2.1 Asin Pumping Station

2.1.5 Structural Calculation of Pumping Station

CONTENTS

1. General Layout

The dimension of pump house is determined by layout of machine. The general layout is shown in Fig.1.

(1) Up/down stream direction

L1: space for stop log

L2: space for inspection road for stop log

L3: space for screen belt conveyor (in future)

L4: space for inspection road for screw and gates

L5: space for screw

L6: space for gear and engine

L7: space for pump control building

(2) Design water level

WL1: design high water level Semarang River Side

WL2: design high water level behind the screen

WL3: design low water level behind the screen

WL4: design high water in the pump pond

WL5: design low water level in the pump pond

(3) Design structure elevation

EL1: pumping station ground level

EL2: pump pond bottom elevation

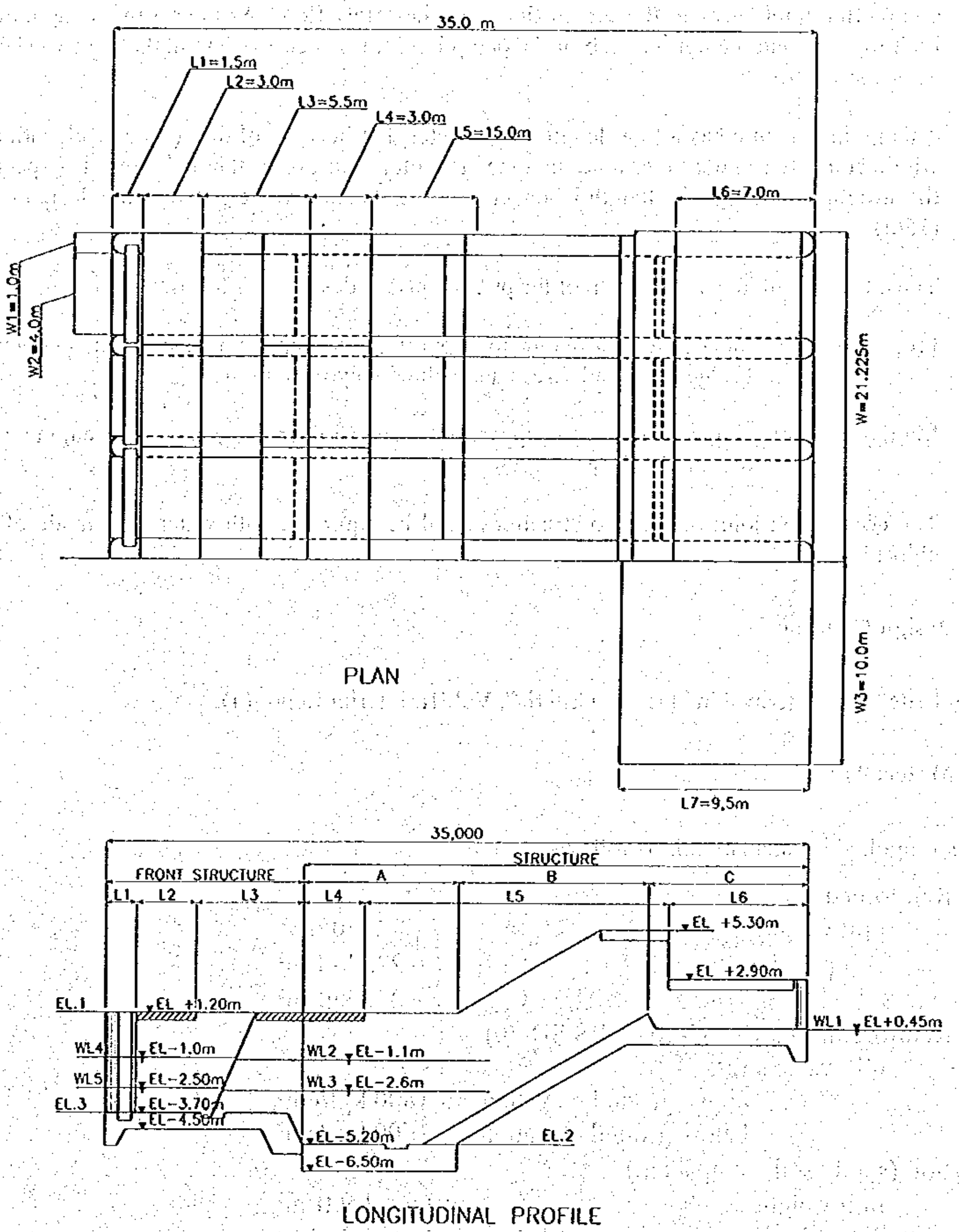
EL3: screen bottom elevation

(4) Right/left bank direction

W1: space for inspection road

W2: space for screw/engine system

Figure 1 General Layout



(5) Structure configuration

The total length of the pump house including the intake basin is 35 m and it is too long to construct in one piece of concrete structure, considering the development of cracks caused by contraction of concrete.

Looking at the location of machines and the force distribution, it is reasonable to make a contraction joint between the screen floor and the screw floor. As the screw is supported by both top slab and the bottom slab of the pump house, it is necessary to make the two slabs act as one structure.

This main structure has a total length of 25 meter, but because of difference of elevation, the whole concrete can not be cast at one time. Therefore, no excess thermal stress is expected in the structure, although the length is longer than the standard value stated in the design criteria (15m).

Thus, the structural configuration of the pump house is designed as follows;

Front Structure: independent structure to support the weight of intake basin, maintenance bridge No.2 and screen and belt conveyor (in future).

Main Structure: single structure to support the weight of screw, gear system engine and all the building load.

The contraction joint of the two structures shall be equipped with water stop made of vinyl chloride

2. Design Criteria

Design Criteria is described in "Design Criteria", Vol.III, Interim Report(4).

2.1 Materials

Materials applied in calculation is as follows;

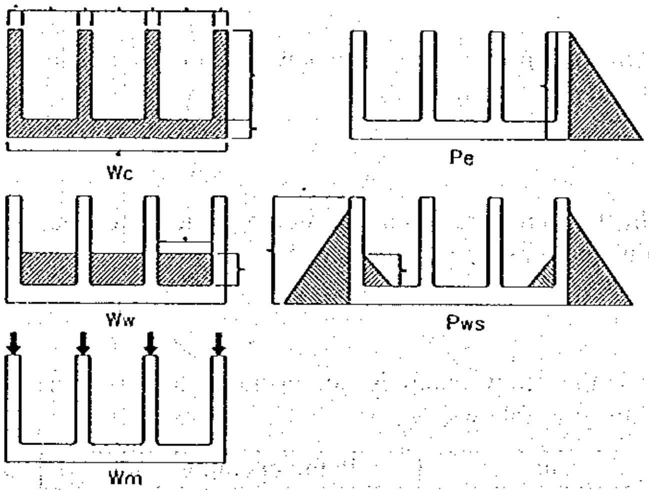
- Reinforced Concrete
  - unit weight: 2.50 m^3/t
  - compressive strength: $C_1 = \sigma_{28} = 225$ kgf/m^2
    $C_2 = \sigma_{28} = 225$ kgf/m^2
- Reinforcing Bar (SII U-30 or JIS SD-30)
  - allowable stress
    - above ground elevation : 1800 kgf/cm^2
    - below ground elevation : 1600 kgf/cm^2
- Soil (sandy soil, compacted)
  - unit weight: wet $\gamma = 1.9$ tf/m^3
    submerged $\gamma = 0.9$ tf/m^3
  - internal friction angle: $\phi = 25.6°$ (N=7.5)

2.2 Loads

Loads to be considered are listed below.

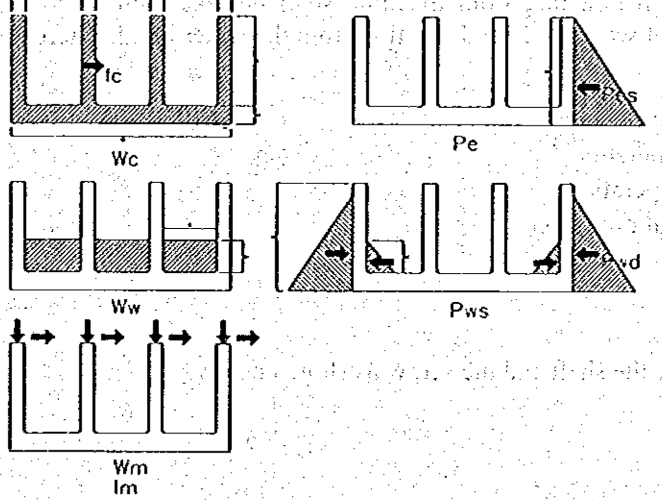
Normal condition

Wc: weight of concrete slab including inspection path no.1 and no.2
Ww: weight of water
Wm: weight of machine and other structures
Pe: earth pressure
Pws: hydro-static pressure



Seismic condition

Wc: weight of concrete slab including inspection path no.1 and no.2
Ww: weight of water
Wm: weight of machine and other structures
Ic, Im: seismic inertia of above all items except water
Pes: seismic earth pressure
Pws: hydro-static pressure
Pwd: hydro-dynamic pressure



2.3 Cases of Analysis

(1) Seismic status

Structural analysis is to be made in both normal condition (without earthquake) and seismic condition (with earthquake).

(2) Operation status

Since an operated screw generates dynamic force, the analysis is to be made in both cases of with pump operation and without pump operation.

(3) Stoplog status

When stop log is closed, hydrostatic pressure acts on the stoplog. Therefore, both stoplog-open and stoplog-closed status should be considered.

(4) Combination of status

When the stop log is closed, the screw pump is not operated for maintenance purpose. Therefore, combination of status is as follows;

Case	Seismic status	Pump operation status
1	Normal	Not operated
2	Normal	Operated
3	Earthquake	Operated
4	Earthquake	Not operated

3. Stability Analysis

3.1 Weight of Screw

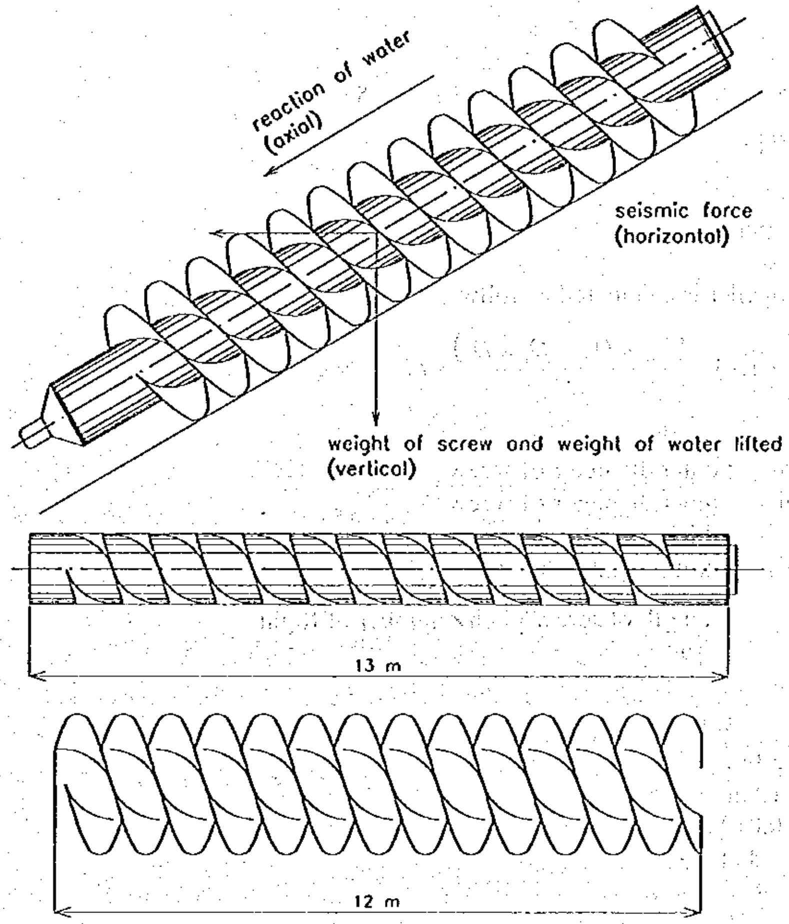
3.1.1 General

In the design of civil structure, all forces acting from machine shall be taken into account. They include weight of screw itself, weight of water lifted and reaction from the water lifted. There are three calculation cases as follows;

- (case 1) normal condition without operation
- (case 2) normal condition with operation
- (case 3) seismic condition with operation
- (case 4) seismic condition without operation

3.1.2 Weight of screw

Calculation of screw weight is done for the shaft and the screw as shown below.



