar is shown as follows.



[Case-4]

Member of shape	Top slab		Bottom slab	
	Inside	Rectangle	Inside	Outside
M	tf-m	6.00	10.00	-20.00
N	tf	0.00	0.00	0.00
S	tf	0.00	0.00	60.00
B	cm	100.00	100.00	100.00
D	cm	90.00	70.00	70.00
A <sub>c</sub>	cm <sup>2</sup>	9000	7000	7000
A <sub>s</sub>	cm <sup>2</sup>	3.84	8.42	17.24
P=A <sub>s</sub> /(B×D)		0.00043	0.0012	0.00246
N=Es/Ec		15	15	15
X <sub>0</sub>	cm	9.600	12.100	16.600
K=X <sub>0</sub> /D		0.107	0.173	0.237
M/(B×D <sup>2</sup> )	kgf/cm <sup>2</sup>	0.741	2.041	4.082
S/(B×D)	kgf/cm <sup>2</sup>	0.000	0.000	8.571
(C)		19.396	12.282	9.150
(S)		162.000	58.800	29.400
(Z)		1.037	1.061	1.086
σ <sub>c</sub>	kgf/cm <sup>2</sup>	14.40	25.10	37.30
σ <sub>s</sub>	kgf/cm <sup>2</sup>	1800.00	1800.00	1800.00
τ	kgf/cm <sup>2</sup>	0.00	0.00	0.00
σ <sub>ca</sub>	kgf/cm <sup>2</sup>	75.00	75.00	75.00
σ <sub>sa</sub>	kgf/cm <sup>2</sup>	1800.00	1800.00	1800.00
ε <sub>a</sub>	kgf/cm <sup>2</sup>	6.50	6.50	6.50

Result of FEM method is adopted at outside of top slab. (refer to

stress – strain analysis)

### Result of FEM method around top slab

$$\text{Tension stress} = 18.10 + 1.60 = 19.70 \text{ t/m}^2$$

#### Necessary reinforcing bar section area

$$As = 197 \text{ kgf/cm}^2 \times 20 \text{ cm} / 1800 \text{ kgf/cm}^2 = 2.19 \text{ cm}^2$$

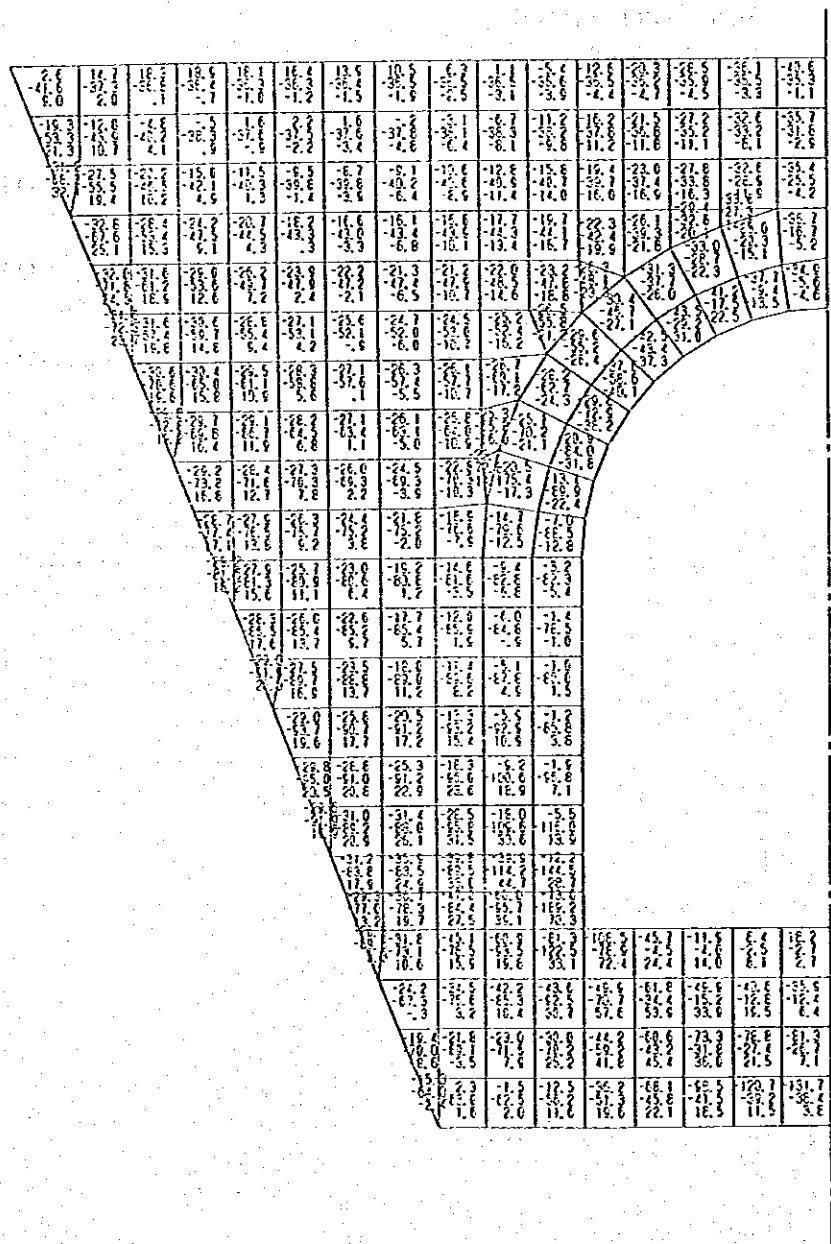
### Area of reinforcement

- i) Inside of top slab  
 $As = 3.84 \text{ cm}^2 \leq 10.05 \text{ cm}^2 (\text{D16@200})$  ..... O.K.
  - ii) Out side of top slab  
 $As = 2.19 \text{ cm}^2 \leq 10.05 \text{ cm}^2 (\text{D16@200})$  ..... O.K.
  - iii) Inside of bottom slab  
 $As = 8.42 \text{ cm}^2 \leq 10.05 \text{ cm}^2 (\text{D16@200})$  ..... O.K.
  - iv) Outside of bottom slab  
 $As = 17.24 \text{ cm}^2 \leq 19.00 \text{ cm}^2 (\text{D22@200})$  ..... O.K.

# STRESS - STRAIN ANALYSIS CASE 4

## Value of Stress

D. C.



Up :  $\sigma_x$

Mid :  $\sigma_y$

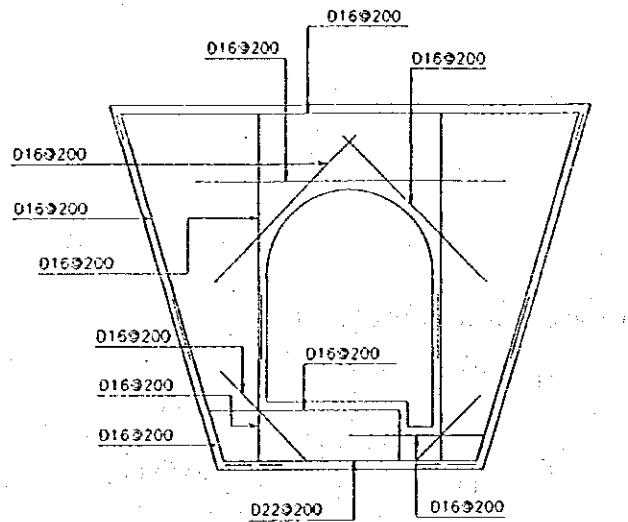
Low :  $\tau_{xy}$

GEO. SCALE (m)

3.0000E-1

UNIT (t/m<sup>2</sup>)

Figure of main reinforcing bar is shown as follows.



## (2) Gallery for B-52

There is gallery for B-52 at downstream dam slope. And height of cover material is about 54.0 m from top slab of gallery to dam slope.

In structural calculation, it is estimated that portal rigid frame is fixed in foundation ground.

Standard cross section is shown as follows.

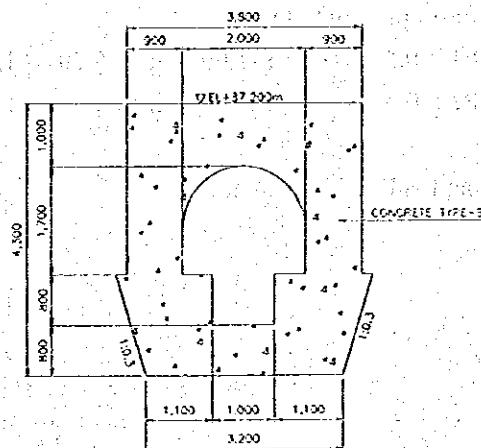
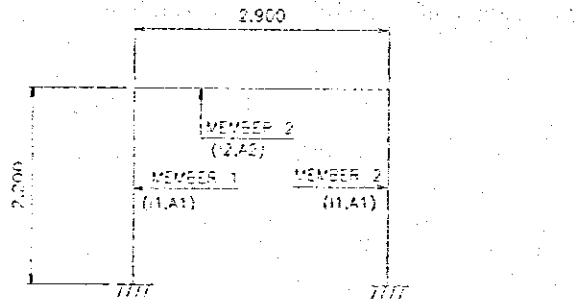


Figure of frame dimension is shown as follows.



