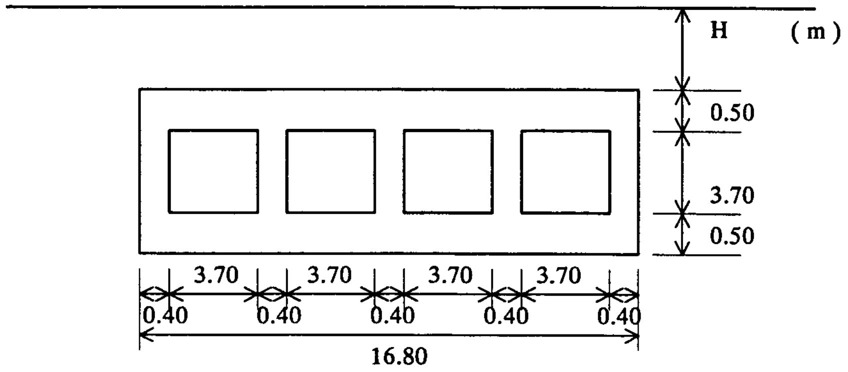
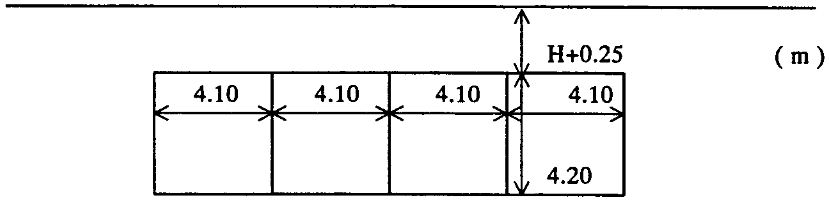
APPENDIX C.4.3-1 Structural Computation of 4-Cell Box Culvert

(1) Sectional Dimension for Calculation



Rigid Frame Dimension



(2) Calculation of Load

(a) Own Weight and Earth Weight Applied for Top Slab (W_1)

The earth cover is from 1.0m to 5.0m. At 1.0m, box culvert is affected by mostly wheel load, and the loads distribute as Figure 1. On the other hand, at 5.0m box culvert is affected by the earth pressure more than wheel loads because unit wheel load scattered widely and becomes smaller (Figure 2). So, two cases, the case at H = 1.0m and at H = 5.0m, shall be calculated and compared, then at the strictest condition calculation should be done.

Vertical load applied for top slab shall be calculated by following equation;

W1 = [Own Weight of Top Slab] + [Vertical Earth Pressure] + [Wheel Load]

- Own Weight of Top Slab

  Concrete Weight of Top Slab $0.5 \times 2.45 = 1.225$ tf/m^2

- Vertical Earth Pressure

  Vertical earth pressure shall be calculated by following equations; $Wv = \gamma \cdot H$

  H=1.0m $Wv = 1.8 \times 1.0m = 1.8$ tf/m^2

  H=5.0m $Wv = 1.8 \times 5.0m = 9.0$ tf/m^2

- Wheel Load

$$q = \frac{P \cdot \beta}{W} = \frac{P \cdot \beta}{2H + 0.2} \qquad P = \frac{[\text{Wheel Load}]}{[\text{Vehicle Occupation Width}]} \times (1 + i)$$

where, q : Vertical load by wheel load (tf/m^2)

P : Back wheel load per unit width

β : Decreasing Coefficient of sectional force $\beta = 0.9$

W : Distribute width(m)

H : Earth Cover from the top of the box culvert to the surface of backfill earth

i : Impact Coefficient $H < 4.0m$; $i = 0.3$

$H \geqq 4.0m$: $i = 0.0$

Wheel load	q (tf/m²)	
	H = 1.0m	H = 5.0m
23.3t	3.540	0.587
23.4t	3.556	0.590
7.5t	1.140	0.189
5.0t	0.760	0.126

Comparing Figure of Load Distribution at H = 1.0m and H = 5.0m, obviously the latter (H = 5.0m) is larger. So the strictest condition is H = 5.0m, then the Earth Cover should be calculated as H = 5.0m.

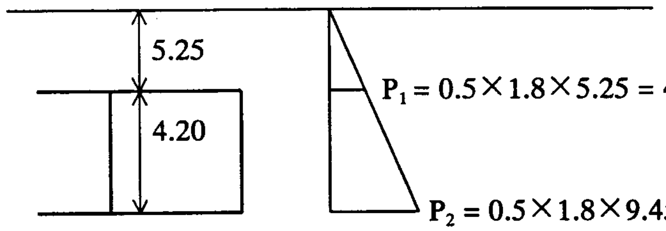
(b) Reaction Force of Bottom Slab (W_2)

At H =5.0m, vertical load shall be assumed as uniform distributed load.

Concrete Weight of Top Slab	1.225	
Vertical Soil Pressure	9.000	
Max. Live Load	1.953	
+) Concrete Weight of Side Slab	1.255	(= 4.2×0.4×2.45×5 / (4.1×4))
Total W_2 =	**13.433**	tf/m²

(c) Side Earth Pressure (P_1 ~ P_2)

Side earth pressure should be calculated by following equation ; $P = K_0 \times \gamma_t \times H$



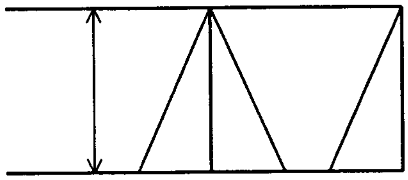
$P_1 = 0.5 \times 1.8 \times 5.25 = 4.725$ tf/m²

$P_2 = 0.5 \times 1.8 \times 9.45 = 8.505$ tf/m²

(d) Inner Water Pressure (P_3)

Inner water pressure should be calculated by following equation ; $P = \gamma_w \times H_w$