(1) Weight of the shaft

Weight of the shaft is calculated as follows;

$$W = 1 \times 3.14 \times \frac{(D_o + D_i)}{2} \times t \times W_S$$

where l ; length of shaft

Do ; outer diameter

Di ; inner diameter

t ; thickness of plate

ws ; unit weight of steel

here for Asin Pumping station

l = 13 m

Do = 1.500 m

Di = 1.490 m

t = 0.012 m

Ws = 7.85 t/m³

therefore

$$W = 1 \times 3.14 \times \frac{(1.500 + 1.488)}{2} \times 0.0012 \times 7.85$$

$$= 5.74 \text{ t}$$

(2) Weight of propeller

Weight of propeller is calculated as follws;

$$W = n \times 3.14 \times \frac{(D_o \times D_o - D_i \times D_i)}{4} \times t \times W_S \times \sqrt{2}$$

where
- n : number of screw
- Do : outer diameter of screw
- Di : inner diameter of screw
- t : thickness of plate
- Ws : unit weight of steel

here n = length of screw/pitch × number of flight

$$= \frac{12}{3} \times 3$$

$$= 12$$

Do = 3.0m
Di = 1.5m
t = 0.010m
Ws = 7.85 t/m3

therefore

$$W = 12 \times 3.14 \times \frac{(3 \times 3 - 15 \times 1.5)}{4} \times 4 \times 0.010 \times 7.85 \times \sqrt{2}$$

$$= 4.99 \times \sqrt{2}$$

$$= 7.06$$

(3) Total weight of screw

Total weight of screw = weight of shaft + weight of propeller
= 5.74+7.06
= 12.80

By adding 10% for other parts
total weight of screw system = 12.80×1.1=14.1 t
The direction of the force is vertical and it is divided into axial and radial components.
Axial component = 14.1 × SIN 30° = 7.05 t
Radial component = 14.1 × COS 30° = 12.21 t

3.1.3 Weight of water lifted

The weight of water lifted is calculated as follows;

$$W = 12 \times 3.14 \times \frac{(3 \times 3 - 15 \times 1.5)}{4} \times 4 \times 0.010 \times 7.85 \times \sqrt{2}$$

$$= 4.99 \times \sqrt{2}$$

$$= 7.06$$

where

W : weight of water lifted (t)

l : length of shaft (m)

Dp : diameter of propeller (m)

Ds : diameter of shaft (m)

Ww : unit weight of water (t/m^3)

$$W = 12 \times 3.14 \times \frac{1}{2} \times \frac{(1.5 \times 1.5 - 0.75 \times 0.75)}{4} \times W_w$$

$= 7.948$ t

The weight is divided into axial component and radial component

Axial component = 7.948 × SIN30° =3.97t (supported by the propeller)

Radial component = 7.948 × COS30° =6.88t (supported by the concrete bed)

3.1.4 Reaction of water lifted

The reaction of water lifter is calculated as follows;

$Fr = Q \times v \times W_w$

where
Fr : reaction of water lifted (t)
Q : discharge (m^3/s)
v : velocity of water (m/s)
W_w : unit mass of water (t/m^3)

here Q=3 m^3/s
v = Q/A
A = section area of flow
= $1/2 \times 3.14 \times (1.5^2 - 0.75^2)$
= 2.649 m^2
= 3/2.649=1.13m/s
Ww = 1.0 t/m^3

therefore
Fr = 3×1.13×1
= 3.39 t

The direction of the force is axial.

3.1.5 Combination of force

(case-1) normal condition without operation

weight of screw	:	axial component	= 7.05 ~ 8 t
		radial component	= 12.21 ~ 13 t

(case-2) normal condition with operation

weight of screw	:	axial component	= 7.05 t
		radial component	= 12.21 t
weight of water lifted		axial component	= 3.97t

radial component = 6.88t

reaction from water lifted
axial component = 0
radial component = 3.39 t

combined force
axial component = 7.05+3.97+0= 11.02 ~ 12t
radial component = 12.21+6.88+3.39=22.48 ~ 23t

(case-3) seismic condition with operation

weight of screw
axial component = 7.05 t
radial component = 12.21 t

weight of water lifted
axial component = 3.97t
radial component = 6.88t

seismic force acting on the screw
seismic force (horizontal)= 14.08(weight)×0.11(seismic coefficient) =1.55 t
axial component = 1.55×COS30° = 1.34 t
radial component = 1.55 × SIN30°=0.78 t

seismic force acting on water
seismic force (horizontal) = 7.948(weight)×0.11(seismic coefficient)=0.87t
axial component = 0.87 × COS30° = 0.75 t
radial component = 0.87 × SIN30° = 0.44 t

reaction from water lifted
axial component = 0
radial component = 3.39 t

combined force
axial component = 7.05+3.97+1.34+0.75 = 13.11~14 t
radial component =12.21+6.88+0.78+0.44+3.39=23.17~24t

(case-4) seismic condition without operation

weight of screw
axial component = 7.05 t
radial component = 12.21 t

seismic force acting on the screw
axial component = 1.34 t
radial component = 0.78 t

combined force
axial component = 7.05 + 1.34 = 8.39 t ~ 9 t
radial component = 12.21 + 0.78 = 12.99 ~ 13 t

The conclusion is

case(1) normal without operation	axial force	=	8 t
	radial force	=	13 t
case(2) normal with operation	axial force	=	12 t
	radial force	=	23 t
case(3) seismic with operation	axial force	=	14 t
	radial force	=	24 t
case(4) seismic without operation	axial force	=	9 t
	radial force	=	13 t

All cases and acting points are shown in Table – 1.

In structural analysis of concrete slab, the axial forces shall be applied on both ends of the screw shaft as the full force, considering the uncertainty of force distribution. However, the radial forces shall be applied on both ends of the screw as the half of the force as it is certainly distributed evenly .

3.2 Weight of Machine and Other Structures

The location of machine and other structure is shown in Fig. 2.

The weight of machine and other structures are shown in Table - 2.

The machines to be considered are screw, gear box, engine and screen. For gear box, engine and screen, estimation by factories are adopted. For screen system, future installation is taken into account.

Stop log	3 t
Imbeded material	3 t
Inspection bridge	12 t
Screen	8 t
Belt conveyor	50 t
Secondary concrete	91 t
Gear box	2 t
Engine	17 t
Bridge	47 t

The seismic force acting on each machine can be calculated by multiplying seismic coefficient Kh = 0.11 to the weight of machine.

3.3 Weight of Pump Control Building

The weight of the Pump Control Building (architectural design) is adssumed as 2.5 t/m^2.

Fig. 2 Location of Machines and Other Structures

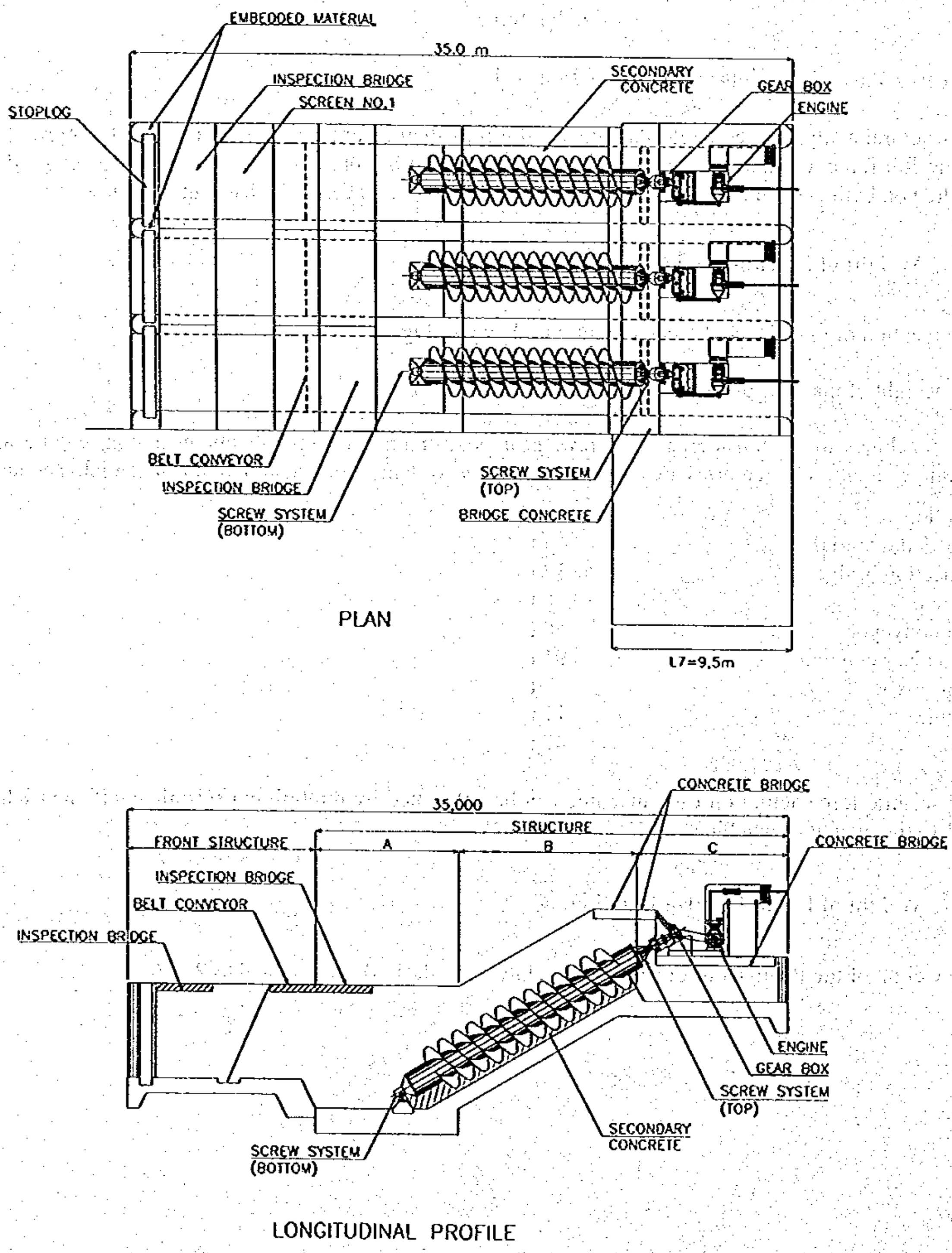


Table - 1 Force Acting from Screw

Y_0 = -6.5 m

(normal without operation condition)

	axial	radial	Fx	Fy	Fz	acting point(Fx)	x		y		z	direction	acting point(Fy) x	Mx	y	My	z	Mz	direction
main structure-A no-1	8	6.5	-10.18	-9.63	0	13.38	-136.199	1.80	-18.32	3.00	-30.533	-x	13.38	-128.844	5.73	-55.184	3.00	-28.8846	-y
main structure-A no-2	8	6.5	-10.18	-9.63	0	13.38	-136.199	1.80	-18.32	8.00	-81.422	-x	13.38	-128.844	5.73	-55.184	8.00	-77.0255	-y
main structure-A no-3	8	6.5	-10.18	-9.63	0	13.38	-136.199	1.80	-18.32	13.00	-132.31	-x	13.38	-128.844	5.73	-55.184	13.00	-125.1664	-y
total			-30.53	-28.88	0	13.38	-408.597	1.80	-54.96	8.00	-244.27	-x	13.38	-386.533	5.73	-165.552	8.00	-231.0765	-y
main structure-C no-1	8	6.5	-10.18	-9.63	0	27.00	-274.800	9.66	-98.3478	3.00	-30.533	-x	27.00	-259.961	5.88	-56.628	3.00	-28.8846	-y
main structure-C no-2	8	6.5	-10.18	-9.63	0	27.00	-274.800	9.66	-98.3478	8.00	-81.422	-x	27.00	-259.961	5.88	-56.628	8.00	-77.0255	-y
main structure-C no-3	8	6.5	-10.18	-9.63	0	27.00	-274.800	9.66	-98.3478	13.00	-132.31	-x	27.00	-259.961	5.88	-56.628	13.00	-125.1664	-y
total			-30.53	-28.88	0	27.00	-824.399	9.66	-295.0434	8.00	-244.27	-x	27.00	-779.883	5.88	-169.885	8.00	-231.0765	-y