### Geometrical moment of inertia

$$I_1 = \frac{bh^3}{12} = \frac{1.00 \times 0.90^3}{12} = 0.06075 \text{ m}^4$$

$$I_2 = \frac{bh^3}{12} = \frac{1.00 \times 1.00^3}{12} = 0.08333 \text{ m}^4$$

### Section area

$$A_1 = 1.00 \times 0.90 = 0.900 \text{ m}^3$$

$$A_2 = 1.00 \times 1.00 = 1.000 \text{ m}^3$$

### Load calculation

#### (i) Top slab

##### a) Weight of slab

$$W_1 = 1.00 \times 2.50 \text{ tf/m}^3 = 2.50 \text{ tf/m}^2$$

##### b) Weight of earth

$$W_2 = (EL+141.00 \text{ m} - EL+87.20 \text{ m}) \times 1.94 \text{ tf/m}^3 = 104.37 \text{ tf/m}^2$$

#### (ii) Side wall

##### a) Weight of wall

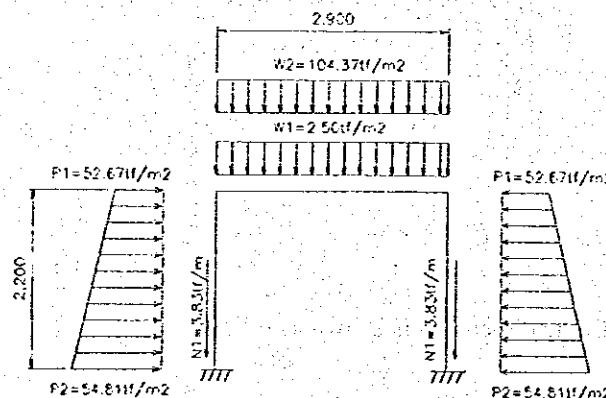
$$N_1 = 1.70 \times 0.90 \times 2.50 \text{ tf/m}^3 = 4.83 \text{ tf/m}$$

##### b) Earth pressure at rest

$$P_1 = 0.50 \times (EL+141.00 - EL+86.70) \times 1.94 \text{ tf/m}^3 = 52.67 \text{ tf/m}^2$$

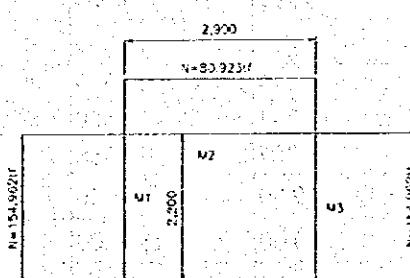
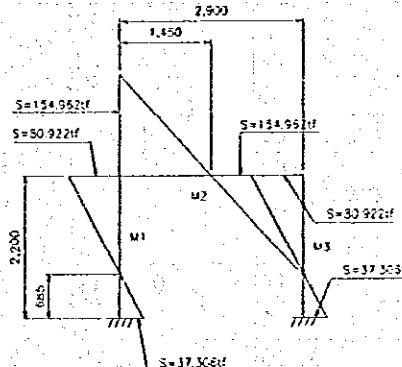
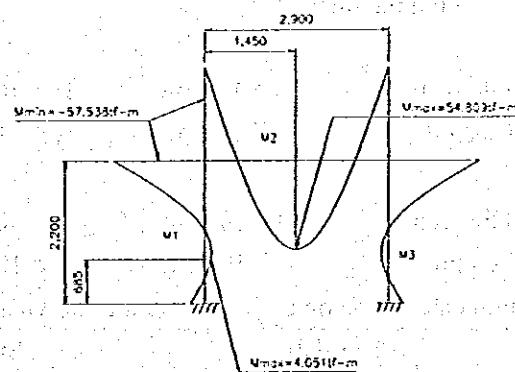
$$P_2 = 0.50 \times (EL+141.00 - EL+84.50) \times 1.94 \text{ tf/m}^3 = 54.81 \text{ tf/m}^2$$

Figure of acting load is shown as follows.



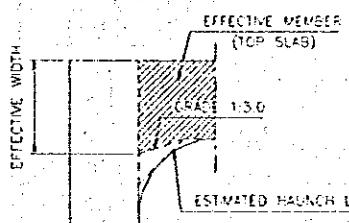
Summary calculation result is shown as follows.

Member	Condition	Distance (m)	Bending moment M (tf-m)	Shearing stress S (tf)	Axial Force N (tf)
M1	Maximum	0.685	4.051	0.000	154.962
	Minimum	2.200	-57.538	80.922	154.962
M2	Maximum	1.450	54.809	0.000	80.922
	Minimum	2.900	-57.538	154.962	80.922
M3	Maximum	1.515	4.051	0.000	154.962
	Minimum	0.000	-57.538	80.922	154.962



### Structural calculation

Inside shape of top slab at gallery is horseshoe. And in structural calculation at edge section, edge member is regarded as having haunch. Treatment of member with haunch is shown as follows.



### Dimension of calculation member

#### Top slab

- |                   |            |            |
|-------------------|------------|------------|
| a) Middle section | B = 100 cm | H = 100 cm |
| b) End section    | B = 100 cm | H = 114 cm |

#### Side wall

- |                   |            |            |
|-------------------|------------|------------|
| a) Middle section | B = 100 cm | H = 90 cm  |
| b) End section    | B = 100 cm | H = 104 cm |

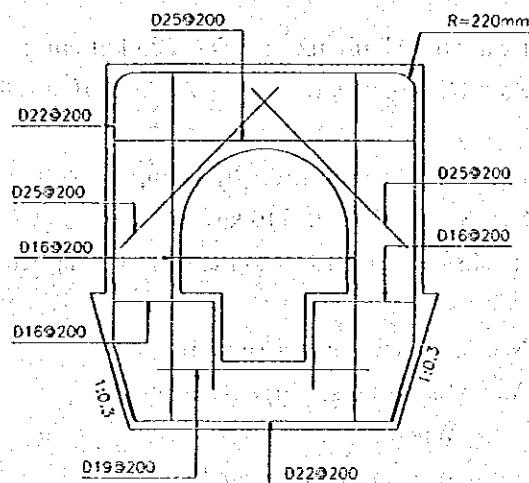
Results of structural calculation on each member are shown as follows.

Member of shape	Top slab		Side wall	
	Inside	Outside	Inside	Outside
	Rectangle	Rectangle	Rectangle	Rectangle
M	1f-m	54.809	-57.538	-57.538
N	1f	80.922	80.922	154.962
S	1f	0.000	154.962	80.922
B	cm	100.00	100.00	100.00
D	cm	90.00	104.00	94.00
A <sub>c</sub>	cm <sup>2</sup>	9000	10400	9400
A <sub>s</sub>	cm <sup>2</sup>	19.22	15.02	19.00
P=As/(B×D)		0.00214	0.00144	0.00202
N=Es/Ec		15	15	15
X <sub>0</sub>	cm	33.10	35.20	52.00
K=X <sub>0</sub> /D		0.368	0.338	0.553
M/(B×D <sup>2</sup> )	kgf/cm <sup>2</sup>	6.767	5.320	6.512
S/(B×D)	kgf/cm <sup>2</sup>	0.000	14.900	8.609
(C)		10.316	11.535	10.047
(S)		17.734	22.558	8.121
(Z)		1.307	1.388	1.688
σ <sub>c</sub>	kgf/cm <sup>2</sup>	69.80	61.40	65.40
σ <sub>s</sub>	kgf/cm <sup>2</sup>	1800.00	1800.00	793.00
τ	kgf/cm <sup>2</sup>	0.00	14.90	8.61
σ <sub>ca</sub>	kgf/cm <sup>2</sup>	75.00	75.00	75.00
σ <sub>sa</sub>	kgf/cm <sup>2</sup>	1800.00	1800.00	1800.00
τ <sub>a</sub>	kgf/cm <sup>2</sup>	6.50		

### **Area of reinforcement**

- (i) Inside of top slab  
 $As = 19.22 \text{ cm}^2 \leq 24.55 \text{ cm}^2 (\text{D25@200})$  ..... O.K.
  - (ii) Out side of top slab  
 $As = 15.02 \text{ cm}^2 \leq 19.00 \text{ cm}^2 (\text{D22@200})$  ..... O.K.  
With shear reinforcement
  - (iii) Outside of bottom slab  
 $As = 19.00 \text{ cm}^2 \leq 19.00 \text{ cm}^2 (\text{D22@200})$  ..... O.K.  
With shear reinforcement

Figure of main reinforcing bar is shown as follows.



### Calculation of stirrup

In structural calculation, stirrup bar is arranged at member having above allowable shearing stress ( $\tau_a = 6.50 \text{ kgf/cm}^2$ ).