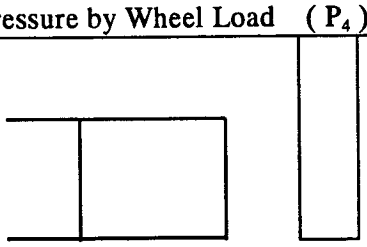
0.35

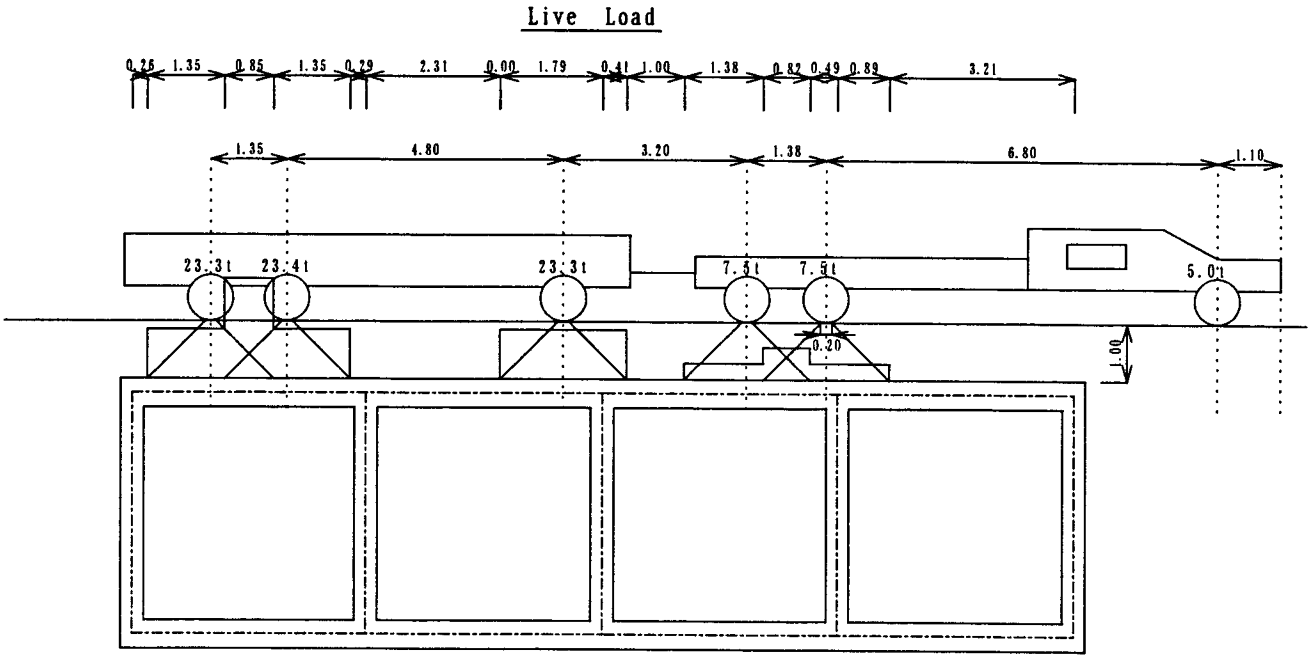


$P_3 = 1.0 \times 3.70 + 0.35 = 4.05$ tf/m²

(e) Side Pressure by Wheel Load (P_4)

$P_4 = 0.5 \times 1.177 = 0.589$ tf/m²





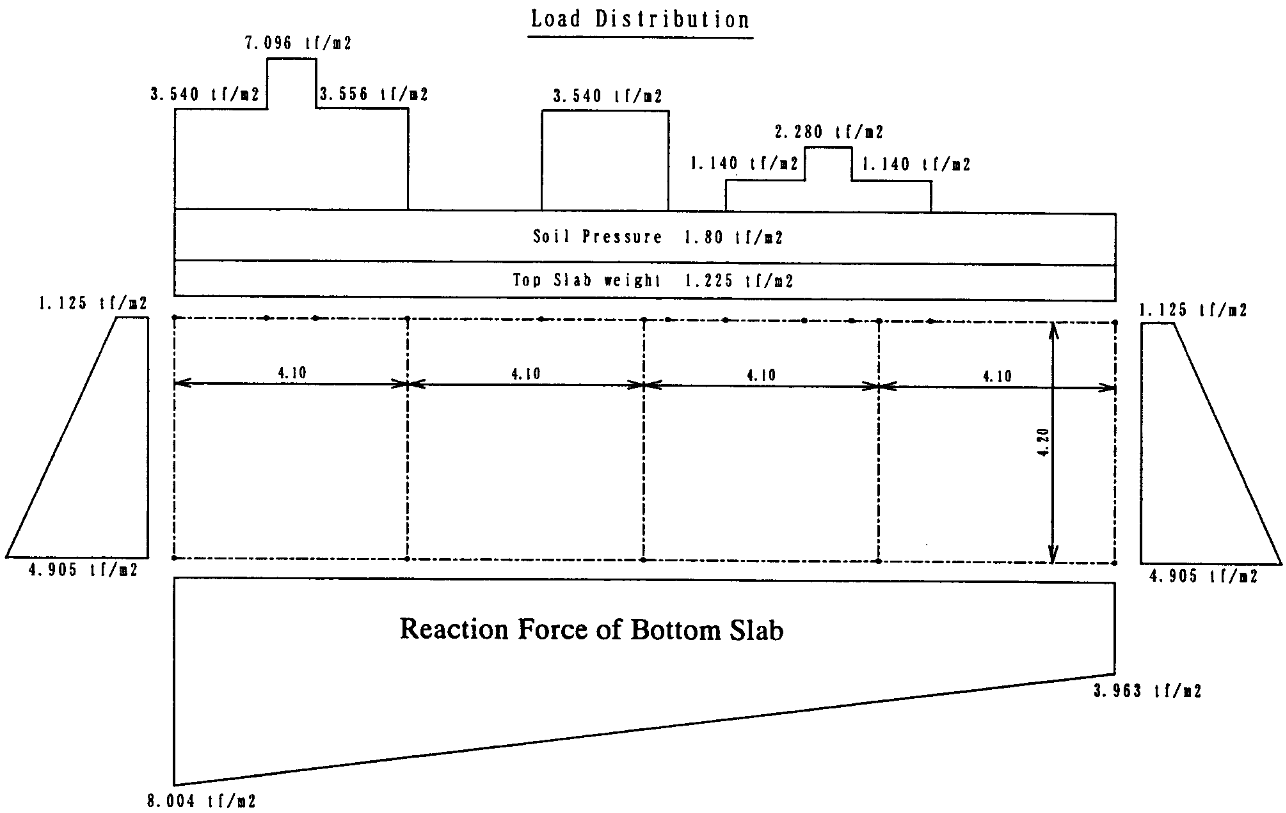


Figure 1 Live load and Load Distribution for Top Slab at H = 1.0m

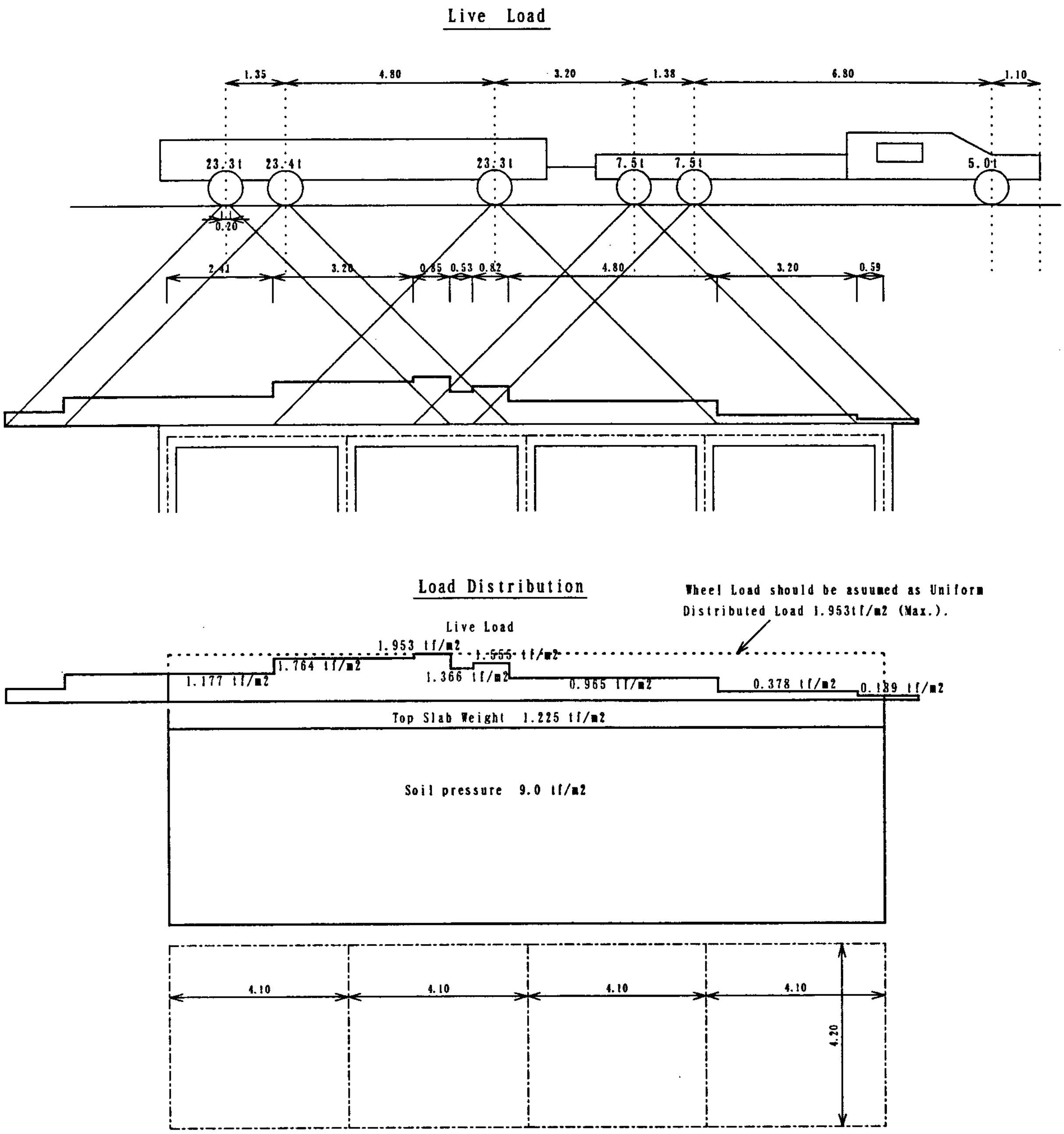
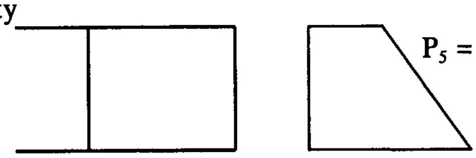