(normal with operation condition)

	axial	radial	Fx	Fy	Fz														
main structure-A no-1	12	11.5	-16.14	-15.96	0	13.38	-216.002	1.80	-29.0543	3.00	-48.424	-x	13.38	-213.551	1.80	-28.725	3.00	-47.8742	-y
main structure-A no-2	12	11.5	-16.14	-15.96	0	13.38	-216.002	1.80	-29.0543	8.00	-129.13	-x	13.38	-213.551	1.80	-28.725	8.00	-127.6645	-y
main structure-A no-3	12	11.5	-16.14	-15.96	0	13.38	-216.002	1.80	-29.0543	13.00	-209.84		13.38	-213.551	1.80	-28.725	13.00	-207.4548	-y
total			-48.42	-47.87	0	13.38	-648.007	1.80	-87.1628	8.00	-387.39		13.38	-640.652	1.80	-86.174	8.00	-382.9934	-y
main structure-C no-1	12	11.5	-16.14	-15.96	0	27.00	-435.814	9.66	-155.973	3.00	-48.424	-x	27.00	-430.868	9.66	-154.203	3.00	-47.8742	-y
main structure-C no-2	12	11.5	-16.14	-15.96	0	27.00	-435.814	9.66	-155.973	8.00	-129.13	-x	27.00	-430.868	9.66	-154.203	8.00	-127.6645	-y
main structure-C no-3	12	11.5	-16.14	-15.96	0	27.00	-435.814	9.66	-155.973	13.00	-209.84	-x	27.00	-430.868	9.66	-154.203	13.00	-207.4548	-y
total			-48.42	-47.87	0	27.00	-1307.442	9.66	-467.919	8.00	-387.39	-x	27.00	-1292.603	9.66	-462.608	8.00	-382.9934	-y

(earthquake with operation condition)

	axial	radial	Fx	Fy	Fz														
main structure-A no-1	14	12	-18.12	-17.39	0	13.38	-242.528	1.80	-32.6222	3.00	-54.37	-x	13.38	-232.722	1.80	-31.303	3.00	-52.1720	-y
main structure-A no-2	14	12	-18.12	-17.39	0	13.38	-242.528	1.80	-32.6222	8.00	-144.99	-x	13.38	-232.722	1.80	-31.303	8.00	-139.1254	-y
main structure-A no-3	14	12	-18.12	-17.39	0	13.38	-242.528	1.80	-32.6222	13.00	-235.6	-x	13.38	-232.722	1.80	-31.303	13.00	-226.0788	-y
total			-54.37	-52.17	0	13.38	-727.584	1.80	-97.8667	8.00	-434.96	-x	13.38	-698.166	1.80	-93.910	8.00	-417.3763	-y
main structure-C no-1	14	12	-18.12	-17.39	0	27.00	-489.333	9.66	-175.127	3.00	-54.37	-x	27.00	-469.548	9.66	-168.046	3.00	-52.1720	-y
main structure-C no-2	14	12	-18.12	-17.39	0	27.00	-489.333	9.66	-175.127	8.00	-144.99	-x	27.00	-469.548	9.66	-168.046	8.00	-139.1254	-y
main structure-C no-3	14	12	-18.12	-17.39	0	27.00	-489.333	9.66	-175.127	13.00	-235.6	-x	27.00	-469.548	9.66	-168.046	13.00	-226.0788	-y
tota			-54.37	-52.17	0	27.00	-1468.000	9.66	-525.381	8.00	-434.96	-x	27.00	-1408.645	9.66	-504.138	8.00	-417.3763	-y

(earthquake without operation condition)

	axial	radial	Fx	Fy	Fz	acting point(Fx)	x		y		z	direction	acting point(Fy) x	Mx	y	My	z	Mz	direction	acting point(Fz) x	Mx	y	My	z	Mz	direction
main structure-A no-1	9	6.5	-11.04	-10.13	1.114075	13.38	-147.790	1.80	-19.88	3.00	-33.132	-x	13.38	-135.532	1.80	-18.230	3.00	-30.3839	-y	13.38	14.90856	1.80	2.005336	3.00	3.342226	z
main structure-A no-2	9	6.5	-11.04	-10.13	1.114075	13.38	-147.790	1.80	-19.88	8.00	-88.351	-x	13.38	-135.532	1.80	-18.230	8.00	-81.0237	-y	13.38	14.90856	1.80	2.005336	8.00	8.912604	z
main structure-A no-3	9	6.5	-11.04	-10.13	1.114075	13.38	-147.790	1.80	-19.88	13.00	-143.57	-x	13.38	-135.532	1.80	-18.230	13.00	-131.6635	-y	13.38	14.90856	1.80	2.005336	13.00	14.482981	z
total			-33.13	-30.38	3.342226	13.38	-443.370	1.80	-59.64	8.00	-265.05	-x	13.38	-406.597	1.80	-54.691	8.00	-243.0710	-y	13.38	44.72567	1.80	6.016007	8.00	26.737811	z
main structure-C no-1	9	6.5	-11.04	-10.13	1.114075	27.00	-298.186	9.66	-106.7175	3.00	-33.132	-x	27.00	-273.455	9.66	-97.866	3.00	-30.3839	-y	20.73	23.08977	5.81	6.47501	3.00	3.342226	z
main structure-C no-2	9	6.5	-11.04	-10.13	1.114075	27.00	-298.186	9.66	-106.7175	8.00	-88.351	-x	27.00	-273.455	9.66	-97.866	8.00	-81.0237	-y	20.73	23.08977	5.81	6.47501	8.00	8.912604	z
main structure-C no-3	9	6.5	-11.04	-10.13	1.114075	27.00	-298.186	9.66	-106.7175	8.00	-88.351	-x	27.00	-273.455	9.66	-97.866	13.00	-131.6635	-y	20.73	23.08977	5.81	6.47501	13.00	14.48298	z
total			-33.13	-30.38	3.342226	27.00	-894.558	9.66	-320.1524	6.33	-209.83	-x	27.00	-820.365	9.66	-293.599	8.00	-243.0710	-y	20.73	69.26931	5.81	19.425	8.00	26.73781	z

Table - 2 Weight of Machine and Other Structures

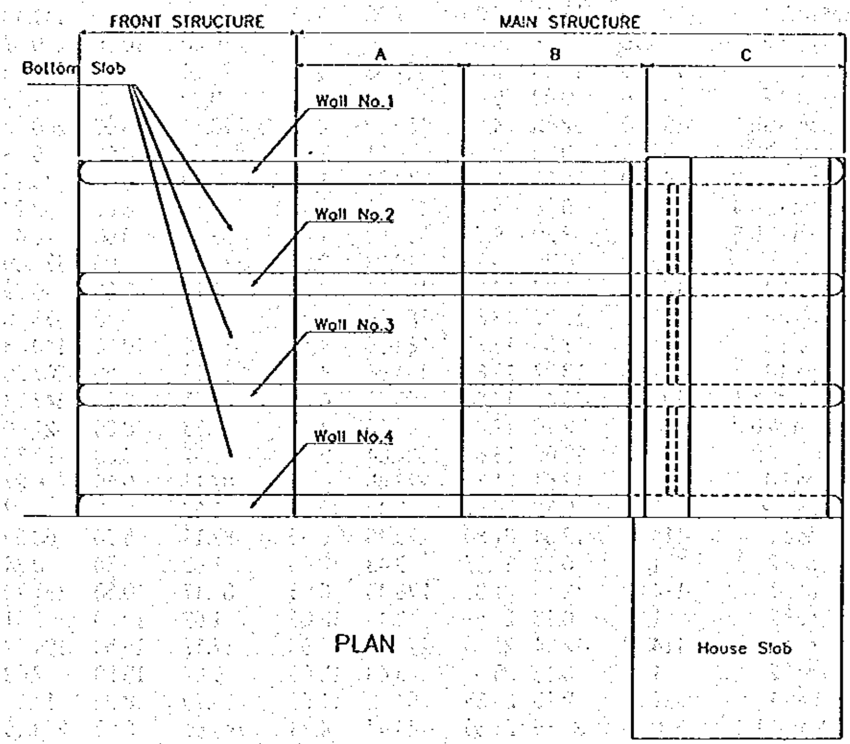
Y_0= -6.5

name	weight	x	Mx	y	My	z	Mz
				acting point			
front structure							
stop log no.1	-3.00	1.15	-3.45	4.20	-12.60	3.00	-9
stop log no.2	-3.00	1.15	-3.45	4.20	-12.60	8.00	-24
stop log no.3	-3.00	1.15	-3.45	4.20	-12.60	13.00	-39
imbeded material no.1	-3.00	1.15	-3.45	4.20	-12.60	3.00	-9
imbeded material no.2	-3.00	1.15	-3.45	4.20	-12.60	8.00	-24
imbeded material no.3	-3.00	1.15	-3.45	4.20	-12.60	13.00	-39
inspection bridge-No.1-1	-12.00	3.00	-36.00	7.50	-90.00	3.00	-36
inspection bridge-No.1-2	-12.00	3.00	-36.00	7.50	-90.00	8.00	-96
inspection bridge-No.1-3	-12.00	3.00	-36.00	7.50	-90.00	13.00	-156
screen no.1	-8.00	6.50	-52.00	2.80	-22.40	3.00	-24
screen no.2	-8.00	6.50	-52.00	2.80	-22.40	8.00	-64
screen no.3	-8.00	6.50	-52.00	2.80	-22.40	13.00	-104
beltconbeyor	-56.00	9.25	-518.00	7.70	-431.20	8.00	-448
total	-134.00	5.99	-802.70	6.30	-844.00	8.00	-1072
main structure A							
inspection bridge-No.2-1	-12.00	11.50	-138.00	7.50	-90.00	3.00	-36
inspection bridge-No.2-2	-12.00	11.50	-138.00	7.50	-90.00	8.00	-96
inspection bridge-No.2-3	-12.00	11.50	-138.00	7.50	-90.00	13.00	-156
screw system no.1(bottom)	-7.05	13.38	-94.34	1.80	-12.69	3.00	-21.15
screw system no.2(bottom)	-7.05	13.38	-94.34	1.80	-12.69	8.00	-56.4
screw system no.3(bottom)	-7.05	13.38	-94.34	1.80	-12.69	13.00	-91.65
total	-57.15	12.20	-697.03	5.39	-308.07	8.00	-457.2
main structure B				1.64			
secondary concrete no.1	-90.95	16.81	-1,528.48	6.21	-564.86	3.00	-272.8369
secondary concrete no.2	-90.95	16.81	-1,528.48	6.21	-564.86	8.00	-727.5651
secondary concrete no.3	-90.95	16.81	-1,528.48	6.21	-564.86	13.00	-1182.293
bridge-Cno.1	-6.50	25.35	-164.79	11.55	-75.08	3.00	-19.5
bridge-Cno.2	-6.50	25.35	-164.79	11.55	-75.08	8.00	-52
bridge-Cno.3	-6.50	25.35	-164.79	11.55	-75.08	13.00	-84.5
total	-292.34	17.38	-5079.79	6.57	-1919.82	8.00	-2338.70
main structure C							
screw system no1.(top)	-7.05	27.00	-190.35	9.66	-68.12	3.00	-21.15
screw system no.2(top)	-7.05	27.00	-190.35	9.66	-68.12	8.00	-56.4
screw system no3.(top)	-7.05	27.00	-190.35	9.66	-68.12	13.00	-91.65
gear box no.1	-2	29.10	-58.20	10.44	-20.87	3.00	-6
gear box no.2	-2	29.10	-58.20	10.44	-20.87	8.00	-16
gear box no.3	-2	29.10	-58.20	10.44	-20.87	13.00	-26
engine no.1	-13	31.00	-403.00	10.44	-135.68	3.00	-39
engine no.2	-13	31.00	-403.00	10.44	-135.68	8.00	-104
engine no.3	-13	31.00	-403.00	10.44	-135.68	13.00	-169
bridge-Cno.1-1	-10.00	27.50	-275.00	11.55	-115.50	3.00	-30
bridge-Cno.2-1	-10.00	27.50	-275.00	11.55	-115.50	8.00	-80
bridge-Cno.3-1	-10.00	27.50	-275.00	11.55	-115.50	13.00	-130
bridge-Cno.2-2	-31.63	31.50	-996.19	9.15	-289.37	3.00	-94.875
bridge-Cno.2-2	-31.63	31.50	-996.19	9.15	-289.37	8.00	-253
bridge-Cno.3-2	-31.63	31.50	-996.19	9.15	-289.37	13.00	-411.125
total	-191.03	30.20	-5768.21	9.89	-1888.64	8.00	-1528.20

3.4 Weight of Civil Structure

Weight of civil structure is calculated by dividing it into small parts as show in the figure below.