Stirrup is calculated with following formula.

$$Aw = \frac{S_s \times S}{\sigma_{sc} \times d}$$

Where:

**Aw** : Total section area of stirrup ( $\text{cm}^2$ )

S : Stirrup interval at direction of member axis (cm)

#### Ss 10: Imposing shearing stress by stirrup (kgf)

$$S_S = S - S_C$$

S : Affecting shearing stress (kgf)

Sc : Imposing shearing stress by concrete (kgf)

$$Sc = \frac{1}{2} \times \tau_o \times b \times d$$

$\sigma_{sa}$  : Allowable tension stress of reinforcing bar ( $\text{kgf/cm}^2$ )

- $d$  : Effective height of member (cm)  
 $b$  : Effective length of member (cm)  
 $\tau_a$  : Allowable shearing stress without stirrup ( $\text{kgf/cm}^2$ )

#### Case of top slab (Outside)

- a) Dimension of member and affecting shearing stress

$$b = 100 \text{ cm}$$

$$d = 90 \text{ cm } (h = 100 \text{ cm})$$

$$S = 154.96 \text{ tf}$$

- b) Imposing shearing stress by concrete

$$Sc = \frac{1}{2} \times \tau_a \times b \times d$$

$$(\tau_a = 6.50 \text{ kgf/cm}^2 : \sigma_{ck} = 225 \text{ kgf/cm}^2)$$

$$Sc = 1/2 \times 6.50 \times 100 \times 90 = 29,250 \text{ kgf}$$

- c) Imposing shearing stress by stirrup

$$S_s = S - Sc \approx 125,710 \text{ kgf}$$

$$\tau = S_s / (b \times d) = 13.97 \text{ kgf/cm}^2 \leq 16.00 \text{ kgf/cm}^2 \dots \text{O.K.}$$

- d) Necessary section area of stirrup

$$A_{wr} = S_s \times s / (\sigma_{sa} \times d) = 15.52 \text{ cm}^2$$

Where;

$$\sigma_{sa} = 1800 \text{ kgf/cm}^2$$

$$s = 20 \text{ cm}$$

$$Aw = D22@200 = 19.00 \text{ cm}^2 \geq A_{wr} \dots \text{O.K.}$$

#### Case of side wall (Outside)

- a) Dimension of member and affecting shearing stress

$$b = 100 \text{ cm}$$

$$d = 80 \text{ cm } (h = 90 \text{ cm})$$

$$S = 8092 \text{ tf}$$

- b) Imposing shearing stress by concrete

$$Sc = \frac{1}{2} \times \tau_a \times b \times d$$

$$(\tau_a = 6.50 \text{ kgf/cm}^2 : \sigma_{ck} = 225 \text{ kgf/cm}^2)$$

$$Sc = l/2 \times 6.50 \times 100 \times 80 = 26,000 \text{ kgf}$$

- c) Imposing shearing stress by stirrup

$$Ss = S - Sc \approx 54,920 \text{ kgf}$$

$$\tau = Ss/(b \times d) = 6.87 \text{ kgf/cm}^2 \leq 16.00 \text{ kgf/cm}^2 \dots \text{O.K}$$

- d) Necessary section area of stirrup

$$Awr = Ss \times s / (\sigma_{sa} \times d) = 11.44 \text{ cm}^2$$

Where;

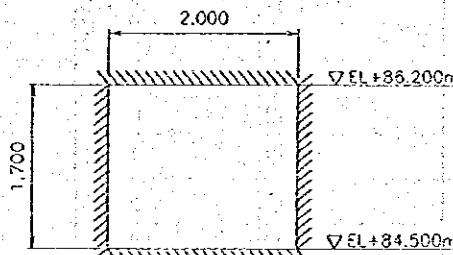
$$\sigma_{sa} = 1800 \text{ kgf/cm}^2$$

$$s = 30 \text{ cm}$$

$$Aw = D19@200 = 14.20 \text{ cm}^2 \geq Awr \dots \text{O.K}$$

#### Consideration of Downstream side wall

Downstream side wall at B-52 is regarded as slab fixed in 4 sides.



$$\text{Slenderness ratio: } \frac{t_y}{t_x} = 2.00 / 1.70 = 1.18$$

#### Load calculation

$$P1 = 0.50 \times (\text{EL} + 141.00 - \text{EL} + 86.20) \times 1.94 \text{ tf/m}^3 = 53.16 \text{ tf/m}^2$$

$$P2 = 0.50 \times (\text{EL} + 141.00 - \text{EL} + 84.50) \times 1.94 \text{ tf/m}^3 = 54.81 \text{ tf/m}^2$$

#### Bending moment

$$Mx1 = -(0.063 \times 53.16 + 0.04 \times 1.65) \times 1.70^2 = -9.87 \text{ tf-m}$$

$$Mx2 = (0.024 \times 53.16 + 0.013 \times 1.65) \times 1.70^2 = 3.75 \text{ tf-m}$$

$$Mx3 = -(0.063 \times 53.16 + 0.024 \times 1.65) \times 1.70^2 = -9.79 \text{ tf-m}$$

$$My1 = -(0.055 \times 53.16 + 0.028 \times 1.65) \times 1.70^2 = -8.58 \text{ tf-m}$$

$$My2 = (0.016 \times 53.16 + 0.008 \times 1.65) \times 1.70^2 = 2.45 \text{ tf-m}$$

#### Shearing stress

$$Sx = (0.48 \times 53.16 + 0.35 \times 1.65) \times 1.70 = 44.36 \text{ tf}$$

$$Sy = (0.45 \times 53.16 + 0.35 \times 1.65) \times 1.70 = 41.65 \text{ tf}$$

#### Combination of load

Short side section ( $L = 1.70 \text{ m}$ )

$$M_x = -9.87 \text{ tf-m} \quad S_x = 44.36 \text{ tf}$$

Long side section ( $L = 2.00 \text{ m}$ )

$$M_x = -8.58 \text{ tf-m} \quad S_y = 41.65 \text{ tf}$$

Results of structural calculation on each member are shown as follows.

Direction		Downstream side			
		Vertical	Horizontal		
Member of shape	Rectangle	Rectangle			
M	tf-m	-9.870	-8.580		
N	tf	0.000	0.000		
S	tf	44.360	41.650		
B	cm	100.00	100.00		
D	cm	80.00	80.00		
Ac	cm <sup>2</sup>	8000	8000		
As	cm <sup>2</sup>	7.22	6.25		
P=As/(B×D)		0.0009	0.00078		
N=E <sub>s</sub> /E <sub>c</sub>		15	15		
X <sub>0</sub>	cm	12.10	11.30		
K=X <sub>0</sub> /D		0.152	0.142		
M/(B×D <sup>2</sup> )	kgf/cm <sup>2</sup>	1.542	1.341		
S/(B×D)	kgf/cm <sup>2</sup>	5.545	5.206		
(C)		13.899	14.798		
(S)		77.812	89.510		
(Z)		1.053	1.050		
$\sigma_c$	kgf/cm <sup>2</sup>	21.40	19.80		
$\sigma_s$	kgf/cm <sup>2</sup>	1800.00	1800.00		
$\tau$	kgf/cm <sup>2</sup>	5.55	5.21		
$\sigma_{ca}$	kgf/cm <sup>2</sup>	75.00	75.00		
$\sigma_{sa}$	kgf/cm <sup>2</sup>	1800.00	1800.00		
$\tau_a$	kgf/cm <sup>2</sup>	6.50	6.50		

#### Area of reinforcement

(i) Vertical direction ( $L = 1.70 \text{ m}$ )

$$A_s = 7.22 \text{ cm}^2 \leq 9.37 \text{ cm}^2 (\text{D19@300}) \dots \text{O.K}$$

(ii) Horizontal section ( $L = 2.00 \text{ m}$ )

$$A_s = 6.52 \text{ cm}^2 \leq 9.37 \text{ cm}^2 (\text{D19@300}) \dots \text{O.K}$$

## 2.4 Spillway

Spillway, the bathtub type of side channel spillway, consists of five (5) portions. Those are overflow weir, side channel, control portion, chute and stilling basin.

### 2.4.1 Design Conditions

#### Loading Condition to be Considered

The safety of the spillway structure should be verified through detailed structural calculations.

The combination of loads needed for the structural calculation is given hereunder.