Figure 2 Live load and load distribution for top slab at H = 5.0m

(f) Side Load input data

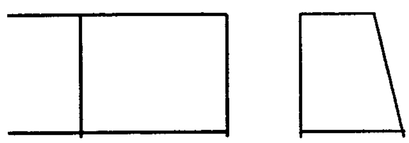
(i)Empty



$P_5 = 4.725 + 0.589 = 5.314$ tf/m^2

$P_6 = 8.505 + 0.589 = 9.094$ tf/m^2

(ii) Full



$P_7 = 4.725 + 0.589 = 5.314$ tf/m^2

$P_8 = 8.505 + 0.589 - 3.70 = 5.394$ tf/m^2

(g) Result of calculation

Upper : Element Number
Middle: Required Reinforcement
Lower : Required Perimeter

		Top Slab		Side Slab	Bottom Slab	
		Outside	Inside	Outside	Outside	Inside
Case 1	Empty	⑤ 24.246 45.189	⑧ 12.700 0.000	⑬ 19.183 37.297	① 31.447 50.152	① 17.640 0.000
Case 3	4cell Full	⑤ 26.059 46.325	⑧ 14.925 0.000	⑬ 13.752 23.915	① 32.891 51.720	① 19.425 0.000
Case 2-1	3cell Full 	⑤ 25.943 46.302	⑤ 14.663 0.000	⑨ 17.578 34.528	① 32.338 54.747	① 17.412 0.000
Case 2-2	3cell Full 	⑤ 26.246 46.330	⑧ 15.211 0.000	⑬ 12.913 23.618	② 32.614 54.461	① 18.053 0.000
Max.		26.246 46.330	15.211 0.000	19.183 37.297	32.891 54.747	19.425 0.000

Stress Analysis of North Sinai Box Culvert (4 cell)

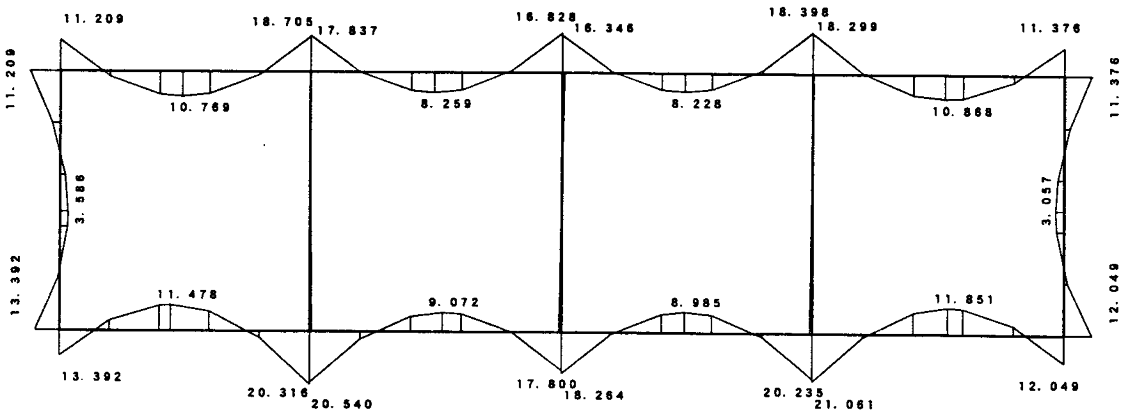
		Top Slab Outside	Top Slab Inside	Side Slab Outside	Bottom Slab Outside	Bottom Slab Inside
Bending Moment	M (kgf·cm)	1,946,400	1,201,200	1,339,200	2,198,900	1,301,400
Axial Force	N (kgf)	10,270	9,789	23,137	260	260
Shearing Force	S (kgf)	27,470	-	16,971	30,666	-
Width	b (cm)	100	100	100	100	100
Thickness	h (cm)	50.0	50.0	50.0	50.0	50.0
Effective Depth	d (cm)	43.0	43.0	43.0	43.0	43.0
Cover (Compressive)	d_1 (cm)	7.0	7.0	7.0	7.0	7.0
Cover (Tensile)	d_2 (cm)	7.0	7.0	7.0	7.0	7.0
Required Effective Depth	d_0 (cm)	37.4	30.1	34.0	38.1	29.3
Judge	Axial Direction Force	Compressive	Compressive	Compressive	Compressive	Compressive
	Tensile Steel	Required	Required	Required	Required	Required
	Compressive Steel	Not Required	Not Required	Not Required	Not Required	Not Required
Max. Compressive Stress σ_{c1}		-	-	-	-	-
Min. Compressive Stress σ_{c2}		-	-	-	-	-
Area of Tensile Reinforcement As		26.24	15.21	19.18	32.88	19.43
Area of Compressive Reinforcement As'(Smaller Area of Tensile Reinforcement, in case Compressive one isn't required)		-	-	-	-	-
Min. Area of Reinforcement	(cm^2)	0.85	0.85	0.85	0.85	0.85
Required Area of Reinforcement	As (cm^2)	26.24	15.21	19.18	32.88	19.43
Required Perimeter	U (cm^2)	46.32	-	37.30	51.71	-