Table 3 shows the forces acting from civil structure.



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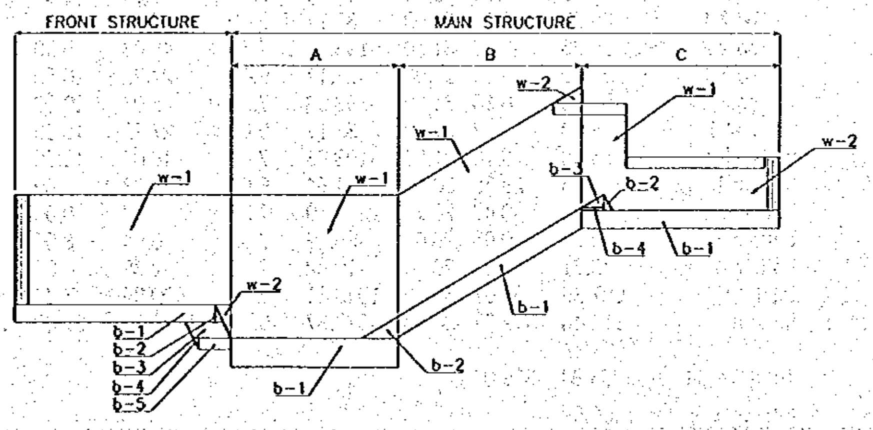

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Table - 3 Force Acting from Civil Structure

weight of concrete

Y_0= -6.50

slab name	name	weight	inertia	acting point x	Mx	y	My	z	Mz	direction
front structure	wall no.1-1	-122.50	-13.48	5.00	-67.38	5.25	-70.74	0.50	-6.74	-z
	wall no.1-2	-0.76	-0.08	9.63	-0.80	2.43	-0.20	0.50	-0.04	-z
	wall no.2-1	-122.50	-13.48	5.00	-67.38	5.25	-70.74	5.50	-74.11	-z
	wall no.2-2	-0.76	-0.08	9.63	-0.80	2.43	-0.20	5.50	-0.46	-z
	wall no.3-1	-122.50	-13.48	5.00	-67.38	5.25	-70.74	10.50	-141.49	-z
	wall no.3-2	-0.76	-0.08	9.63	-0.80	2.43	-0.20	10.50	-0.87	-z
	wall no.4-1	-122.50	-13.48	5.00	-67.38	5.25	-70.74	15.50	-208.86	-z
	wall no.4-2	-0.76	-0.08	9.63	-0.80	2.43	-0.20	15.50	-1.29	-z
	bottom slab 1	-296.00	-32.56	4.63	-150.59	2.40	-78.14	8.00	-260.48	-z
	bottom slab 2	-6.40	-0.70	9.38	-6.61	2.27	-1.60	8.00	-5.63	-z
	bottom slab 3	-49.00	-5.39	8.95	-48.24	1.65	-8.89	8.00	-43.12	-z
	bottom slab 4	-2.50	-0.28	8.42	-2.31	1.13	-0.31	8.00	-2.20	-z
	bottom slab 5	-30.00	-3.30	9.25	-30.53	1.05	-3.47	8.00	-26.40	-z
	total	-876.93	-96.46	5.30	-510.98	3.90	-376.19	8.00	-771.69	-z
main structure-A	wall no.1-1	-121.58	-13.37	13.80	-184.56	4.50	-60.18	0.50	-6.69	-z
	wall no.2-1	-121.58	-13.37	13.80	-184.56	4.50	-60.18	5.50	-73.56	-z
	wall no.3-1	-121.58	-13.37	13.80	-184.56	4.50	-60.18	10.50	-140.43	-z
	wall no.4-1	-121.58	-13.37	13.80	-184.56	4.50	-60.18	15.50	-207.30	-z
	bottom slab-1	-395.15	-43.47	13.80	-599.81	0.65	-28.25	8.00	-347.73	-z
	bottom slab-2	-24.54	-2.70	17.04	-46.00	1.62	-4.38	8.00	-21.60	-z
	total	-906.03	-99.66	13.89	-1384.04	2.74	-273.37	8.00	-797.30	-z
main structure -B	wall no.1-1	-114.03	-12.54	21.80	-273.45	6.95	-87.17	0.50	-6.27	-z
	wall no.1-2	1.22	0.13	25.57	3.43	12.05	1.62	0.50	0.07	-z
	wall no2-1	-114.03	-12.54	21.80	-273.45	6.95	-87.17	5.50	-68.99	-z
	wall no2-2	1.22	0.13	25.57	3.43	12.05	1.62	5.50	0.74	-z
	wall no3-1	-114.03	-12.54	21.80	-273.45	6.95	-87.17	10.50	-131.70	-z
	wall no3-2	1.22	0.13	25.57	3.43	12.05	1.62	10.50	1.41	-z
	wall no4-1	-114.03	-12.54	21.80	-273.45	6.95	-87.17	15.50	-194.42	-z
	wall no4-2	1.22	0.13	25.57	3.43	12.05	1.62	15.50	2.08	-z
	top slab-1	-19.52	-2.15	25.35	-54.42	11.55	-24.79	8.00	-17.17	-z
	bottom slab-1	-310.45	-34.15	21.80	-744.47	4.24	-144.66	8.00	-273.19	-z
	total	-781.19	-85.93	21.87	-1878.94	5.95	-511.67	8.00	-687.45	-z
main structure-C	wall no.1-1	-34.30	-3.77	27.00	-101.88	9.00	-33.96	0.39	-1.46	-z
	wall no1-2	-68.58	-7.54	31.50	-237.63	7.80	-58.84	0.39	-2.92	-z
	wall no.2-1	-28.00	-3.08	27.00	-83.17	9.00	-27.72	5.50	-16.94	-z
	wall no.2-2	-55.98	-6.16	31.50	-193.98	7.80	-48.03	5.50	-33.87	-z
	wall no.3-1	-28.00	-3.08	27.00	-83.17	9.00	-27.72	10.50	-32.34	-z
	wall no.2-2	-55.98	-6.16	31.50	-193.98	7.80	-48.03	10.50	-64.66	-z
	wall no4-1	-28.00	-3.08	27.00	-83.17	9.00	-27.72	15.50	-47.74	-z
	wall no4-2	-55.98	-6.16	31.50	-193.98	7.80	-48.03	15.50	-95.45	-z
	bottom-1	-215.95	-23.75	30.50	-724.54	6.60	-156.78	7.89	-187.37	-z
	bottom-2	-4.24	-0.47	26.14	-12.19	7.23	-3.37	8.00	-3.73	-z
	bottom-3	-8.62	-0.95	26.67	-25.29	7.32	-6.94	8.00	-7.59	-z
	bottom-4	-3.71	-0.41	26.50	-10.82	7.06	-2.88	8.00	-3.27	-z
	total	-587.36	-64.61	30.09	-1943.81	7.58	-490.04	7.70	-497.34	-z
house structure	bottom	-112.48	-12.37	30.50	-377.37	9.15	-1029.15	21.00	-259.82	-z
	Total Weight	-3263.98	-359.04							
	total volume	1305.59								

3.5 Weight of Water

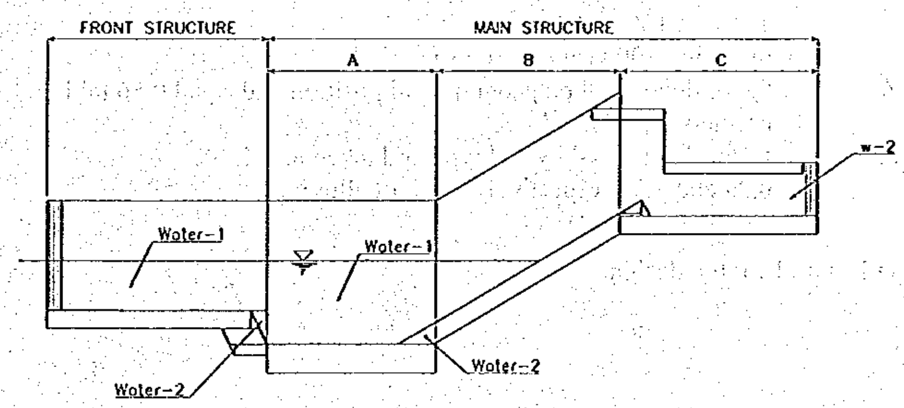
Water weight is calculated as shown in Table – 4.

Table - 4 Weight of Water

water level = -2.60 m

Y_0= -6.1

water body name	name	weight	acting point						direction
			x	Mx	y	My	z	Mz	
front structure	water no1-1	-44.00	5.00	-220.00	2.95	-129.80	3.00	-132.00	-y
	water no1-2	-2.25	9.75	-21.94	1.90	-4.28	3.00	-6.75	-y
	water no2-1	-44.00	5.00	-220.00	2.95	-129.80	8.00	-352.00	-y
	water no2-2	-2.25	9.79	-22.02	1.90	-4.28	8.00	-18.00	-y
	water no3-1	-44.00	5.00	-220.00	2.95	-129.80	13.00	-572.00	-y
	water no3-2	-2.25	9.79	-22.02	1.90	-4.28	13.00	-29.25	-y
	total	-138.75	5.23	-725.99	2.90	-402.23	8.00	-1110.00	-y
									-y
main structure-A	water no1-1	-79.03	13.80	-1090.57	2.25	-177.82	3.00	-237.09	-y
	water no1-2	3.27	17.04	55.76	1.22	4.01	3.00	9.82	-y
	water no2-1	-79.03	13.80	-1090.57	2.25	-177.82	8.00	-632.24	-y
	water no2-2	3.27	17.04	55.76	1.22	4.01	8.00	26.18	-y
	water no3-1	-79.03	13.80	-1090.57	2.25	-177.82	13.00	-1027.38	-y
	water no3-2	3.27	17.04	55.76	1.22	4.01	13.00	42.54	-y
	total	-227.27	13.66	-3104.44	2.29	-521.43	8.00	-1818.17	
main structure-C	wall no.1	-22.40	30.50	-683.22	6.45	-144.48	3.00	-67.20	-y
	wall no.2	-22.40	30.50	-683.22	6.45	-144.48	8.00	-179.20	-y
	wall no.3	-22.40	30.50	-683.22	6.45	-144.48	13.00	-291.20	-y
	total	-67.20	30.50	-2049.67	6.45	-433.44	8.00	-537.60	-y



LONGITUDINAL PROFILE

3.6 Hydrostatic Pressure

Hydrostatic pressure is lateral pressure and uplift. Lateral pressure is calculated in Table - 5 while uplift is calculated in Table - 6.

3.7 Earth Pressure

The earth pressure coefficient is calculated in Table - 7.

The earth pressure is calculated in Table – 8.