Structure facing Reservoir Water

Case	Condition of Reservoir	Combination of Loads
1	Normal Water Surface	Self weight Earth pressure with earthquake (100 %) Hydrostatic pressure Hydrodynamic pressure (100 %) Inertial force during seismic motion (100 %) Uplift pressure
2	Surcharge Water Surface	Self weight Earth pressure with earthquake (50 %) Hydrostatic pressure Hydrodynamic pressure (50 %) Inertial force during seismic motion (50 %) Uplift pressure
3	Maximum Water Surface	Self weight Earth pressure Hydrostatic pressure Uplift pressure
4	Empty Reservoir	Self weight Inertial force during seismic motion (50 %)

Structure not facing Reservoir Water

Case	Condition	Combination of Loads
1	Normal Condition	Self weight Earth pressure Hydrostatic pressure Uplift pressure
2	Earthquake Condition	Self weight Earth pressure with earthquake (100 %) Hydrostatic pressure Hydrodynamic pressure (100 %) Inertial force during seismic motion (100 %) Uplift pressure

## **Structural Stability**

The spillway structures should be founded on rock and should be safe against shear and overturning. It is a usual practice to determine the cross sectional area for a two-dimensional design process based on the assumption that the structure consists of a number of cantilevered beams which are independent of each other. The required conditions of the structural safety are described hereinafter.

### **(1) Conditions for Safety against Shear**

Regarding shear safety, an evaluation should be made using Henny's formula for the contact plane of the rock foundation.

$$SF = \frac{\tau_0 \cdot l + f \cdot V}{H}$$

Where,

SF : safety factor

H : total shearing force acting in the shear plane per unit width (tf/m)

V : total normal force acting on the shear plane per unit width (tf/m)

$\tau_0$  : shear strength of rock foundation (tf/m<sup>2</sup>)

l : length of shear plane (m)

f : coefficient of internal friction of rock foundation

### **(2) Overturning**

When the location of the resulting force of a load is within the central one-third point, tensile stress in the vertical direction is not produced at the upstream face of the structure.

The following formula is used for the stability evaluation.

$$e = \frac{b}{2} - \frac{M}{V}$$

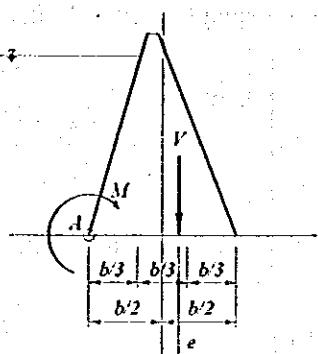
Where,

b : width of base (m)

M : total moment at point A per unit width (tf-m/m)

V : total normal force acting on the shear plane per unit width (tf/m)

e : eccentricity (m)



### (3) Bearing Capacity of Foundation

The maximum principal stress in the foundation must be kept within allowable rock bearing capacity, which derived from the following:

$$q_1 = \frac{V}{b} \cdot \left( 1 + \frac{6e}{b} \right)$$

$$q_2 = \frac{V}{b} \cdot \left( 1 - \frac{6e}{b} \right)$$

Where,

$q_1$  : maximum principal stress ( $\text{tf/m}^2/\text{m}$ )

$q_2$  : minimum principal stress ( $\text{tf/m}^2/\text{m}$ )

$V$  : total normal force acting on the shear plane per unit width ( $\text{tf/m}$ )

$b$  : width of base (m)

$e$  : eccentricity (m)

#### Required Conditions

The following conditions shall be satisfied in stability calculations:

#### Structure facing Reservoir Water

Case	Condition of Reservoir	Earthquake	Structural Stability	
			Against Shear	Against Overturning
1	Normal Water Surface	100 %	$SF \geq 4$	$e = \frac{b \cdot M}{2 \cdot V} < \frac{b}{6}$
2	Surcharge Water Surface	50 %	$SF \geq 4$	$e = \frac{b \cdot M}{2 \cdot V} < \frac{b}{6}$
3	Maximum Water Surface	0 %	$SF \geq 4$	$e = \frac{b \cdot M}{2 \cdot V} < \frac{b}{6}$
4	Empty Reservoir	50 %	$SF \geq 4$	$e = \frac{b \cdot M}{2 \cdot V} < \frac{b}{6}$

### Structure not facing Reservoir Water

Case	Condition	Earthquake	Structural Stability	
			Against Shear	Against Overturning
1	Normal Condition	0 %	SF ≥ 4	$e = \frac{b}{2} - \frac{M}{V} < \frac{b}{6}$
2	Earthquake Condition	100 %	SF ≥ 4	$e = \frac{b}{2} - \frac{M}{V} < \frac{b}{3}$

Notes SF : safety factor

b : width of base (m)

M : total moment at point A per unit width (tf-m/m)

V : total normal force acting on the shear plane per unit width (tf/m)

e : eccentricity (m)

### **Material Properties**

Material properties to be used for structural calculation are summarized below:

#### (1) Shear Strength of Foundation Rock

Rock Class	Estimated Shear Strength	Coefficient of Internal Friction
CL class	$\tau_o = 30 \text{ tf/m}^2$	0.7
CM-L class	$\tau_o = 45 \text{ tf/m}^2$	0.8
CM-H class	$\tau_o = 50 \text{ tf/m}^2$	0.8

#### (2) Properties of Construction Material

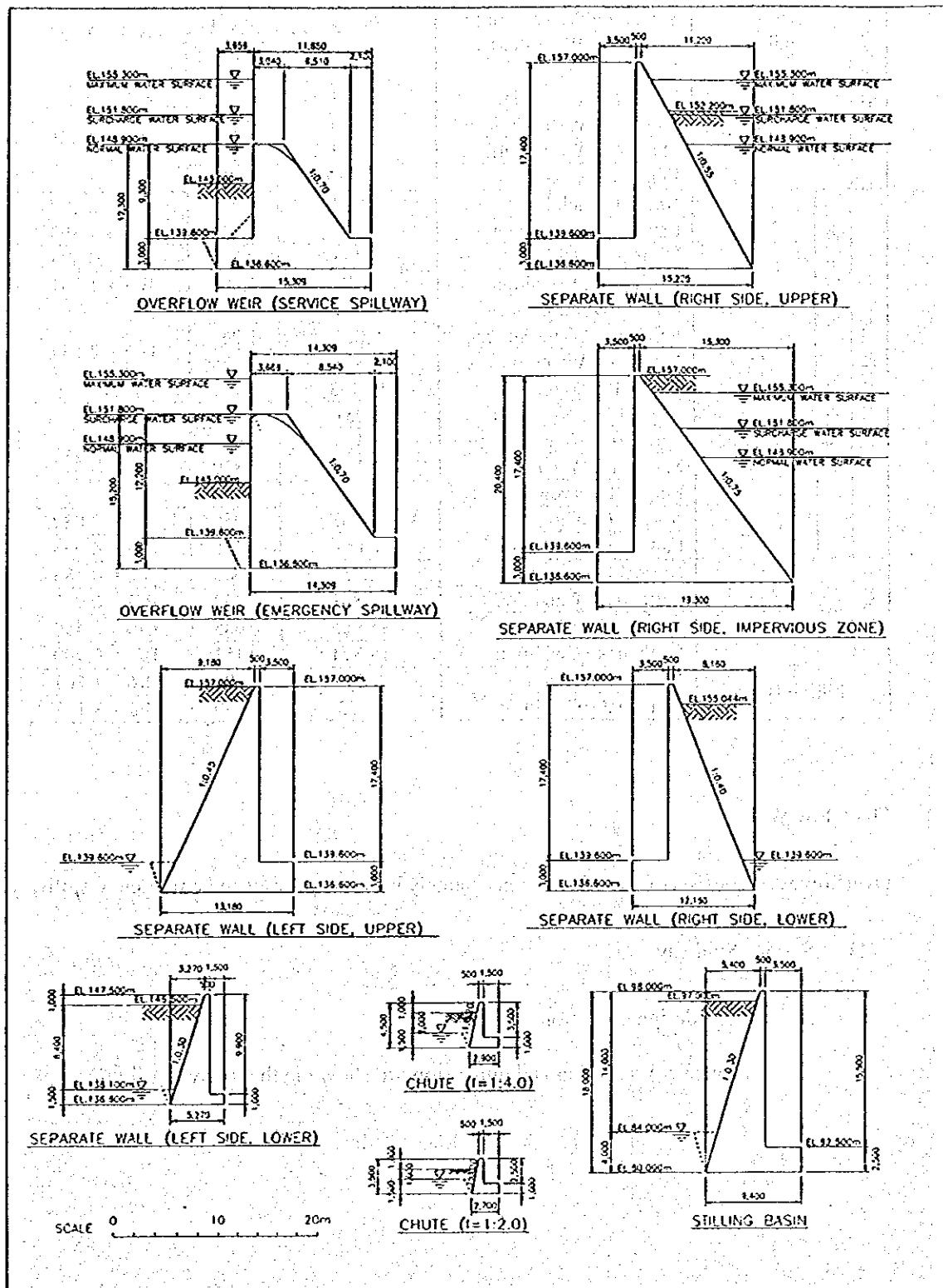
Material	Unit Weight ( $\text{tf/m}^3$ )
Reinforced Concrete (Thick Structure)	2.35
Reinforced Concrete (Thin Structure)	2.50

Material	Wet Density ( $\text{tf/m}^3$ )	Submerged Density ( $\text{tf/m}^3$ )	Internal Friction Angle (degree)
Impervious Material (Dam)	2.11	1.19	30.0
Semi-pervious Material (Dam)	2.11	1.27	35.0
Pervious Material (Dam)	1.94	1.16	45.0
Sandy Soil (Backfill)	1.90	0.90	35.0

## 2.4.2 Stability Analysis

### Results of Structural Design

Sections analyzed are shown in following figures.