Design of Reinforcement

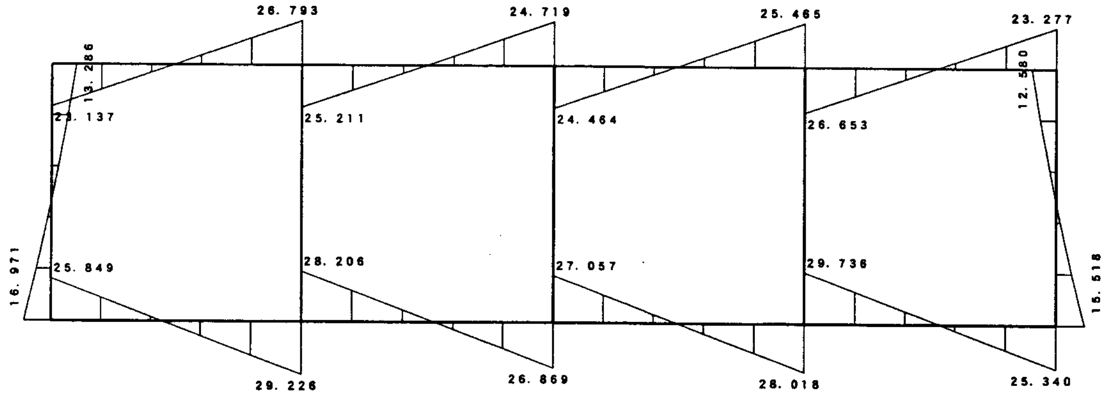
Main Reinforcement 1	Diameter	D_1 (■■)	22	22	25	25	25
	Pitch	$c.to.c$ (■■)	250	250	250	250	250
	Area	As_1 (cm^2)	15.20	15.20	19.64	19.64	19.64
	Perimeter	U_1 (cm)	28.00	28.00	32.00	32.00	32.00
Main Reinforcement 2	Diameter	D_2 (■■)	19	-	22	22	-
	Pitch	$c.to.c$ (■■)	250	-	250	250	-
	Area	As_2 (cm^2)	11.34	-	15.20	15.20	-
	Perimeter	U_2 (cm)	24.00	-	28.00	28.00	-
Area of Reinforcement As(cm2)			26.54	15.20	34.84	34.84	19.64
Perimeter of Reinforcement U(cm2)			52.00	28.00	60.00	60.00	32.00

Stress Check

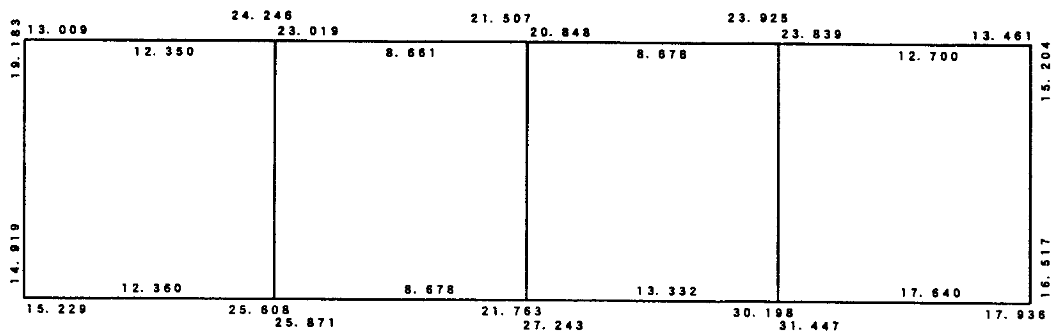
Distance form Neutral axis to Compressive Edge x			16.157	13.587	20.947	16.637	13.283
$j = 1 - x/(3\ d)$			0.875	0.895	0.838	0.871	0.897
Reinforcement	Tensile Stress	σ_s	1,747	1,711	734	1,654	1,722
		Judge (σ_{sa}=1,800kgf/cm^2)	O.K.	O.K.	O.K.	O.K.	O.K.
Concrete	Compressive Stress	σ_c	70.1	52.7	46.5	69.6	51.3
		Judge (σ_{ca}=85kgf/cm^2)	O.K.	O.K.	O.K.	O.K.	O.K.
	Shear Stress	τ	6.4	-	3.9	7.1	-
		Judge (τ_a=8.0kgf/cm^2)	O.K.		O.K.	O.K.	



Moment in t-m

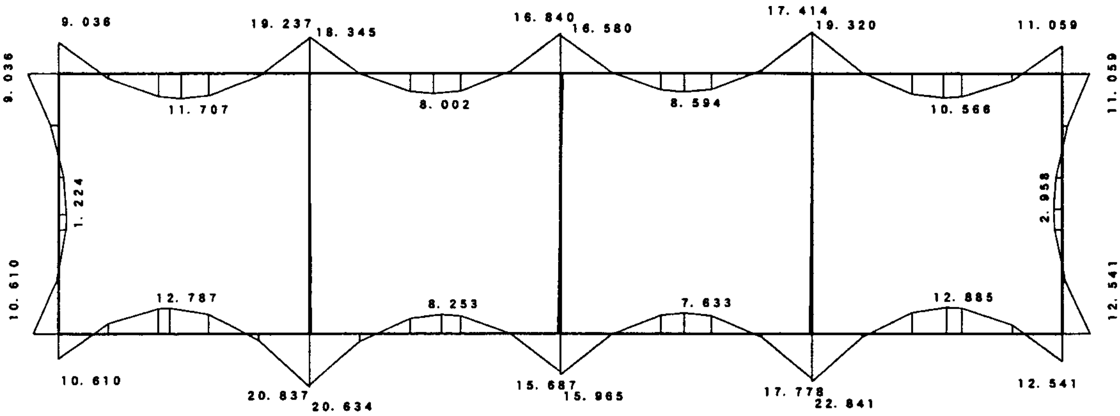


Shearing Force in ton

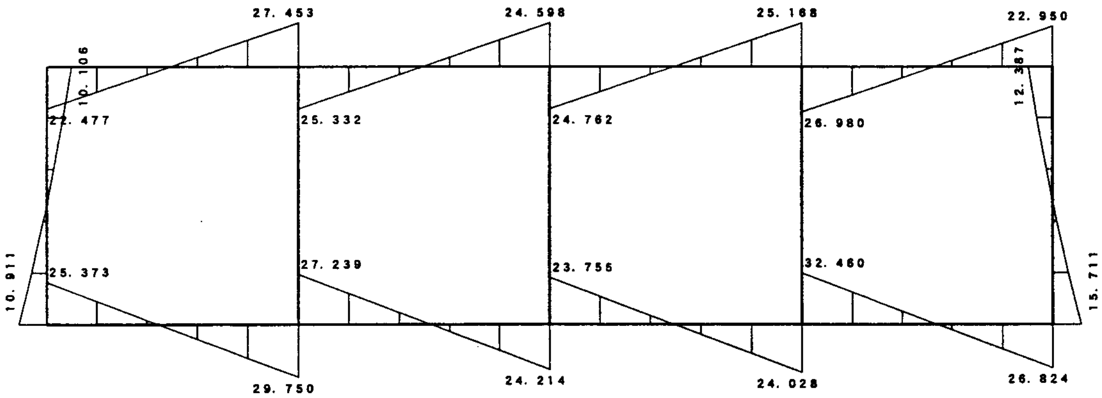


Necessary Reinforcement in cm2

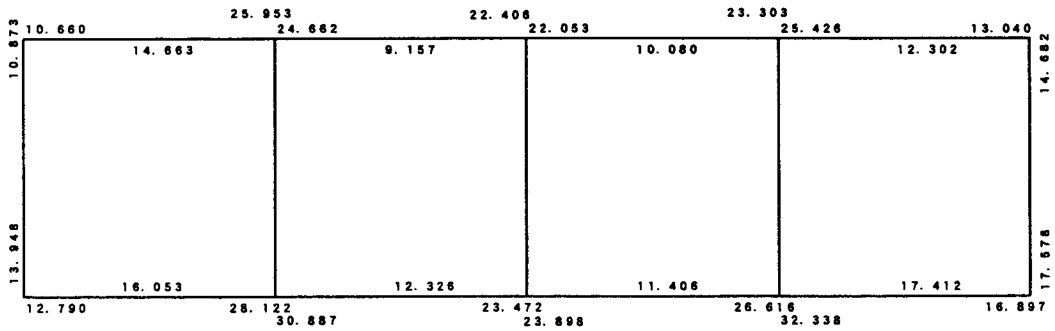
Result of Structural Computation (Case1)