3.8 Seismic Forces

3.8.1 Calculation of Seismic Coefficient

According to the Design Criteria of the Project, earthquake load is calculated as follows:

$G = E \times M$

where
- G : earthquake load
- E : horizontal earthquake factor
- M : total dead load

the earthquake factor is calculated using the following equation;

$E = ad/g$

$ad = n(ac \times Z)^m$

where
- ad : design shock acceleration (cm/s²)
- ac : basic shock acceleration (cm/s²)
  where
  ac : 160 cm/s²
  by taking 100 years for return period
- Z : factor depending on geographical position and equal 0.56 taking northern Java Island
- n,m : factor determined by soil type and taken as 0.29 and 1.32 respectively, for soft alluvium

Finally, we get E = 0.11 for the design.

Table - 5 Water Pressure (normal condition) to the Stop Log

water sressure(normal condition) to the stop log

water -1.00

Y_0= -6.5

earth pressure	name	height	width	P	acting point						direction
					x	Mx	y	My	z	Mz	
front slab	wp	3.50	16.00	98.00	1.15	112.70	4.67	457.33	8.00	784.00	x

Table - 6 Uplift

water level(U/S) = -1.00 m water level(D/S)= -0.48 m *

Y_0= -6.1

water body name	name	uplift	acting point						direction
			x	Mx	y	My	z	Mz	
front slab	uplift	594.56	5.00	2,972.80	1.95	1,158.38	8.00	4,756.48	y
main slab-A	uplift	683.30	13.80	9,429.23	0.00	0.00	8.00	5,466.42	y
main slab-B	uplift	264.86	21.80	5,774.14	3.35	887.29	8.00	2,118.90	y
main slab-C	wall no.1	109.49	30.50	3,339.69	5.80	635.07	8.00	875.96	y

uplift pre the water pressure inside of the steel sheet pile

Table - 7 Calculation of Earth Pressure Coefficient (ϕ=25.6°)

normal condition

phai	25.6	conversion(3.14/180)	0.0174444	Kas
delta	8.533			Kp
theta	0	cos(pahi-theta)	0.9019304	
alpha	0	cos(theta)	1	
		cos(theta+delta)	0.9889409	
phai-theta	25.6	sin(pahi+delta)	0.5608706	
theta+delta	8.533	sin(phai-alpha)	0.4318815	
phai+delta	34.13	cos(theta-alpha)	1	
phai-alpha	25.6	cos(phai+theta)	0.9019304	
theta-alpha	0	sin(phai-delta)	0.2933399	
phai+theta	25.6	sin(phai+alpha)	0.4318815	
phai-delta	17.07			
phai+alhpa	25.6			

seismic condition		seismicity(kh)	0.11		
phai	25.6	conversion(3.14/180)	0.0174444	Kea	0.474
delta	0			Kep	2.338
theta	0	cos(pahi-theta0-theta)	0.9437448		
alpha	0	cos(theta0)	0.9940044		
theta0	6.28	cos(theta)	1		
		cos(theta+theta0+delta)	0.9940044		
phai-theta0-theta	19.32	sin(pahi+delta)	0.4318815		
theta+theta0+delta	6.28	sin(phai-alpha-theta0)	0.3306746		
phai+delta	25.6	cos(theta-alpha)	1		
phai-alpha-theta0	19.32	cos(phai-theta0+theta)	0.9437448		
theta-alpha	0	cos(theta-theta0+delta)	0.9940044		
phai-theta0+theta	19.32	sin(phai-delta)	0.4318815		
theta-theta0+delta	-6.28	sin(phai+alpha-theta0)	0.3306746		
phai-delta	25.6				
phai+alpha-theta0	19.32				

Table - 8 Force Acting from Earth (normal condition)

ground level= 1.20
g.water level= 0.35

phai= 25.60 (natural soil) over burden = 1.00 t/m²

Y_0= -6.5

earth pressure	name	height	width	wight of soil wet	wight of soil submerged	Ka	P	x	Mx	acting point y	My	z	Mz	direction
front slab	ep-1	5.90	10.00	1.90	0.90	0.37	-77.45	5.00	-387.27	3.72	-288.13	16.00	-1,239.25	-z
main slab-A	ep-1	7.70	7.599	1.90	0.90	0.37	-95.25	13.80	-1,314.42	2.57	-244.48	16.00	-1,524.02	-z
main slab-B	ep-1	3.950	8.403	1.90	0.90	0.37	-17.67	21.80	-385.16	5.98	-105.71	16.00	-282.68	-z
main slab-C	ep-1	1.50	8.998	1.90	0.90	0.37	-6.97	30.50	-212.53	6.70	-46.69	16.00	-111.49	-z

3.9 Total Forces

Total forces which would act on the structure are shown in Table 9 ~ (1/4 ~ 4/4)

For pile analysis, critical cases were selected according to Table 10.

Table 9 (1/4) Total Forces

(case-1-1) normal condition and stop log open (pump operated)

		point of action			direction			Moment footing C.		
slab name	Total Force	x	y	z	X	Y	Z	Mx	My	Mz
front	-555.12	5.77	6.32	8.00		*		0	0	427
	-77.45	5.00	3.72	16.00			*	133	0	0
main-A	-48.42	13.38	1.80	8.00	*			0	0	87
	-959.34	13.56	4.30	8.00		*		0	0	-230
	-104.09	13.76	2.50	15.32			*	260	1,037	0
main-C	-48.42	27.00	9.66	8.00	*			0	0	168
	-1,727.29	29.41	8.82	7.90		*		173	0	1,883
	-15.81	28.54	8.36	11.53			*	34	31	0
house	-337.43	30.50	10.18	16.00		*		0	0	0

Table 9 (2/4) Total Forces

(case-1-2) normal condition and stop log closed (pump not operation)

		point of action			direction			Moment footing C.		
slab name	Total Force	x	y	z	X	Y	Z	Mx	My	Mz
front	98.00	1.15	4.67	8.00	*			0	0	588
	-416.37	5.95	7.46	8.00		*		0	0	396
	-77.45	5.00	3.72	16.00			*	133	0	0
main-A	-30.53	13.38	1.80	8.00	*			0	0	55
	-713.10	13.53	5.01	8.00		*		0	0	-192
	-104.09	13.76	2.50	15.32			*	260	1,037	0
main-C	-1,612.22	29.43	8.90	7.89		*		177	0	1,725
	-15.81	28.54	8.36	11.53			*	34	31	0

Table 9 (3/4) Total Forces

(case-2-1) earthquake condition and stop log open(pump operated)

		point of action			direction			Moment footing C.		
slab name	Total Force	x	y	z	X	Y	Z	Mx	My	Mz
front	111.20	5.39	4.22	8.00	*			0	0	667
	-555.12	5.77	6.32	8.00		*		0	0	427
	-349.87	5.12	3.79	11.27			*	626	42	0
main-A	-278.41	13.54	2.22	8.00	*			0	0	618
	-963.66	13.56	4.29	8.00		*		0	0	-231
	-379.09	13.38	2.83	11.72			*	1,073	3,632	0
main-C	-203.71	28.31	9.03	7.90	*			0	20	576
	-1,679.42	29.48	8.80	7.89		*		185	0	1,713
	-218.70	29.06	9.04	8.28			*	621	315	0
house	37.12	30.50	10.18	16.00	*			0	0	9
	-337.43	30.50	10.18	16.00		*		0	0	0
	37.12	30.50	10.18	16.00			*	9	0	0

Table 9 (4/4) Total Forces

(case-2-2) earthquake condition and stop log closed(pump not operated operation)

		point of action			direction			Moment footing C.		
slab name	Total Force	x	y	z	X	Y	Z	Mx	My	Mz
front	209.20	3.40	4.43	8.00	*			0	0	1,255
	-416.37	5.95	7.46	8.00		*		0	0	396
	-222.29	5.20	3.97	12.00			*	438	44	0
main-A	-254.57	13.55	2.26	8.00	*			0	0	575
	-713.10	13.53	5.01	8.00		*		0	0	-192
	-285.56	13.38	2.53	8.00			*	722	2,736	0
main-C	-285.31	28.58	9.19	8.00	*			0	0	853
	-1,641.10	29.39	8.91	7.89		*		181	0	1,822
	-218.70	29.06	9.04	8.28			*	621	315	0

Table 10 Total Forces (Summary)

case no.	slab name	V	H	critical case
		t	t	
	F	555	77	
normal, stoplog open	A	959	104	
	C	1,727	48	*
	H	337	0	*
	F	416	98	*
normal, stoplog closed	A	713	104	*
	C	1,612	16	
	H	337	0	
	F	555	350	*
earthquake, stoplog open	A	964	379	*
	C	1,679	219	
	H	337	37	*
	F	416	222	
earthquake, stoplog closed	A	713	285	
	C	1,641	219	*
	H	337	37	

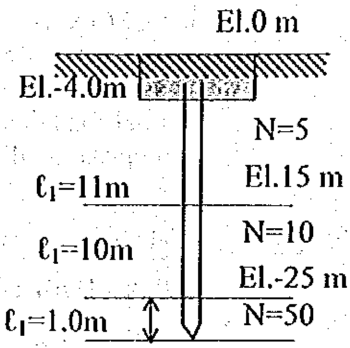
normal condition: no earthquake
earthquake condition: earthquake

in stop log open condition, water weight is included
in stop log closed condition, water pressure on stop log is included
in earthquake condition, inertia on screw has vertical component
in stop log open condition, driving force of screw is included

3.10 Pile Foundation Analysis

3.10.1 Pile Stress Analysis

(1) N-value for design of pile foundation



Geological condition at the site is assumed as shown in Figure-11.

N-value at pile tip (Nt): 50
average N-value 3.75D above the tip to pile tip (N2):

3.75 D = 3.75 x 0.5 = 1.875
N2 = (0.875 x 10 + 1.0 x 50) / 1.875 = 31.3 → 31

N-value for pile design (N): N = (50+31)/2 = 40.5 → 40

(2) Estimation of internal friction angle

$\phi = 15 + \sqrt{(15 \times N)} = 15 + \sqrt{(15 \times 40)} = 39.5 \rightarrow 40$

(3) Allowable compressive bearing capacity (Ra)

$$Ra = \frac{\{qd \times A + u(li \times fi)\}}{SF}$$

qd : ultimate bearing capacity per unit are at pile tip (tf/m^2)
A : Area of pile tip ($=\pi R^2/4 = 0.196$ m^2)
li : stratum depth (l_1= 11.0 m, l_2= 10 m, l_3= 1 m)
u : circumferential length of pile (= 1.571 m)
fi : maximum skin firiction of stratum
(f_1= 2.5 tf/m^2, f_2= 3 tf/m^2, f_3= 3 tf/m^2)
SF : safety factor (normal: 3, earthquake:2)

- ultimate bearing capacity (qd)

$$qd = 1.3 \times c \times N + 0.3 \times R \times \gamma_1 + N_\gamma \times Df \times Nq$$

c : cohesion (= 0)
Nc, N_γ, Nq : bearing capacity foctors
Nc = 92, N_γ= 110, Nq = 85
γ_1 : unit weight of soil below pile tip (= 0.8 tf/m^3)
γ_2 : unit weight of soil above pile tip (= 0.8 tf/m^3)
R : diameter of pile (= 0.5 m)
Df : Pile length (= 22.0 m)

qd = 0.3 x 0.5 x 0.8 x 110 + 0.8 x 22.0 x 85 = 1509.2 tf/m^2

$$Ra = \frac{\{1509.2 \times 0.196 + 1.571 \times (11.00 \times 2.5 + 10 \times 3 + 1 \times 3)\}}{SF} = \frac{390.8}{SF}$$

- Normal condition: Ra = 130 tf
- Earthquake condition: Ra = 195 tf

(4) Allowable pull-out capacity (Pa)

$$Pa = \frac{Pu}{SF + \overline{w}}$$

Pu: ultimate axial pull-out capacity of pile determined by ground conditions (tf)

Pu = UΣ(li x fi) = 95

w : effective weight of pile (= 1.6 tf/m x 22.0 m = 35.2 tf)

SF: safety factor (normal: 6, earthquake:3)

-Normal condition: Pa = 51.0 tf

-Earthquake condition: Pa = 69.9 tf

(5) Allowable lateral bearing capacity (Ha)

Ha = (k x D /β) x δa

k: coefficient of lateral reaction of foundation ground (kgf/cm^3)

D: pile diameter(= 0.5 m)