The results of stability analysis are summarized as follows:

Parts	Loading Condition	Structural Stability		
		Against Shear	Against Overturning (m)	
		$SF \geq 4$	e	$<B/6$ or $<B/3$
Overflow Weir	Service Spillway	Normal Water Surface	6.626	1.078
		Surcharge Water Surface	6.165	0.191
		Maximum Water Surface	5.774	1.490
		Empty Reservoir	30.199	0.574
	Emergency Spillway	Normal Water Surface	5.795	0.441
		Surcharge Water Surface	5.450	0.889
		Maximum Water Surface	4.967	1.589
		Empty Reservoir	20.259	1.405
Control Portion	Upper	Normal Condition	6.887	1.296
		Earthquake Condition	4.081	2.614
		Normal Condition	7.445	0.785
		Earthquake Condition	4.373	1.603
	Upper	Normal Water Surface	4.297	1.879
		Surcharge Water Surface	5.081	1.964
		Maximum Water Surface	4.895	2.175
		Empty Reservoir	10.143	0.771
	Impervious Zone	Normal Water Surface	4.051	2.093
		Surcharge Water Surface	4.433	2.018
		Maximum Water Surface	4.834	1.859
		Empty Reservoir	5.612	1.409
	Lower	Normal Condition	7.010	1.055
		Earthquake Condition	4.133	2.355
Chute	i=1:4	Normal Condition	24.133	0.060
	i=1:4	Earthquake Condition	12.863	0.262
	i=1:2	Normal Condition	35.965	0.085
	i=1:2	Earthquake Condition	18.371	0.153
	Stilling Basin	Normal Condition	6.709	1.108
		Earthquake Condition	4.053	2.530

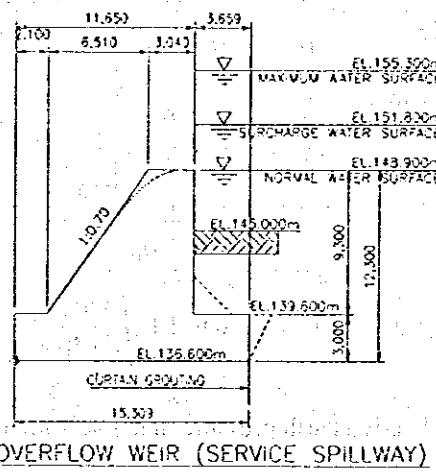
### Overflow Weir

Overflow weir consists of two (2) portions, namely service spillway and emergency spillway.

#### (1) Service Spillway

##### (a) Basic design condition

Typical cross section and dimension are shown in the following figure.



Design conditions, such as material properties, are shown in the following tables.

Item	Symbol	Unit	Value	Description
Unit weight of concrete	$\gamma_c$	(tf/m <sup>3</sup> )	2.35	Thick structure
Unit weight of wetted backfill soil	$\gamma_t$	(tf/m <sup>3</sup> )	1.90	Wet density
Unit weight of submerged backfill soil	$\gamma_s$	(tf/m <sup>3</sup> )	0.90	Submerged density
Horizontal seismic coefficient	$K_h$	-	0.16	100%
Shear strength of foundation rock	$\tau_0$	(tf/m <sup>2</sup> )	45	CM-L class
Coefficient of internal friction of foundation rock	f	-	0.8	CM-L class

< Coefficient of earth pressure >

$$K_a = \frac{\cos^2(\phi - 0)}{\cos^2 0 \cdot \cos(\theta + \delta) \cdot \left[ 1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \alpha)}{\cos(\theta + \delta) \cdot \cos(\theta - \alpha)}} \right]^2}$$

Ka : Coefficient of active earth pressure under normal condition

Item	Symbol	Unit	Value	Description
Angle between wall backside surface and vertical plane	$\theta$	(degree)	0.0	
Angle between ground surface and horizontal plane	$\alpha$	(degree)	0.0	
Internal friction angle of soil	$\phi$	(degree)	35.0	Sandy soil
Friction angle of soil to concrete	$\delta$	(degree)	23.3	$\delta = 2/3 \phi$

$$Kea = \frac{\cos^2(\phi - \theta_0 - \alpha)}{\cos \theta_0 \cdot \cos^2 \phi \cdot \cos(\theta + \theta_0 + \delta) \cdot \left[ 1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \alpha - \theta_0)}{\cos(\theta + \theta_0 + \delta) \cdot \cos(\theta - \alpha)}} \right]^2}$$

Kea : Coefficient of active earth pressure under seismic condition

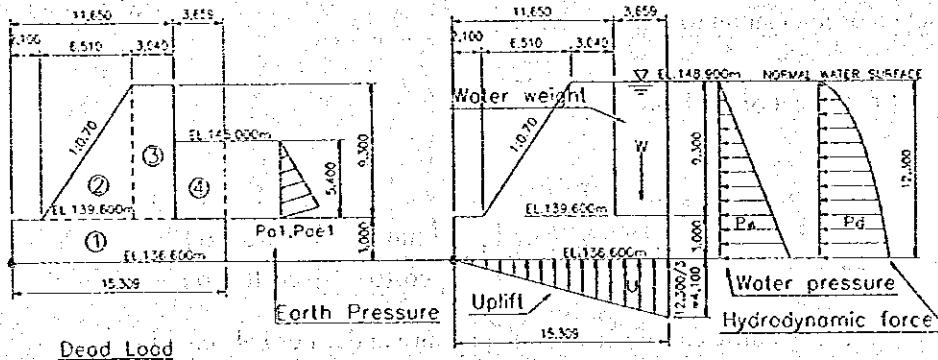
Item	Symbol	Unit	Value	Description
Friction angle of soil to concrete	$\delta_c$	(degree)	17.5	$\delta_c = 1/2 \phi$
Seismic composite angle	$\theta_0$	(degree)	various	$\tan \theta_0 = Kh$

(b) Case 1 : Service Spillway, Normal Water Surface : EL.148.900m

Horizontal seismic coefficient :  $Kh=0.16$  (100%)

### (i) Loading Calculation

Structural model and load combinations are shown in the following figure.



Each load is calculated hereinafter.

#### Dead Load

	A( $m^2$ )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
1(concrete)	45.93	107.93	7.65	826.14	-17.27	1.50	-25.90
2(concrete)	30.27	71.14	6.44	458.13	-11.38	6.10	-69.43
3(concrete)	28.27	66.43	10.13	672.98	-10.63	7.65	-81.32
4(soil)	19.76	17.78	13.48	239.71	-2.85	5.70	-16.22
Total	124.23	263.29		2196.96	-42.13		-192.87

### Earth Pressure with Earthquake

Seismic composite angle :  $\theta_0 = 9.1$ (degree) ( $\tan\theta_0 = Kh = 0.16$ )

Coefficient of active earth pressure :  $Kea = 0.348$

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pae1	-	1.37	11.65	16.00	-4.36	4.80	-20.91
Total	-	1.37		16.00	-4.36		-20.91

### Water Pressure

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
W,Pw	34.03	34.03	13.48	458.71	-75.65	4.10	-310.14
Total		34.03		458.71	-75.65		-310.14

### Hydrodynamic Force (due to Earthquake)

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pd	-	-	-	-	-14.12	4.92	-69.47
Total		-		-	-14.12		-69.47

### Uplift

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
U	-	-31.38	10.21	-320.30	-	-	-
Total		-31.38		-320.30	-	-	-

### (ii) Stability Analysis (Normal Water Surface)

#### Seismic condition (with Earthquake), Kh=0.16(100%)

Total Load	V(tf)	H(tf)	Mx(tf-m)	My(tf-m)
Dead Load	263.3	-42.1	2,197.0	-192.9
Earth Pressure	1.4	-4.4	16.0	-20.9
Water Pressure	34.0	-75.6	458.7	-310.1
Hydrodynamic	0.0	-14.1	0.0	-69.5
Uplift	-31.4	0.0	-320.3	0.0
Total	267.3	-136.2	2,351.4	-593.4

#### Safety against overturning

$$d = 6.577 \text{ m}$$

$$e = B/2 - d = 1.078 \text{ m} < 2.552 \text{ m} = b/6 \quad \text{OK}$$

#### Safety against shear

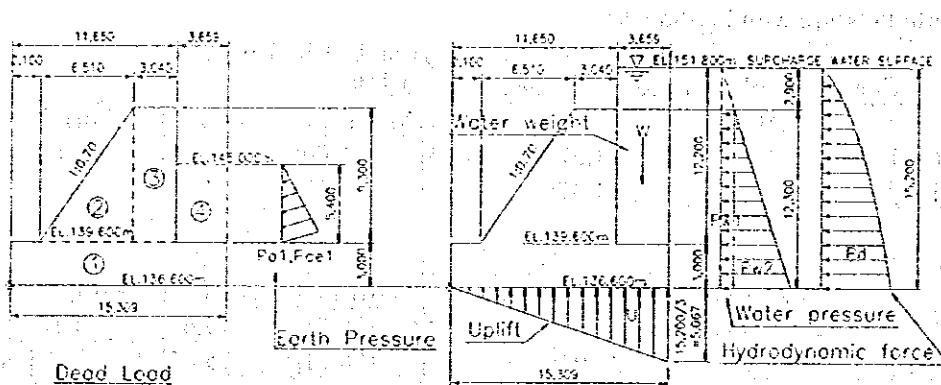
$$SF = (Vf + \tau_0 l)/H = 6.626 > 4 \quad \text{OK}$$

### (c) Case 2 : Service Spillway, Surcharge Water Surface : EL.151.800m

Horizontal seismic coefficient : Kh=0.08 (50%)

#### (i) Loading Calculation

Structural model and load combinations are shown in the following figure.