Moment in t-m

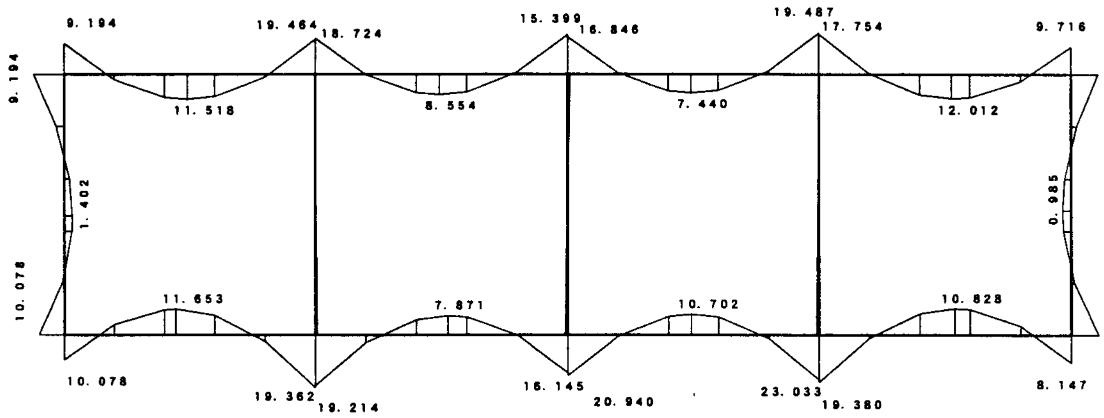


Shearing Force in ton

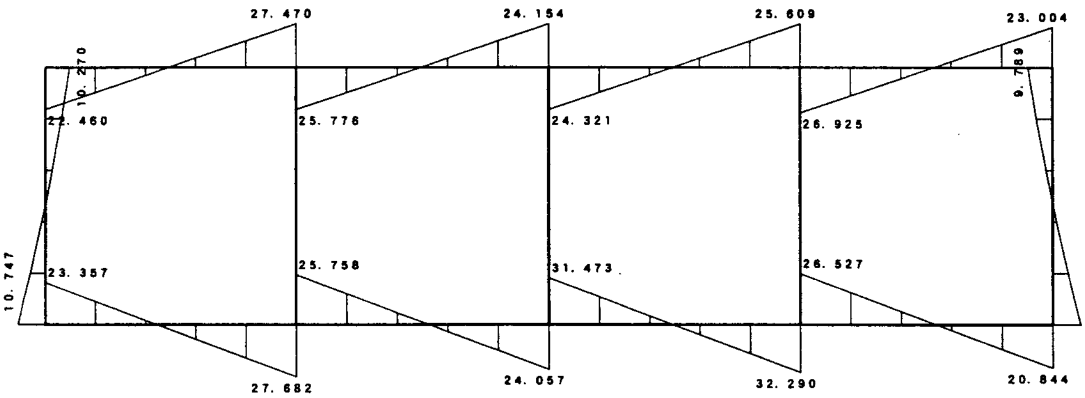


Necessary Reinforcement in cm2

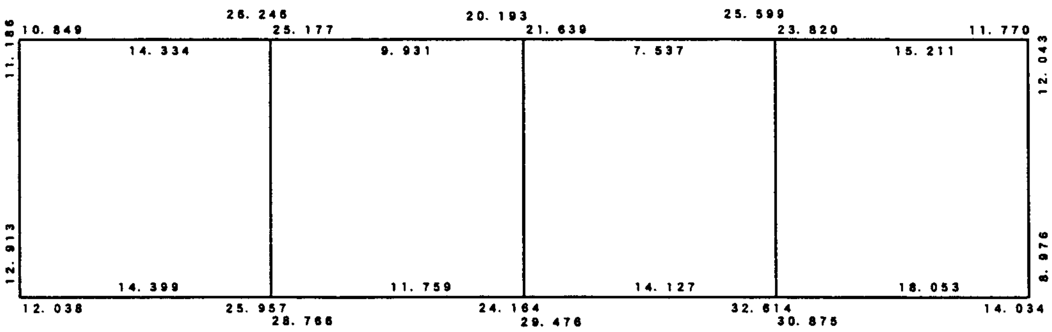
Result of Structural Computation (Case2-1)



Moment in t-m

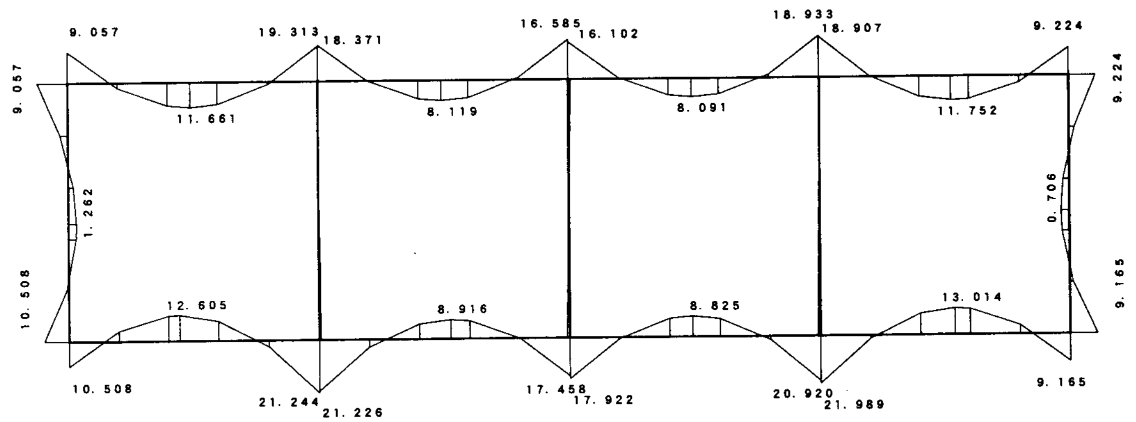


Shearing Force in ton

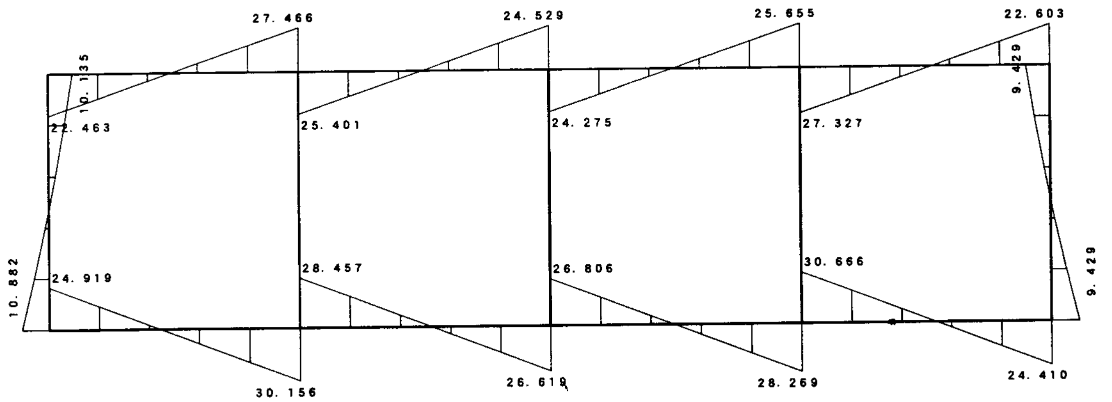


Necessary Reinforcement in cm2

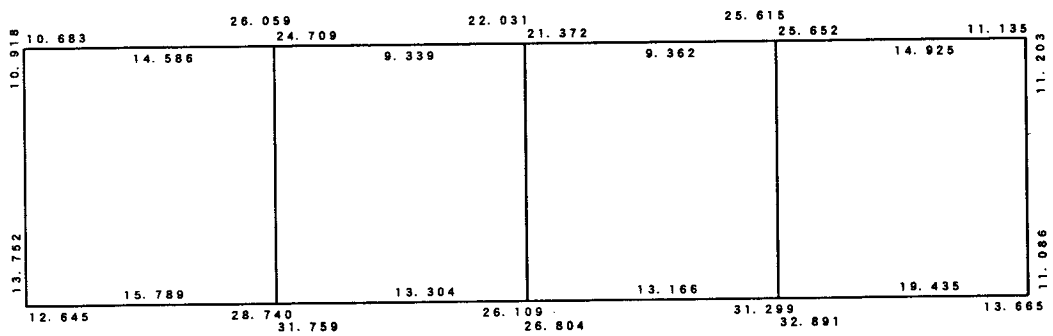
Result of Structural Computation (Case2-2)