β: charactaristic value of pile (cm^{-1})

$$\beta = \sqrt[4]{\frac{k \cdot D}{4 \cdot E \cdot I}}$$

E: coefficient of elasticity of pile body (= 400,000 kgf/cm^2)

I: momet of inertia of corss section of pile body (= 260,604.6 m^4)

δa: allowable displacement of pile (normal: 1.0 cm, earthquake: 1.5 cm)

(5)-1 Estimation of coefficient of lateral reaction of foundation ground (k)

$k = k_0(B_H/30)^{-3/4}$

$k_0 = \frac{1}{30} \times \alpha \times E_0$

E0 = 28N = 140, α=1 (normal), α=2 (earthquake)

$$B_H = \sqrt{\frac{D}{\beta}}$$

D = 0.5 m

k = 1.70 (normal condition)

k = 3.40 (earthquake condition)(details see table-5)

(5)-2 Allowable lateral bearing capacity (Ha)

$$Ha = \left(K \times \frac{D}{\beta}\right) \times \delta a$$

K: 1.70 kgf/cm^3 (normal), 3.40 kgf/cm^3 (earthquake)

D: pile diameter(= 50 cm)

β: 0.0038 cm^{-1}, 1/β= 264.5 cm

δa: allowable displacement of pile (normal: 1.0 cm, earthquake: 1.5 cm)

Ha = 22.5 t (normal),

Ha = 67.4 t (earthquake)

6) Load and moment for a pile

6)-1 Load and moment at footing center

Load and moment at footing center is calculated as follows:

Name of Structure	normal(X)			normal(Z)			seismic(ZX)			seismic(ZZ)			seismic(XX)			seismic(XZ)		
	V	H	M	V	H	M	V	H	M	V	H	M	V	H	M	V	H	M
Front Structure	-416	98	984	-416	-77	133	-555	0	427	-555	-350	626	-555	111	1094	-555	-77	133
Main Structure-A	-713	-31	-137	-713	-104	260	-964	-48	-144	-964	-379	1073	-964	-278	387	-964	-104	260
Main Structure-C	-1727	-48	-143	-1727	-16	34	-1641	0	1822	-1641	-219	802	-1641	-285	853	-1641	-16	215
House Slab	-337	0	0	-337	0	0	-337	37	9	-337	37	9	-337	0	0	-337	0	0

6)-2 Layout of pile

Layout of piles is shown below

Name of Structure	Pile Arrangement		
	X	Z	total
Front Structure	6	9	54
Main Structure-A	5	10	50
Main Structure-B	3	6	18
Main Structure-C	4	7	28
House Slab	3	4	12

6)-3 Calculation of displacement

Displacement calculated is shown below

Displacement of Piles and Load on Piles (Asin Pumping Station)

Front Structure
displacement

		delta H(cm)			alpha H(10-5 radian)		
	delta y	delta x	delta z	delta H	alpha x	alpha z	alphs H
normal	-0.031	0.082	-0.064	0.10	1.55	-0.4	1.60
earthquake: z	-0.042	0.00005	-0.17	0.17	0.05	-1.52	1.52
earthquake:x	-0.042	0.056	-0.038	0.07	1.49	-0.334	1.53

load on

	Pv(t)				
	Pvmax	Pvmin	Ph(t)	Mo(tm)	Mm(tm)
normal	8.5	6.9	2.31	3.06	-0.6
earthquake: z	12.9	7.9	6.48	7.28	-1.5
earthquake: x	11.7	12.2	2.50	2.81	-0.6

beta(normal)= 0.00378
beta(quake)= 0.004449

Main Structure-A
displacement

		delta H(cm)			alpha H(10-5 radian)		
	delta y	delta x	delta z	delta H	alpha x	alpha z	alphs H
normal	-0.057	-0.028	-0.093	0.097	-0.73	-0.58	0.93
earthquake: z	-0.078	-0.026	-0.202	0.204	-0.95	-1.76	2.00
earthquake:x	-0.078	-0.153	-0.055	0.163	-5.27	-0.48	5.29

load

	Pv(t)				
	Pvmax	Pvmin	Ph(t)	Mo(tm)	Mm(tm)
normal	15.6	12.6	2.17	2.87	-0.5968
earthquake: z	23.0	15.7	7.61	8.47	-1.7618
earthquake: x	23.2	15.4	5.94	6.61	-1.3752

beta(normal)= 0.00378
beta(quake)= 0.00449

Main Structure- C
displacement

		delta H(cm)			alpha H(10-5 radian)		
	delta y	delta x	delta z	delta H	alpha x	alpha z	alphs H
normal	-0.249	-0.078	-0.025	0.082	-1.65	-0.15	1.66
earthquake: z	-0.237	0.001	-0.208	0.208	-0.46	-1.74	1.80
earthquake:x	-0.237	-0.277	-0.015	0.277	-7.81	-0.12	7.81

load

	Pv(t)				
	Pvmax	Pvmin	Ph(t)	Mo(tm)	Mm(tm)
normal	59.5	56.9	0.56	0.74	-0.154
earthquake: z	62.1	51.2	7.82	8.71	-1.8104
earthquake: x	60.4	53.1	10.18	11.34	-2.3568

beta(normal)= 0.00378
beta(quake)= 0.00449

House Slab
displacement

		delta H(cm)			alpha H(10-5 radian)		
	delta y	delta x	delta z	delta H	alpha x	alpha z	alphs H
normal	-0.11	0.000	0.000	0.000	0.00	0.00	0.00
earthquake: z	-0.11	0.000	-0.083	0.083	0.00	-1.74	1.74
earthquake:x	-0.11	-0.083	0.000	0.083	-1.66	0.00	1.66

load

	Pv(t)				
	Pvmax	Pvmin	Ph(t)	Mo(tm)	Mm(tm)
normal	27.2	27.2	0	0.00	0
earthquake: z	28.9	25.6	3.08	3.43	-0.7131
earthquake: x	28.7	25.8	3.08	3.43	-0.7131

beta(normal)= 0.00378
beta(quake)= 0.00449

Allowable: normal condition; $\delta y = \delta H = 1.0$ cm, $\alpha = 1/1000 = 1 \times 10^{-3}$

earthquake condition; $\delta y = 1.0$ cm, $\delta H = 1.5$ cm, $\alpha = 1/1000 = 1 \times 10^{-3}$

7) Stress of a Pile

Pile stress are calculated as follows :

Pile stress(slab F 6*9)

normal

c	41	+	3.06	x	100000	/	10416.2	+	8.5	x	1000	/	1182.4	=	77.6
c'	41	-	3.06	x	100000	/	10416.2	+	8.5	x	1000	/	1182.4	=	18.8
p	8152.5	+	321.3	x	100000	/	260604.6	-	42.5	x	1000	/	1182.4	=	8,239.8

earthquake Z

c	41	+	7.28	x	100000	/	10416.2	+	12.9	x	1000	/	1182.4	=	121.8
c'	41	-	7.28	x	100000	/	10416.2	+	12.9	x	1000	/	1182.4	=	-18.0
p	8152.5	+	764.4	x	100000	/	260604.6	-	64.5	x	1000	/	1182.4	=	8,391.3

earthquake X

c	41	+	2.81	x	100000	/	10416.2	+	11.7	x	1000	/	1182.4	=	77.9
c'	41	-	2.81	x	100000	/	10416.2	+	11.7	x	1000	/	1182.4	=	23.9
p	8152.5	+	295.1	x	100000	/	260604.6	-	58.5	x	1000	/	1182.4	=	8,216.2

Pile stress(slab A 5×10)

normal

c	41	+	2.87	x	100000	/	10416.2	+	15.6	x	1000	/	1182.4	=	81.7
c'	41	-	2.87	x	100000	/	10416.2	+	15.6	x	1000	/	1182.4	=	26.6
p	8152.5	+	301.35	x	100000	/	260604.6	-	78	x	1000	/	1182.4	=	8,202.2

earthquake Z

c	41	+	8.47	x	100000	/	10416.2	+	23	x	1000	/	1182.4	=	141.8
c'	41	-	8.47	x	100000	/	10416.2	+	23	x	1000	/	1182.4	=	-20.9
p	8152.5	+	889.35	x	100000	/	260604.6	-	115	x	1000	/	1182.4	=	8,396.5

earthquake X

c	41	+	6.61	x	100000	/	10416.2	+	23.2	x	1000	/	1182.4	=	124.1
c'	41	-	6.61	x	100000	/	10416.2	+	23.2	x	1000	/	1182.4	=	-2.8
p	8152.5	+	694.05	x	100000	/	260604.6	-	116	x	1000	/	1182.4	=	8,320.7

Pile stress(slab C 4x7)

normal

c	41	+	0.74	x	100000	/	10416.2	+	62.4	x	1000	/	1182.4	=	100.9
c'	41	-	0.74	x	100000	/	10416.2	+	62.4	x	1000	/	1182.4	=	86.7
p	8152.5	+	77.7	x	100000	/	260604.6	-	312	x	1000	/	1182.4	=	7,918.4

earthquake Z

c	41	+	8.71	x	100000	/	10416.2	+	63.3	x	1000	/	1182.4	=	178.2
c'	41	-	8.71	x	100000	/	10416.2	+	63.3	x	1000	/	1182.4	=	10.9
p	8152.5	+	914.55	x	100000	/	260604.6	-	316.5	x	1000	/	1182.4	=	8,235.8

earthquake X

c	41	+	11.34	x	100000	/	10416.2	+	61.8	x	1000	/	1182.4	=	202.1
c'	41	-	11.34	x	100000	/	10416.2	+	61.8	x	1000	/	1182.4	=	-15.6
p	8152.5	+	1190.7	x	100000	/	260604.6	-	309	x	1000	/	1182.4	=	8,348.1

Pile stress(slab H 3x4)

normal

c	41	+	0	x	100000	/	10416.2	+	27.2	x	1000	/	1182.4	=	64.0
c'	41	-	0	x	100000	/	10416.2	+	27.2	x	1000	/	1182.4	=	64.0
p	8152.5	+	0	x	100000	/	260604.6	-	136	x	1000	/	1182.4	=	8,037.5

earthquake Z

c	41	+	3.43	x	100000	/	10416.2	+	28.9	x	1000	/	1182.4	=	98.4
c'	41	-	3.43	x	100000	/	10416.2	+	28.9	x	1000	/	1182.4	=	32.5
p	8152.5	+	360.15	x	100000	/	260604.6	-	144.5	x	1000	/	1182.4	=	8,168.5

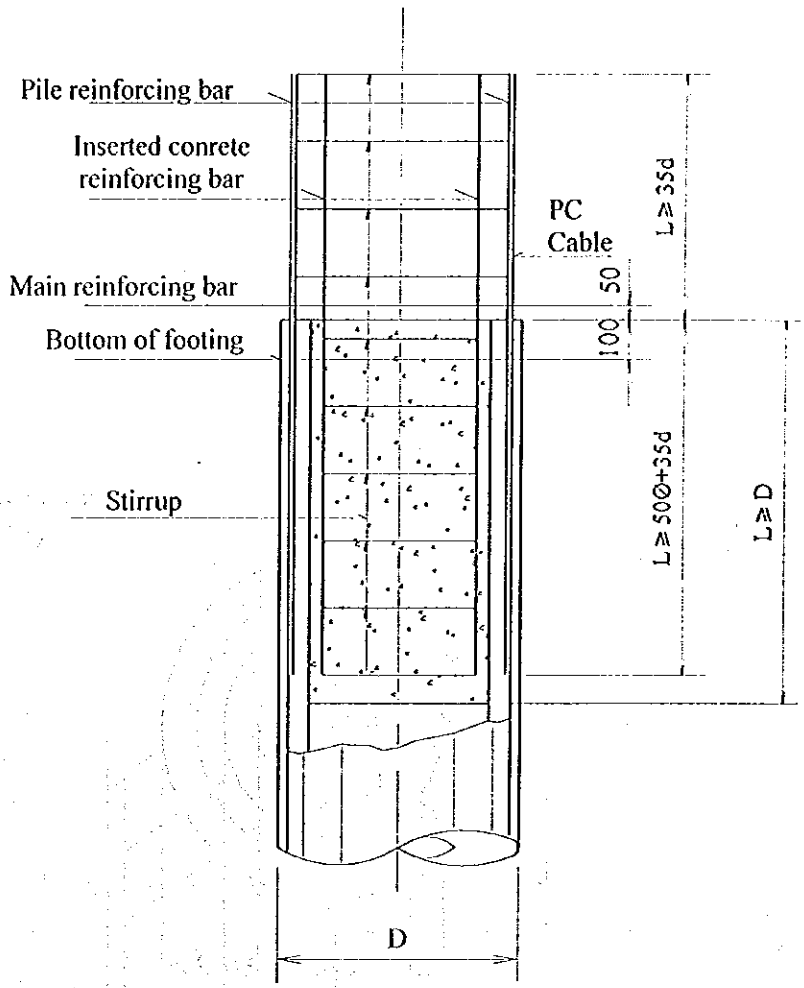
earthquake X

c	41	+	3.43	x	100000	/	10416.2	+	28.7	x	1000	/	1182.4	=	98.2
c'	41	-	3.43	x	100000	/	10416.2	+	28.7	x	1000	/	1182.4	=	32.3
p	8152.5	+	360.15	x	100000	/	260604.6	-	143.5	x	1000	/	1182.4	=	8,169.3

3.10.2 Pile Cap Calculation

(1) General

As the horizontal force acting on the piles are large in this structure, a rigid type connection method is applied in the pile cap treatment. The pile cap design criteria is described in "Design Criteria Report (1)". The concept of the pile cap treatment is shown in a figure below.