Each load is calculated hereinafter.

#### Dead Load

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
1(concrete)	45.93	107.93	7.65	826.14	-8.63	1.50	-12.95
2(concrete)	30.27	71.14	6.44	458.13	-5.69	6.10	-34.72
3(concrete)	28.27	66.43	10.13	672.98	-5.31	7.65	-40.66
4(soil)	19.76	17.78	13.48	239.71	-1.42	5.70	-8.11
Total	124.23	263.29		2196.96	-21.06		-96.43

#### Earth Pressure with Earthquake

Seismic composite angle :  $\theta_0=4.6(\text{degree})$  ( $\tan\theta_0=Kh=0.08$ )

Coefficient of active earth pressure :  $Kea=0.293$

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pae1	-	1.15	11.65	13.45	-3.66	4.80	-17.58
Total	-	1.15		13.45	-3.66		-17.58

#### Water Pressure

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
W,Pw1	44.64	44.64	13.48	601.75	-35.67	6.15	-219.37
Pw2	-	-	-	-	-75.65	4.10	-
Total	-	44.64		601.75	-111.32		-219.37

#### Hydrodynamic Force (due to Earthquake)

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pd	-	-	-	-	-10.78	6.08	-65.55
Total	-	-	-	-	-10.78	-	-65.55

#### Uplift

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
U	-	-38.78	10.21	-395.82	-	-	-
Total	-	-38.78		-395.82	-		-

#### (ii) Stability Analysis (Surcharge Water Surface)

Seismic condition (with Earthquake),  $K_h=0.08(50\%)$

Total Load	V(tf)	H(tf)	Mx(tf-m)	My(tf-m)
Dead Load	263.3	-21.1	2,197.0	-96.4
Earth Pressure	1.2	-3.7	13.5	-17.6
Water Pressure	44.6	-111.3	601.8	-219.4
Hydrodynamic	0.0	-10.8	0.0	-65.6
Uplift	-38.8	0.0	-395.8	0.0
Total	270.3	-146.8	2,416.3	-398.9

Safety against overturning

$$d = 7.464 \text{ m}$$

$$e = B/2 - d = 0.191 \text{ m} < 2.552 \text{ m} = b/6 \quad \text{OK}$$

Safety against shear

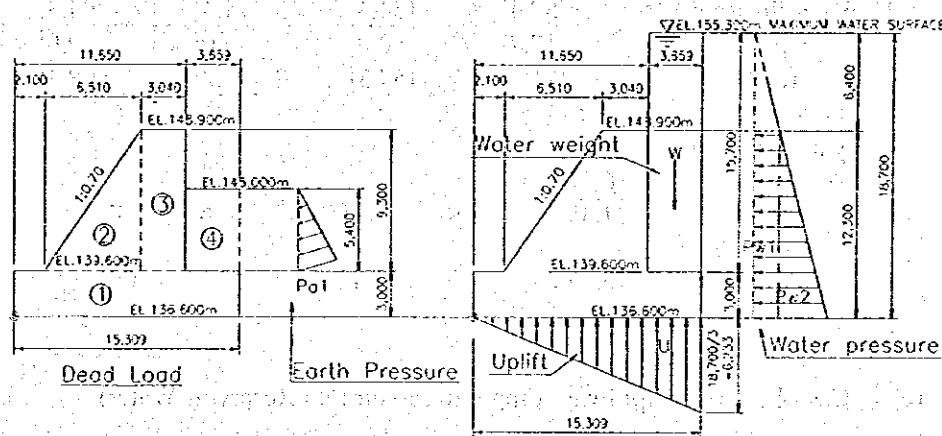
$$SF = (Vf + \tau_0 l) / H = 6.165 > 4 \quad \text{OK}$$

(d) Case 3 : Service Spillway, Maximum Water Surface : EL. 155.300m

Horizontal seismic coefficient :  $K_h=0.0 (0\%)$

(i) Loading Calculation

Structural model and load combinations are shown in the following figure.



Each load is calculated hereinafter.

Dead Load

	A( $m^2$ )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
1(concrete)	45.93	107.93	7.65	826.14	0.00	1.50	0.00
2(concrete)	30.27	71.14	6.44	458.13	0.00	6.10	0.00
3(concrete)	28.27	66.43	10.13	672.98	0.00	7.65	0.00
4(soil)	19.76	17.78	13.48	239.71	0.00	5.70	0.00
Total	124.23	263.29		2196.96	0.00		0.00

### Earth Pressure without Earthquake

Coefficient of active earth pressure :  $K_a=0.244$

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pa1	-	1.27	11.65	14.80	-2.94	4.80	-14.14
Total	-	1.27		14.80	-2.94		-14.14

### Water Pressure

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
W,Pw1	57.45	57.45	13.48	774.38	-78.72	6.15	-484.13
Pw2	-	-	-	-	-75.65	4.10	-310.14
Total		57.45		774.38	-154.37		-794.27

### Uplift

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
U	-	-47.71	10.21	-486.96	-	-	-
Total		-47.71		-486.96	-	-	-

### (ii) Stability Analysis (Maximum Water Surface)

#### Normal condition (without Earthquake)

Total Load	V(tf)	H(tf)	Mx(tf-m)	My(tf-m)
Dead Load	263.3	0.0	2,197.0	0.0
Earth Pressure	1.3	-2.9	14.8	-14.1
Water Pressure	57.4	-154.4	774.4	-794.3
Uplift	-47.7	0.0	-487.0	0.0
Total	274.3	-157.3	2,499.2	-808.4

#### Safety against overturning

$$d = 6.164 \text{ m}$$

$$e = B/2 - d = 1.490 \text{ m} < 2.552 \text{ m} = b/6 \quad \text{OK}$$

#### Safety against shear

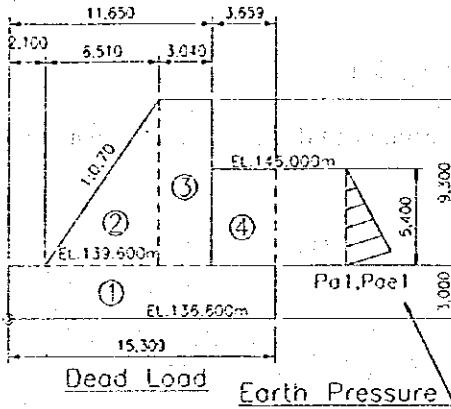
$$SF = (Vf + \tau_0 l) / H = 5.774 > 4 \quad \text{OK}$$

### (e) Case 4 : Service Spillway, Empty Reservoir (No Reservoir Water)

Horizontal seismic coefficient :  $K_h=0.08$  (50%)

#### (i) Loading Calculation

Structural model and load combinations are shown in the following figure.



Each load is calculated hereinafter.