Moment in t-m



Shearing Force in ton



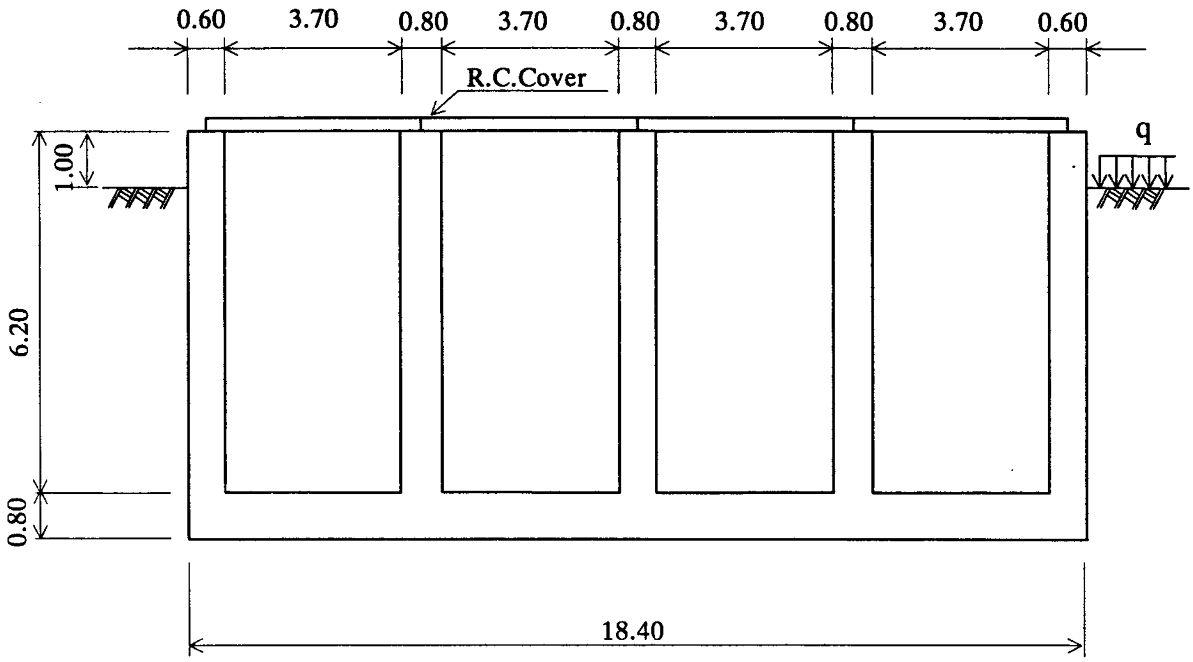
Necessary Reinforcement in cm2

Result of Structural Computation (Case3)

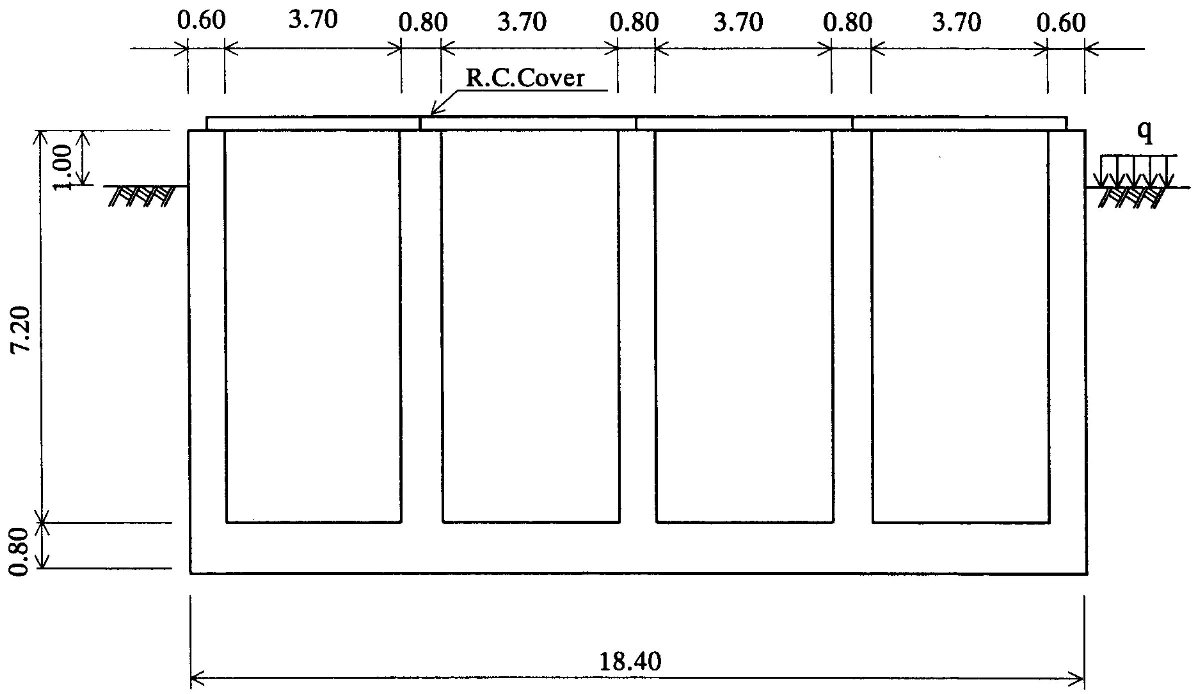
APPENDIX C4.3-2 Structural Computation of Openings

(1) Design Criteria

(a) Sectional Dimension for Analysis



Opening Section (H=6.2 m)

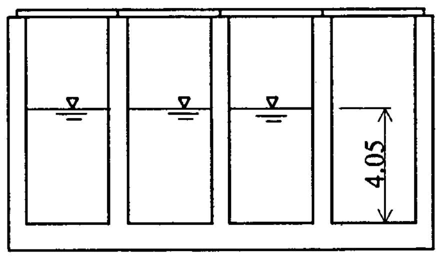


Opening Section (H=7.2 m)

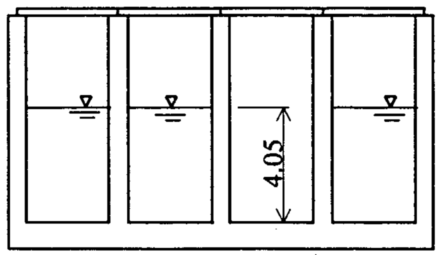
(b) Case of Analysis

Considering condition, next cases should be analyzed each section.