(2) Structural Analysis

Structural analysis is made for each check items as follows;

(a) normal stress in the footing concrete

(b) shearing stress in the footing concrete

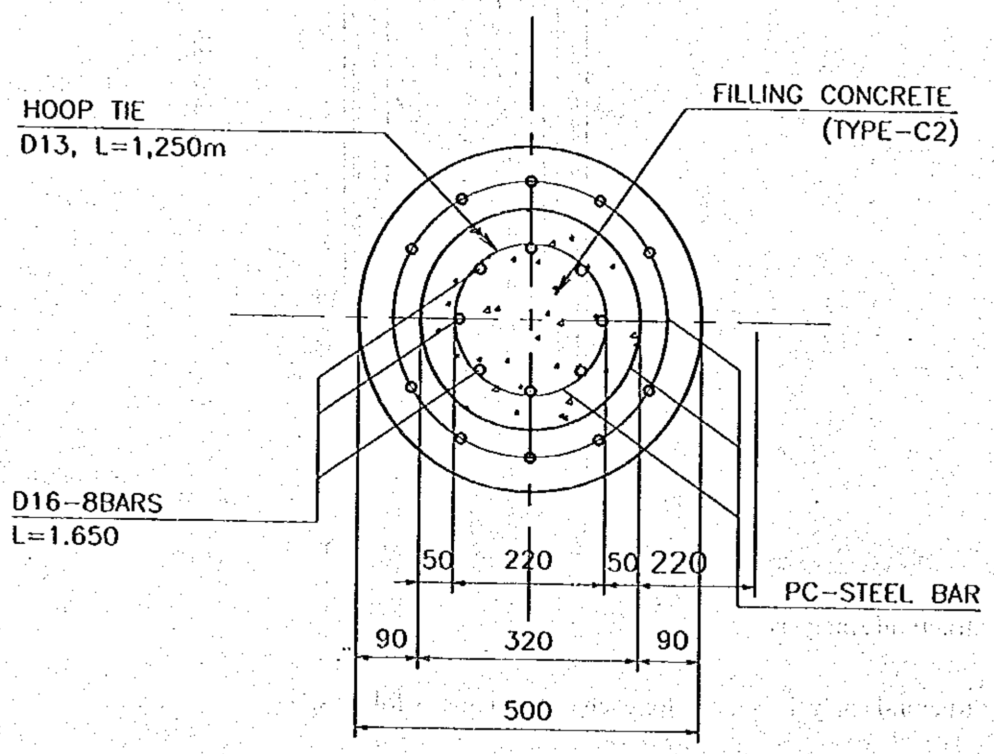
(c) horizontal punching stress in the footing concrete

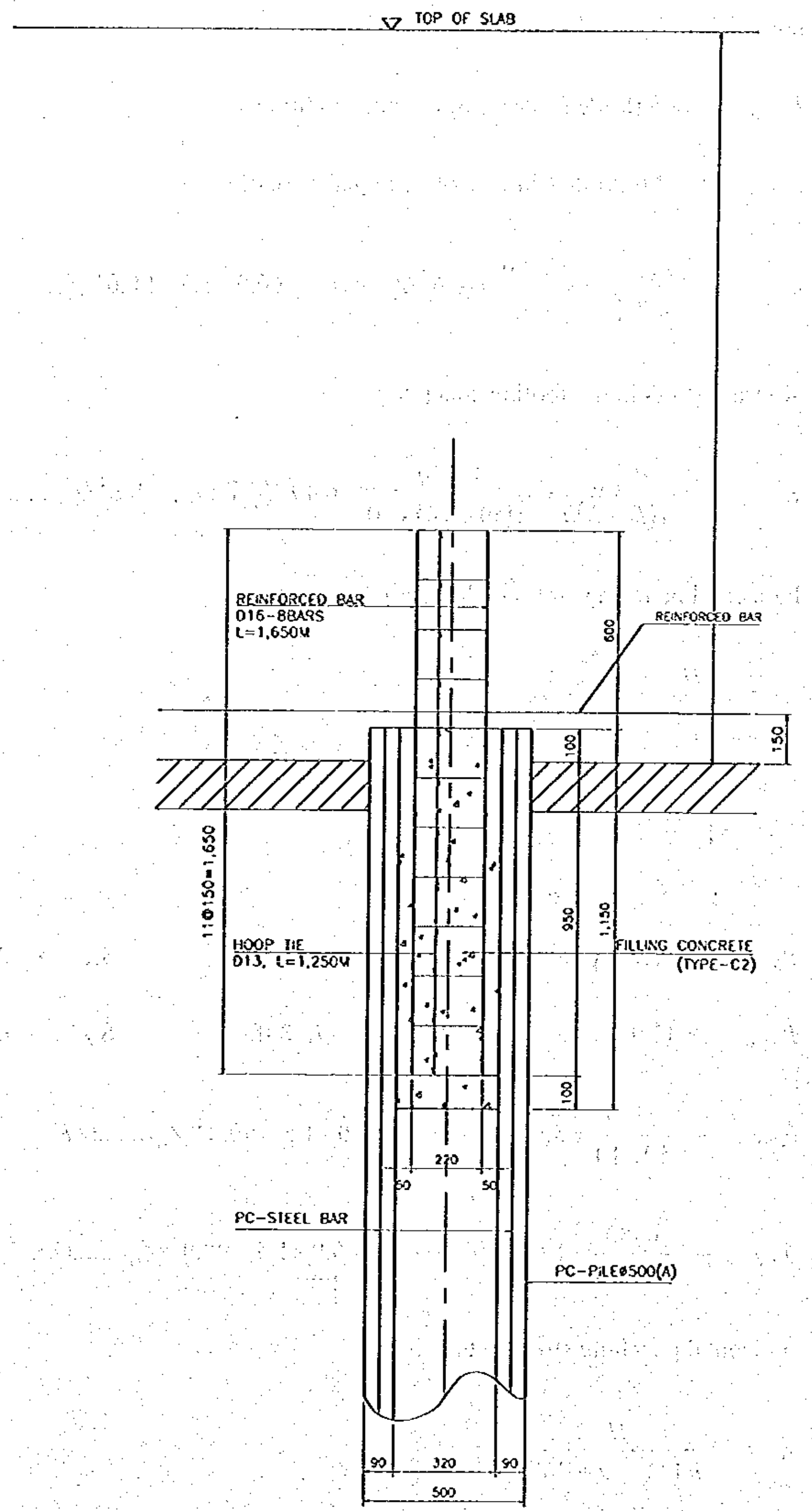
(d) horizontal punching stress in the pile

(e) stress in the imaginary concrete section

(f) reinforcing bar for inserted concrete

(g) height of inserted concrete


HOOP TIE
D13, L=1,250m
FILLING CONCRETE
(TYPE-C2)
D16-8BARS
L=1.650
50
220
50
220
PC-STEEL BAR
90
320
90
500


TOP OF SLAB
REINFORCED BAR
D16-8BARS
L=1,650M
REINFORCED BAR
600
150
100
11@150=1,650
950
1,150
HOOP TIE
D13, L=1,250M
FILLING CONCRETE
(TYPE-C2)
100
220
50
50
PC-STEEL BAR
PC-PILEø500(A)
90
320
90
500

F-F

(a) normal stress in the footing concrete

P_{Nmax} = 8.5 tf/pile (in case of normal condition)

P_{Nmax} = 12.6 tf/pile (in case of earthquake condition)

$$\delta_{cv} = \frac{P_{N\max}}{\pi D^2/4} = \frac{12900}{\frac{\pi}{4}\times 50^2} = 6.6\,{}^{kgf}/_{cm^2} < \delta_{ca} = 60.0\times 1.5 = 90.0\,{}^{kgf}/_{cm^2}$$

(b) shearing stress in the footing concrete

$$\tau_V = \frac{P_{N\max}}{\pi(D+h)h} = \frac{12900}{\pi(50+70)\times 70} = 0.49\,{}^{kgf}/_{cm^2} < \tau_{ca} = 8.8\,{}^{kgf}/_{cm^2} \text{........}O.K.$$

(c) horizontal punching stress in the footing concrete

$$\delta_{ch} = \frac{H}{D\ell}$$

ℓ = inserted pile length (cm)

M = Moment (kgf.cm)

H = Axial Force

P_{Nmax} = 11.7 tf/pile	M.x = 2.81 tf.m	S.x = 2.50 tf
P_{Nmax} = 12.9 tf/pile	M.z = 7.28 tf.m	S.z = 6.48 tf

$$\delta_{ch\text{-}X} = \frac{2500}{50\times 10} = 5.0\,{}^{kgf}/_{cm^2} < \delta_{ca} = 60.0\times 1.5 = 90.0\,{}^{kgf}/_{cm^2} \text{.......}O.K$$

$$\delta_{ch\text{-}Z} = \frac{6480}{50\times 10} = 12.96\,{}^{kgf}/_{cm^2} < \delta_{ca} = 60.0\times 1.5 = 90.0\,{}^{kgf}/_{cm^2} \text{.......}O.K$$

(d) horizontal punching stress in the pile

$$\tau_h = \frac{H}{h'(2\ell + D + 2h')}$$

h' = effective thickness of footing concrete against horizontal punching

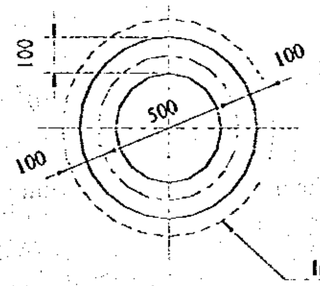
h' = 45 cm (z direction)

$$\tau_h = \frac{6480}{45\times(2\times10+50+2\times45)} = 0.90\,{}^{kgf}/_{cm^2} < \tau_{a3} = 8.8\,{}^{kgf}/_{cm^2} \text{..........} O.K$$

(e) stress in the imaginary concrete section

$N = N_{min} =$ 7.9 tf (in case of earthquake condition)

$M =$ 7.28 tf.m



$D =$ 50 + 10 x 2 = 70.0 cm

$a =$ 11.0 cm x 2 = 22.0 cm

d = 24.0 cm

$\delta_C = 75.0\,{}^{kgf}/_{cm^2} < \delta_{ca} = 75\times15 = 112.5\,{}^{kgf}/_{cm^2}$..........$O.K$

$\delta_S = 1722\,{}^{kgf}/_{cm^2} < \delta_{sa} = 2400\,{}^{kgf}/_{cm^2}$..........$O.K$

D16 – 8 bars

(f) reinforcing bar for inserted concrete

$L_1 \geqq L_0$

bond length in footing L_0 = 35Ø (mm)