#### Dead Load

	A( $m^2$ )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
1(concrete)	45.93	107.93	7.65	826.14	-8.63	1.50	-12.95
2(concrete)	30.27	71.14	6.44	458.13	-5.69	6.10	-34.72
3(concrete)	28.27	66.43	10.13	672.98	-5.31	7.65	-40.66
4(soil)	19.76	37.54	13.48	506.06	-3.00	5.70	-17.12
Total	124.23	283.04		2,463.31	-22.64		-105.44

#### Earth Pressure with Earthquake

Seismic composite angle :  $\theta_0=4.6(\text{degree})$  ( $\tan\theta_0=Kh=0.08$ )

Coefficient of active earth pressure :  $K_{ae}=0.293$

	A( $m^2$ )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pae1	-	2.44	11.65	28.40	-7.73	4.80	-37.11
Total	-	2.44		28.40	-7.73		-37.11

#### (ii) Stability Analysis (Empty Reservoir)

##### Seismic condition (with Earthquake), $Kh=0.08(50\%)$

Total Load	V(tf)	H(tf)	Mx(tf-m)	My(tf-m)
Dead Load	283.0	-22.6	2,463.3	-105.4
Earth Pressure	2.4	-7.7	28.4	-37.1
Water Pressure	-	-	-	-
Hydrodynamic	-	-	-	-
Uplift	-	-	-	-
Total	285.5	-30.4	2,491.7	-142.6

#### Safety against overturning

$$d = 8.229 \text{ m}$$

$$e = B/2 - d = -0.574 \text{ m} < 2.552 \text{ m} = b/6 \quad \text{OK}$$

#### Safety against shear

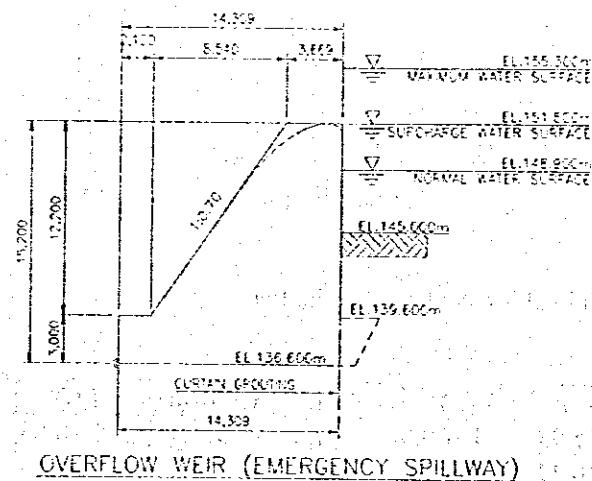
$$SF = (Vf + \tau_0)/H = 30.199 > 4$$

OK

(2) Emergency Spillway

(a) Basic design condition

Typical cross section and dimension are shown in the following figure.



Design conditions, such as material properties, are shown in the following tables.

Item	Symbol	Unit	Value	Description
Unit weight of concrete	$\gamma_c$	(tf/m <sup>3</sup> )	2.35	Thick structure
Unit weight of wetted backfill soil	$\gamma_t$	(tf/m <sup>3</sup> )	1.90	Wet density
Unit weight of submerged backfill soil	$\gamma_s$	(tf/m <sup>3</sup> )	0.90	Submerged density
Horizontal seismic coefficient	$K_h$	-	0.16	100%
Shear strength of foundation rock	$\tau_0$	(tf/m <sup>2</sup> )	45	CM-L class
Coefficient of internal friction of foundation rock	$f$	-	0.8	CM-L class

< Coefficient of earth pressure >

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

Ka : Coefficient of active earth pressure under normal condition

Item	Symbol	Unit	Value	Description
Angle between wall backside surface and vertical plane	$\theta$	(degree)	0.0	
Angle between ground surface and horizontal plane	$\alpha$	(degree)	0.0	
Internal friction angle of soil	$\phi$	(degree)	35.0	Sandy soil
Friction angle of soil to concrete	$\delta$	(degree)	23.3	$\delta = 2/3 \phi$

$$Kea = \frac{\cos^2(\phi - \theta_0 - \alpha)}{\cos \theta_0 \cdot \cos^2 \theta \cdot \cos(\theta + \theta_0 + \delta) \cdot \left[ 1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \alpha - \theta_0)}{\cos(\theta + \theta_0 + \delta) \cdot \cos(\theta - \alpha)}} \right]^2}$$

Kea : Coefficient of active earth pressure under seismic condition

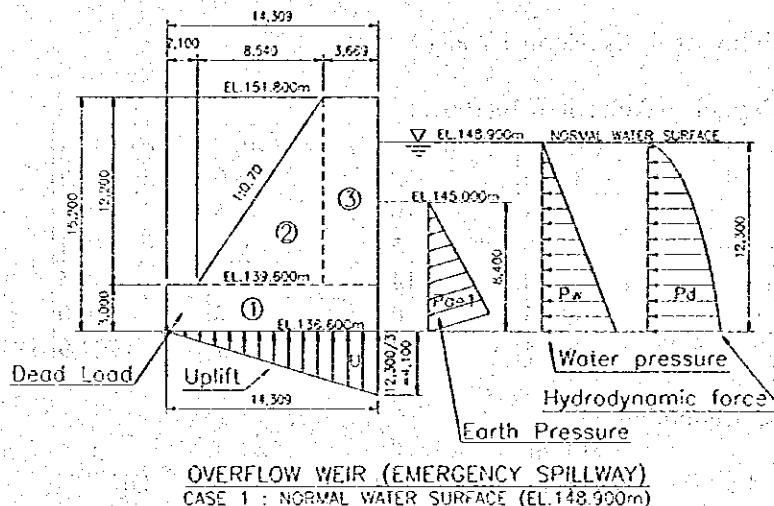
Item	Symbol	Unit	Value	Description
Friction angle of soil to concrete	$\delta_e$	(degree)	17.5	$\delta_e = 1/2 \phi$
Seismic composite angle	$\theta_0$	(degree)	-	$\tan \theta_0 = Kh$

### (b) Case 1 : Emergency Spillway, Normal Water Surface : EL.148.900m

Horizontal seismic coefficient :  $Kh=0.16$  (100%)

#### (i) Loading Calculation

Structural model and load combinations are shown in the following figure.



Each load is calculated hereinafter.

**Dead Load**

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
1(concrete)	42.93	100.88	7.15	721.73	-16.14	1.50	-24.21
2(concrete)	52.09	122.42	7.79	954.07	-19.59	7.07	-138.42
3(concrete)	44.76	105.19	12.47	1,312.20	-16.83	9.10	-153.16
Total	139.78	328.49		2,988.00	-52.56		-315.79

**Earth Pressure with Earthquake**

Seismic composite angle :  $\theta_0 = 9.1$ (degree) ( $\tan\theta_0 = Kh = 0.16$ )

Coefficient of active earth pressure :  $Ke_a = 0.348$

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pae1	-	3.32	14.31	47.55	-10.54	2.80	-29.51
Total	-	3.32		47.55	-10.54		-29.51

**Water Pressure**

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pw	-	-	-	-	-75.65	4.10	-310.14
Total	-	-		-	-75.65		-310.14

**Hydrodynamic Force (due to Earthquake)**

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pd	-	-	-	-	-14.12	4.92	-69.47
Total	-	-		-	-14.12		-69.47

**Uplift**

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
U	-	-29.33	9.54	-279.82	-	-	-
Total	-	-29.33		-279.82	-	-	-

**(ii) Stability Analysis (Normal Water Surface)**

**Seismic condition (with Earthquake); Kh=0.16(100%)**

Total Load	V(tf)	H(tf)	Mx(tf-m)	My(tf-m)
Dead Load	328.5	-52.6	2,988.0	-315.8
Earth Pressure	3.3	-10.5	47.5	-29.5
Water Pressure	0.0	-75.6	0.0	-310.1
Hydrodynamic	0.0	-14.1	0.0	-69.5
Uplift	-29.3	0.0	-279.8	0.0
Total	302.5	-152.9	2,755.7	-724.9

**Safety against overturning**

$$d = 6.714 \text{ m}$$

$$e = B/2 - d = 0.441 \text{ m} < 2.385 \text{ m} = b/6 \quad \text{OK}$$

**Safety against shear**

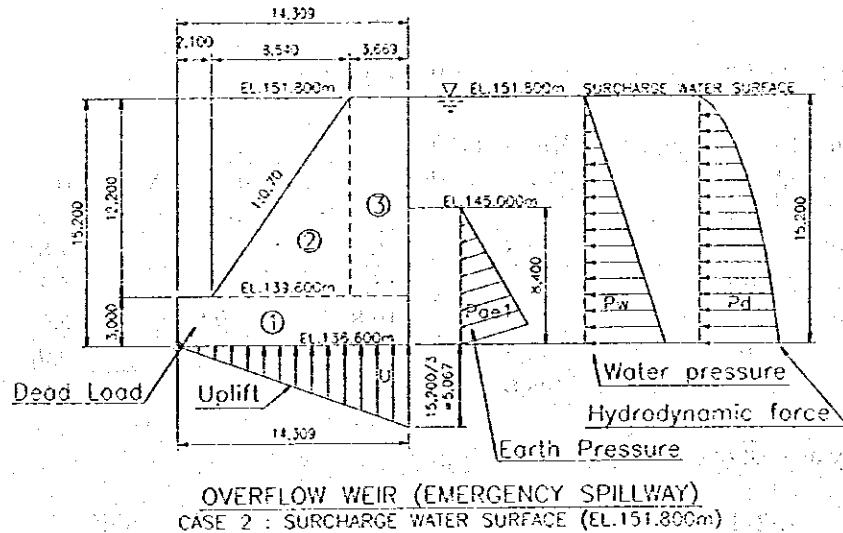
$$SF = (Vf + \tau_0 l)/H = 5.795 > 4 \quad \text{OK}$$

**(c) Case 2 : Emergency Spillway, Surcharge Water Surface : EL.151.800m**

Horizontal seismic coefficient : Kh=0.08 (50%)

### (i) Loading Calculation

Structural model and load combinations are shown in the following figure.