Case 1-1	Empty (Covered)	
Case 1-2	Empty (Not Covered)	
Case 2-1	3 cells filled by Water	(Covered)
Case 2-2	3 cells filled by Water	(Not Covered)
Case 3-1	3 cells filled by Water	(Covered)
Case 3-2	3 cells filled by Water	(Not Covered)



Case 2



Case 3

(c) Active Load

Live Load ; $Q=2.00\ tf/m^2$

(d) Earth Pressure

Coefficient of Earth Pressure ; $Ka=0.333$

Earth Weight ; $\gamma_t=1.8\ tf/m^3$

(e) Design of Reinforcement

Design of reinforcement is decided by using the biggest required area of tension reinforcement

(2) Result of Structural Analysis

Load and sectional force are showed Figure 1～12, and results of analysis are showed Table 1 and 2.

Table 1 Structural Analysis of Opening (H=6.2 m)

Unit ; cm^2

Case		Side Wall (Outside)	Separate Wall	Bottom Plate		
				End (Outside)	Center (Inside)	Center (Outside)
Case 1-1	Covered	24.023	0.000	17.130	4.320	11.533
Case 1-2	Not Covered	27.692	0.000	17.130	0.881	3.885
Case 2-1	Covered	24.023	6.093	17.130	**8.507**	14.033
Case 2-2	Not Covered	**27.692**	**12.970**	**17.130**	6.463	4.287
Case 3-1	Covered	6.155	6.242	6.772	7.495	**17.008**
Case 3-2	Not Covered	9.823	12.970	6.772	3.488	8.665
MAX		27.692	12.970	17.130	8.507	17.008

Table 2 Structural Analysis of Opening (H=7.2 m)

Unit ; cm^2

Case		Side Wall (Outside)	Separate Wall	Bottom Plate		
				End (Outside)	Center (Inside)	Center (Outside)
Case 1-1	Covered	40.089	0.000	27.741	4.585	12.762
Case 1-2	Not Covered	43.758	0.000	27.741	1.591	5.130
Case 2-1	Covered	40.089	16.949	27.741	11.462	15.818
Case 2-2	Not Covered	**43.758**	**23.826**	**27.741**	**14.735**	6.813
Case 3-1	Covered	7.263	17.098	7.831	10.431	**21.049**
Case 3-2	Not Covered	10.932	23.826	7.831	9.504	12.729
MAX		43.758	23.826	27.741	14.735	21.049

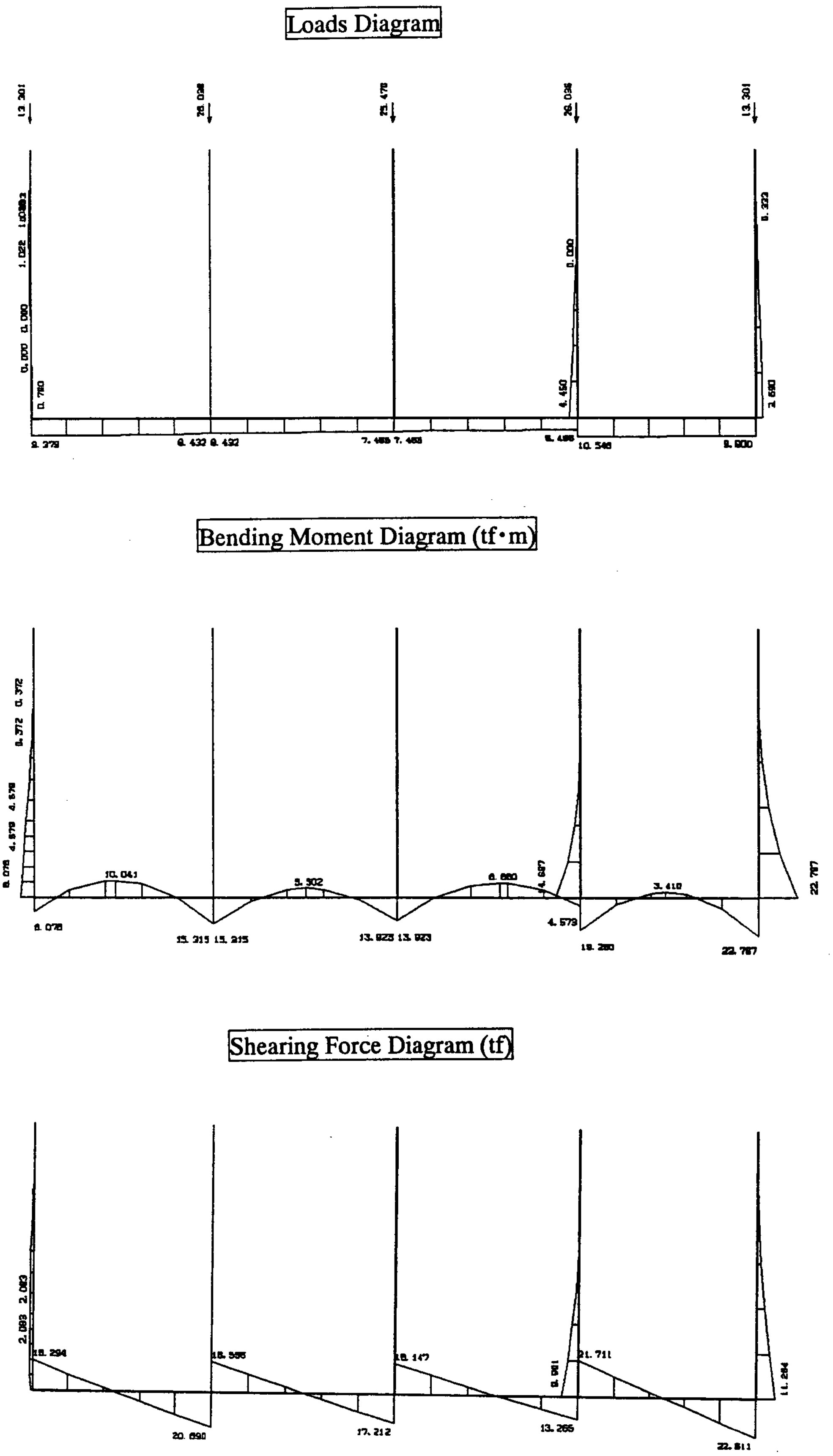
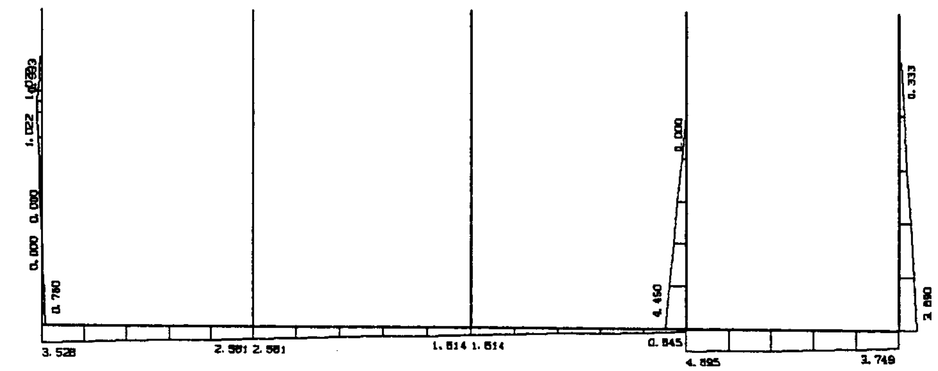
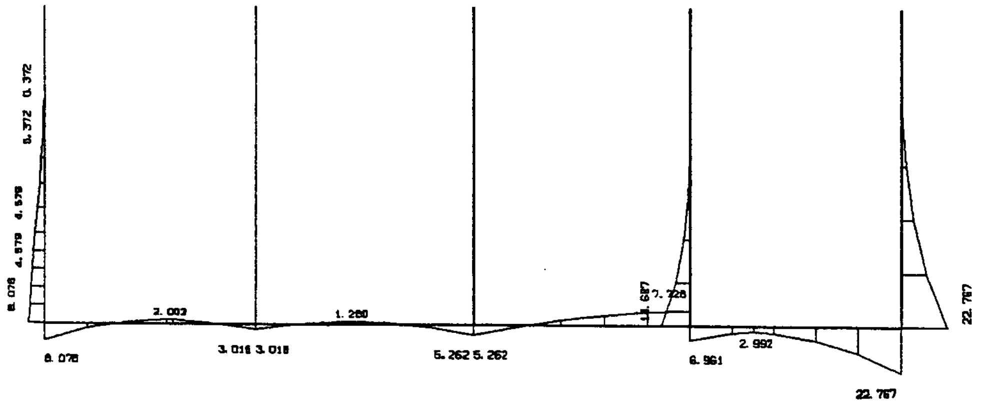