Ø = reinforcing bar diameter (mm)

L_1 = 35 x 16 = 560 ≑ 600 mm

bond length in footing L_2 = 50Ø + L_0

Ø = PC cable diameter (mm)

L_2 = 50 x 9.0 + 35 x 16 = 1010 mm

≑ 1050 mm

Stirrup : D13 per 150 mm pitch

(g) height of inserted concrete

$L_2 \geqq$ 1050 mm

A-A

(a) normal stress in the footing concrete

P_{Nmax} = 15.6 tf/pile (in case of normal condition)

P_{Nmax} = 23.2 tf/pile (in case of earthquake condition)

$$\delta_{cv} = \frac{P_{N\max}}{\pi D^2/4} = \frac{23200}{\frac{\pi}{4}\times 50^2} = 11.8\,kgf/cm^2 < \delta_{ca} = 60.0\times 1.5 = 90.0\,kgf/cm^2$$

(b) shearing stress in the footing concrete

$$\tau_V = \frac{P_{N\max}}{\pi(D+h)h} = \frac{23200}{\pi(50+70)\times 70} = 0.88\,kgf/cm^2 < \tau ca = 8.8\,kgf/cm^2 \text{........O.K.}$$

(c) (c) horizontal punching stress in the footing concrete

$$\delta_{ch} = \frac{H}{D\ell}$$

ℓ = inserted pile length (cm)

M = Moment (kgf.cm)

H = Axial Force

P_{Nmax} = 23.2 tf/pile M.x = 6.61 tf.m S.x = 5.94 tf

P_{Nmax} = 23.0 tf/pile M.z = 8.47 tf.m S.z = 7.61 tf

$$\delta_{ch\text{-}x} = \frac{5940}{50\times 10} = 11.9\,kgf/cm^2 < \delta_{ca} = 60.0\times 1.5 = 90.0\,kgf/cm^2 \text{.......O.K}$$

$$\delta_{ch\text{-}z} = \frac{7610}{50\times 10} = 15.2\,kgf/cm^2 < \delta_{ca} = 60.0\times 1.5 = 90.0\,kgf/cm^2 \text{.......O.K}$$

(d) horizontal punching stress in the pile

$$\tau_h = \frac{H}{h'(2\ell + D + 2h')}$$

h' = effective thickness of footing concrete against horizontal punching

h' = 45 cm (z direction)

$$\tau_h = \frac{7610}{45\times(2\times10+50+2\times45)} = 1.06^{kgf}/_{cm^2} < \tau_{a3} = 8.8^{kgf}/_{cm^2} \ldots\ldots\ldots O.K$$

(e) stress in the imaginary concrete section

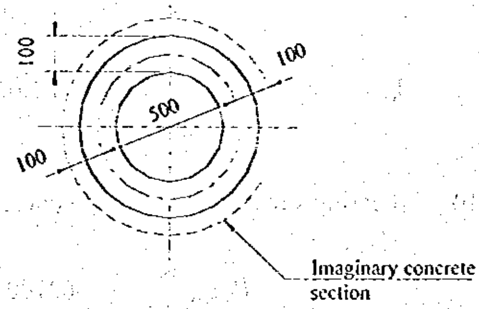
$N = N_{min} =$ 15.7 tf (in case of earthquake condition)

$M =$ 8.47 tf.m

$D =$ 50 + 10 x 2 = 70.0 cm

$a =$ 11.0 cm x 2 = 22.0 cm

d = 24.0 cm



$\delta_C = 79.2^{kgf}/_{cm^2} < \delta_{ca} = 75\times15 = 112.5^{kgf}/_{cm^2} \ldots\ldots\ldots O.K$

$\delta_S = 1534^{kgf}/_{cm^2} < \delta_{sa} = 2400^{kgf}/_{cm^2} \ldots\ldots\ldots O.K$

D16 – 8 bars

(f) reinforcing bar for inserted concrete

$L_1 \geqq L_0$

bond length in footing L_0 = 35Ø (mm)

Ø = reinforcing bar diameter (mm)

L_1 = 35 x 16 = 560 ≒ 600 mm

bond length in footing L_2 = 50Ø + L_0

Ø = PC cable diameter (mm)

L_2 = 50 x 9.0 + 35 x 16 = 1010 mm

≒ 1050 mm

Stirrup : D13 per 150 mm pitch

(g) height of inserted concrete

$L_2 \geqq$ 1050 mm

C-C

(a) normal stress in the footing concrete

P_{Nmax} = 59.5 tf/pile (in case of normal condition)

P_{Nmax} = 62.1 tf/pile (in case of earthquake condition)

$$\delta_{cv} = \frac{P_{N\max}}{\pi D^2/4} = \frac{62100}{\frac{\pi}{4}\times 50^2} = 31.6\ {}^{kgf}/_{cm^2} < \delta_{ca} = 60.0\times 1.5 = 90.0\ {}^{kgf}/_{cm^2}$$

(b) shearing stress in the footing concrete

$$\tau_V = \frac{P_{N\max}}{\pi(D+h)h} = \frac{62100}{\pi(50+70)\times 70} = 2.35\ {}^{kgf}/_{cm^2} < \tau ca = 8.8\ {}^{kgf}/_{cm^2} ........O.K.$$

(c) horizontal punching stress in the footing concrete

$$\delta_{ch} = \frac{H}{D\ell}$$

ℓ = inserted pile length (cm)

M = Moment (kgf.cm)

H = Axial Force

P_{Nmax} = 60.4 tf/pile M.x = 11.3 tf.m S.x = 10.2 tf

P_{Nmax} = 62.1 tf/pile M.z = 8.71 tf.m S.z = 7.82 tf

$$\delta_{ch\text{-}X} = \frac{10200}{50\times 10} = 20.4\ {}^{kgf}/_{cm^2} < \delta_{ca} = 60.0\times 1.5 = 90.0\ {}^{kgf}/_{cm^2} ....O.K$$

$$\delta_{ch\text{-}Z} = \frac{7820}{50\times 10} = 15.6\ {}^{kgf}/_{cm^2} < \delta_{ca} = 60.0\times 1.5 = 90.0\ {}^{kgf}/_{cm^2} ....O.K$$

(d) horizontal punching stress in the pile

$$\tau_h = \frac{H}{h'(2\ell + D + 2h')}$$

h' = effective thickness of footing concrete against horizontal punching

h' = 45 cm (z direction)

$$\tau_h = \frac{10200}{45\times(2\times10+50+2\times45)} = 1.42\,{}^{kgf}/_{cm^2} < \tau_{a3} = 8.8\,{}^{kgf}/_{cm^2} ....O.K$$

(e) stress in the imaginary concrete section

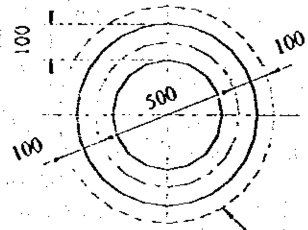
$N = N_{min} =$ 51.2 tf (in case of earthquake condition)

$M =$ 8.71 tf.m

$D =$ 50 + 10 x 2 = 70.0 cm

$a =$ 11.0 cm x 2 = 22.0 cm

d = 24.0 cm



$\delta_C = 45.2\,{}^{kgf}/_{cm^2} < \delta_{ca} = 75\times15 = 112.5\,{}^{kgf}/_{cm^2}$..........O.K

$\delta_S = 41\,{}^{kgf}/_{cm^2} < \delta_{sa} = 2400\,{}^{kgf}/_{cm^2}$..........O.K

D16 – 8 bars

(f) reinforcing bar for inserted concrete

$L_1 \geqslant L_0$

bond length in footing L_0 = 35Ø (mm)

Ø = reinforcing bar diameter (mm)

L_1 = 35 x 16 = 560 ≒ 600 mm

bond length in footing L_2 = 50Ø + L_0

Ø = PC cable diameter (mm)

L_2 = 50 x 9.0 + 35 x 16 = 1010 mm

≒ 1050 mm

Stirrup : D13 per 150 mm pitch

(g) height of inserted concrete

$L_2 \geqslant$ 1050 mm

H-H

(a) normal stress in the footing concrete

P_{Nmax} = 27.2 tf/pile (in case of normal condition)

P_{Nmax} = 28.9 tf/pile (in case of earthquake condition)

$$\delta_{cv} = \frac{P_{N\max}}{\pi D^2/4} = \frac{28900}{\frac{\pi}{4}\times 50^2} = 14.7\,{}^{kgf}/_{cm^2} < \delta_{ca} = 60.0\times 1.5 = 90.0\,{}^{kgf}/_{cm^2}$$

(b) shearing stress in the footing concrete

$$\tau_V = \frac{P_{N\max}}{\pi(D+h)h} = \frac{28900}{\pi(50+70)\times 70} = 1.10\,{}^{kgf}/_{cm^2} < \tau ca = 8.8\,{}^{kgf}/_{cm^2} \text{........}O.K.$$

(c) horizontal punching stress in the footing concrete

$$\delta_{ch} = \frac{H}{D\ell}$$

ℓ = inserted pile length (cm)

M = Moment (kgf.cm)

H = Axial Force

P_{Nmax}	=	28.7 tf/pile	M.x	=	3.43 tf.m	S.x	=	3.08 tf
P_{Nmax}	=	28.9 tf/pile	M.z	=	3.43 tf.m	S.z	=	3.08 tf

$$\delta_{ch\text{-}X} = \frac{3{,}080}{50\times 10} = 6.2\,{}^{kgf}/_{cm^2} < \delta_{ca} = 60.0\times 1.5 = 90.0\,{}^{kgf}/_{cm^2} \text{.......}O.K$$

$$\delta_{ch\text{-}Z} = \frac{3{,}080}{50\times 10} = 6.2\,{}^{kgf}/_{cm^2} < \delta_{ca} = 60.0\times 1.5 = 90.0\,{}^{kgf}/_{cm^2} \text{.......}O.K$$

(d) horizontal punching stress in the pile

$$\tau_h = \frac{H}{h'(2\ell + D + 2h')}$$

h' = effective thickness of footing concrete against horizontal punching

h' = 45 cm (z direction)

$$\tau_h = \frac{3{,}080}{45\times(2\times10+50+2\times45)} = 0.43\,{}^{kgf}/_{cm^2} < \tau_{a3} = 8.8\,{}^{kgf}/_{cm^2} \ldots\ldots\ldots O.K$$

(e) stress in the imaginary concrete section

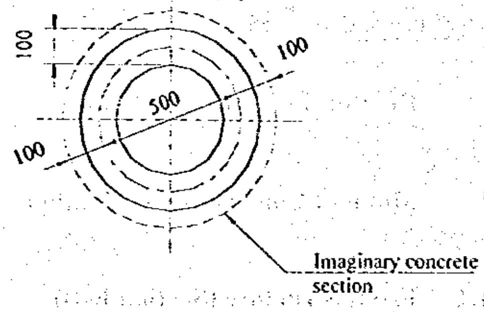
$N = N_{min} =$ 25.6 tf (in case of earthquake condition)

$M =$ 3.43 tf.m

$D =$ 50 + 10 x 2 = 70.0 cm

$a =$ 11.0 cm x 2 = 22.0 cm

d = 24.0 cm



$\delta_C =$ $17.3\,{}^{kgf}/_{cm^2} < \delta_{ca} = 75\times15 = 112.5\,{}^{kgf}/_{cm^2} \ldots\ldots\ldots O.K$

$\delta_S =$ $34\,{}^{kgf}/_{cm^2} < \delta_{sa} = 2400\,{}^{kgf}/_{cm^2} \ldots\ldots\ldots O.K$

D16 – 8 bars

(f) reinforcing bar for inserted concrete

$L_1 \geqslant L_0$

bond length in footing L_0 = 35Ø (mm)

Ø = reinforcing bar diameter (mm)

L_1 = 35 x 16 = 560 ≒ 600 mm

bond length in footing L_2 = 50Ø + L_0

Ø = PC cable diameter (mm)

L_2 = 50 x 9.0 + 35 x 16 = 1010 mm

≒ 1050 mm

Stirrup : D13 per 150 mm pitch

(g) height of inserted concrete

$L_2 \geqslant$ 1050 mm