Each load is calculated hereinafter.

#### Dead Load

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
1(concrete)	42.93	100.88	7.15	721.73	-8.07	1.50	-12.11
2(concrete)	52.09	122.42	7.79	954.07	-9.79	7.07	-69.21
3(concrete)	44.76	105.19	12.47	1,312.20	-8.42	9.10	-76.58
Total	139.78	328.49		2,988.00	-26.28		-157.89

#### Earth Pressure with Earthquake

Seismic composite angle :  $\theta_0=4.6$ (degree) ( $\tan\theta_0=Kh=0.08$ )

Coefficient of active earth pressure :  $Kea=0.293$

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pae1	-	2.79	14.31	39.98	-8.86	2.80	-24.81
Total	-	2.79		39.98	-8.86		-24.81

#### Water Pressure

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pw1	-	-	-	-	-115.52	5.07	-585.30
Total	-	-	-	-	-115.52		-585.30

#### Hydrodynamic Force (due to Earthquake)

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pd	-	-	-	-	-10.78	6.08	-65.55
Total	-	-	-	-	-10.78		-65.55

**Uplift**

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
U	-	-36.25	9.54	-345.80	-	-	-
Total		-36.25		-345.80	-		-

**(ii) Stability Analysis (Surcharge Water Surface)**

Seismic condition (with Earthquake), Kh=0.08(50%)

Total Load	V(tf)	H(tf)	Mx(tf-m)	My(tf-m)
Dead Load	328.5	-26.3	2,988.0	-157.9
Earth Pressure	2.8	-8.9	40.0	-24.8
Water Pressure	0.0	-115.5	0.0	-585.3
Hydrodynamic	0.0	-10.8	0.0	-65.6
Uplift	-36.2	0.0	-345.8	0.0
Total	295.0	-161.4	2,682.2	-833.6

Safety against overturning

$$d = 6.266 \text{ m}$$

$$e = B/2 - d = 0.889 \text{ m} < 2.385 \text{ m} = b/6 \quad \text{OK}$$

Safety against shear

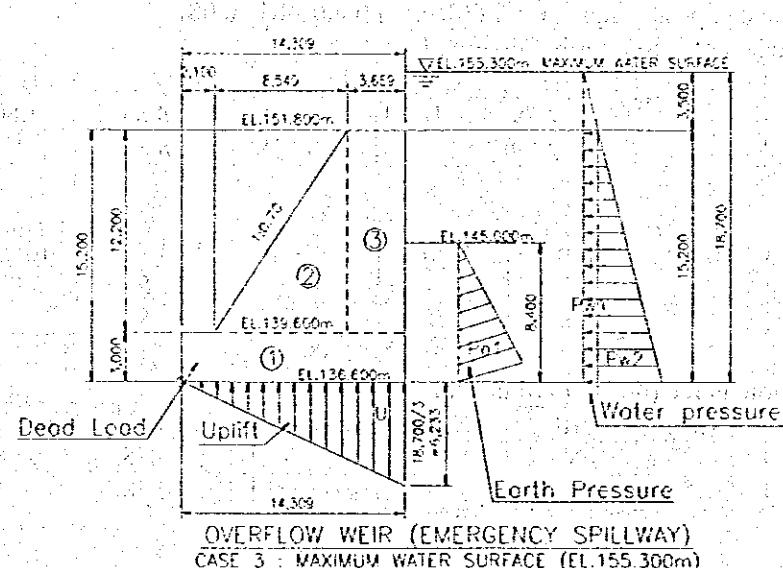
$$SF = (Vf + \tau_0 l)/H = 5.450 > 4 \quad \text{OK}$$

**(d) Case 3 : Emergency Spillway, Maximum Water Surface : EL.155.300m**

Horizontal seismic coefficient : Kh=0.0 (0%)

**(i) Loading Calculation**

Structural model and load combinations are shown in the following figure.



Each load is calculated hereinafter.

**Dead Load**

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
1(concrete)	42.93	100.88	7.15	721.73	0.00	1.50	0.00
2(concrete)	52.09	122.42	7.79	954.07	0.00	7.07	0.00
3(concrete)	44.76	105.19	12.47	1,312.20	0.00	9.10	0.00
Total	139.78	328.49		2,988.00	0.00		0.00

**Earth Pressure without Earthquake**

Coefficient of active earth pressure :  $K_a=0.244$

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
P <sub>a1</sub>	-	3.07	14.31	43.98	-7.13	2.80	-19.95
Total	-	3.07		43.98	-7.13		-19.95

**Water Pressure**

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
P <sub>w1</sub>	-	-	-	-	-53.20	7.60	-404.32
P <sub>w2</sub>	-	-	-	-	-115.52	5.07	-585.30
Total	-	-	-	-	-168.72	-	-989.62

**Uplift**

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
U	-	-44.60	9.54	-425.42	-	-	-
Total	-	-44.60		-425.42	-		-

**(ii) Stability Analysis (Maximum Water Surface)**

**Normal condition (without Earthquake)**

Total Load	V(tf)	H(tf)	Mx(tf-m)	My(tf-m)
Dead Load	328.5	0.0	2,988.0	0.0
Earth Pressure	3.1	-7.1	44.0	-20.0
Water Pressure	0.0	-168.7	0.0	-989.6
Uplift	-44.6	0.0	-425.4	0.0
Total	287.0	-175.8	2,606.6	-1,009.6

**Safety against overturning**

$$d = 5.565 \text{ m}$$

$$e = B/2 - d = 1.589 \text{ m} < 2.385 \text{ m} = b/6 \quad \text{OK}$$

**Safety against shear**

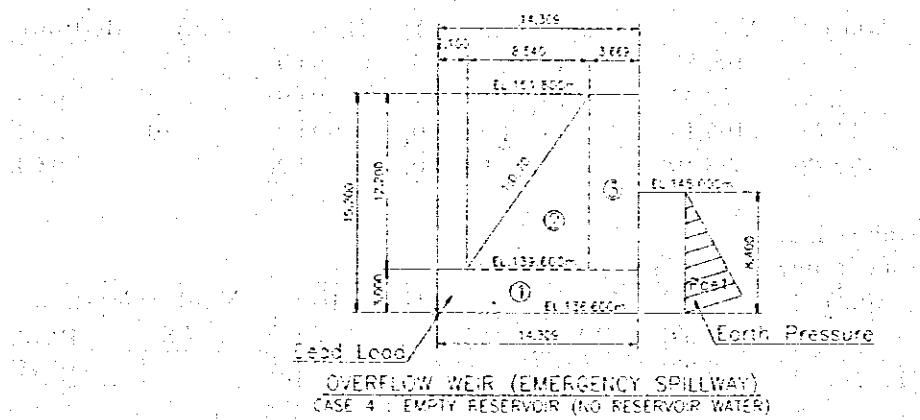
$$SF = (Vf + \tau_0 l)/H = 4.967 > 4 \quad \text{OK}$$

**(e) Case 4 : Emergency Spillway, Empty Reservoir (No Reservoir Water)**

Horizontal seismic coefficient :  $K_h=0.08$  (50%)

**(i) Loading Calculation**

Structural model and load combinations are shown in the following figure.



Each load is calculated hereinafter.

#### Dead Load

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
1(concrete)	42.93	100.88	7.15	721.73	-8.07	1.50	-12.11
2(concrete)	52.09	122.42	7.79	954.07	-9.79	7.07	-69.21
3(concrete)	44.76	105.19	12.47	1,312.20	-8.42	9.10	-76.58
Total	139.78	328.49		2,988.00	-26.28		-157.89

#### Earth Pressure with Earthquake

Seismic composite angle :  $\theta_0 = 4.6(\text{degree})$  ( $\tan\theta_0 = Kh = 0.08$ )

Coefficient of active earth pressure :  $Kea = 0.293$

	A(m <sup>2</sup> )	V(tf)	X(m)	Mx(tf-m)	H(tf)	Y(m)	My(tf-m)
Pae1		5.90	14.31	84.41	-18.71	2.80	-52.38
Total		5.90		84.41	-18.71		-52.38

#### (ii) Stability Analysis (Empty Reservoir)

##### Seismic condition (with Earthquake), Kh=0.08(50%)

Total Load	V(tf)	H(tf)	Mx(tf-m)	My(tf-m)
Dead Load	328.5	-26.3	2,988.0	-157.9
Earth Pressure	5.9	-18.7	84.4	-52.4
Water Pressure	-	-	-	-
Hydrodynamic	-	-	-	-
Uplift	-	-	-	-
Total	334.4	-45.0	3,072.4	-210.3

##### Safety against overturning

$$d = 8.559 \text{ m}$$

$$e = B/2 - d = -1.405 \text{ m} < 2.385 \text{ m} = b/6 \quad \text{OK}$$

##### Safety against shear

$$SF = (Vf + \tau_0 l)/H = 20.259 > 4 \quad \text{OK}$$