Figure Load and Sectional Force of Opening Section (H=6.2m) Case 2-1

Loads Diagram



Bending Moment Diagram (tf·m)



Shearing Force Diagram (tf)

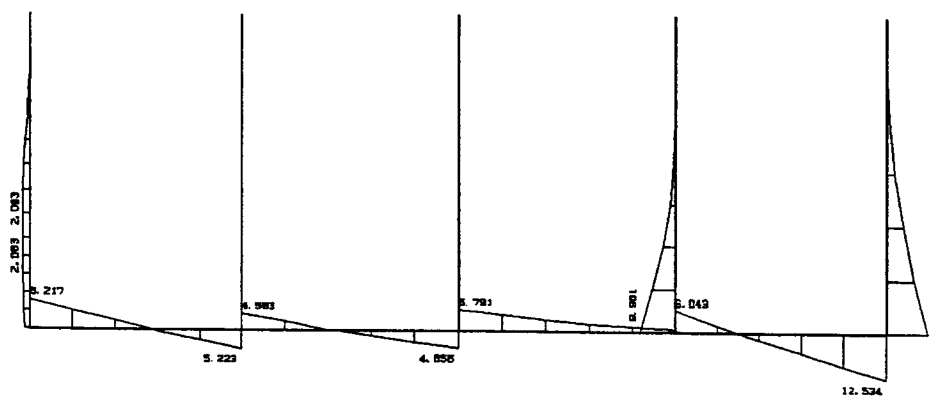
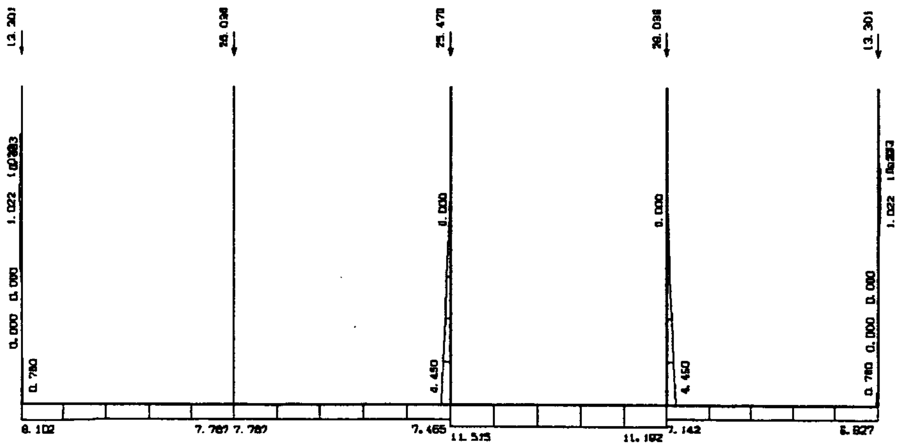
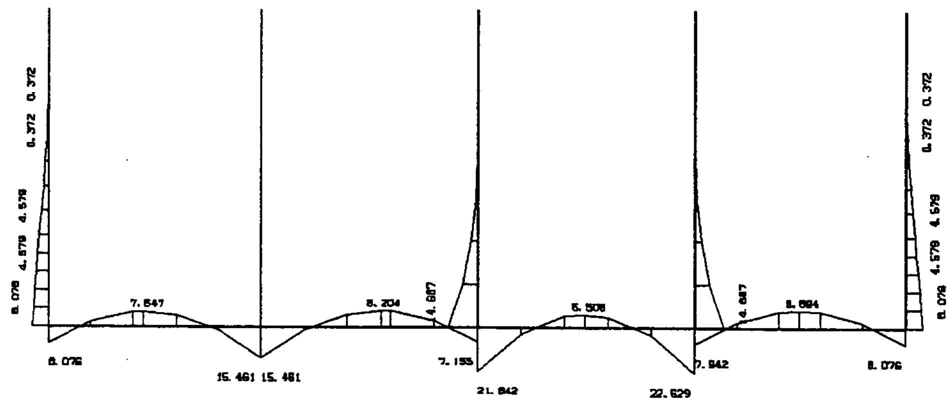


Figure Load and Sectional Force of Opening Section (H=6.2m) Case 2-2

Loads Diagram



Bending Moment Diagram (tf·m)



Shearing Force Diagram (tf)

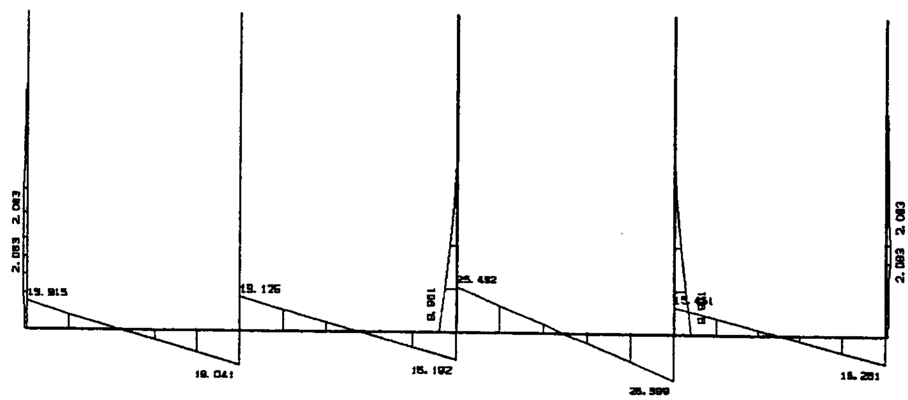
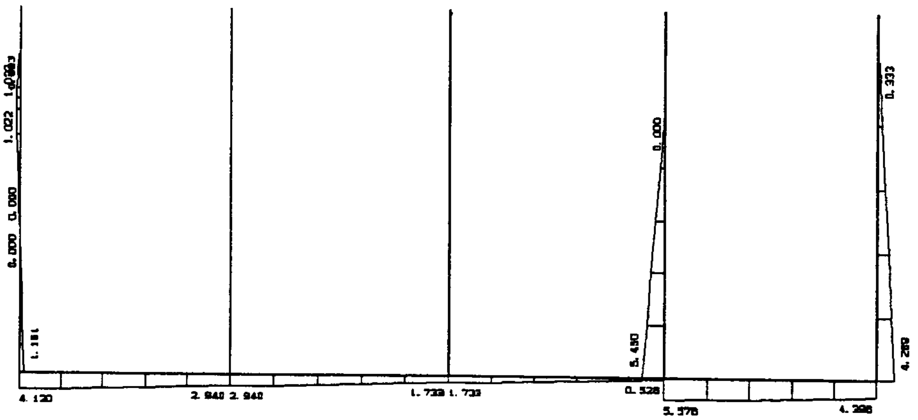
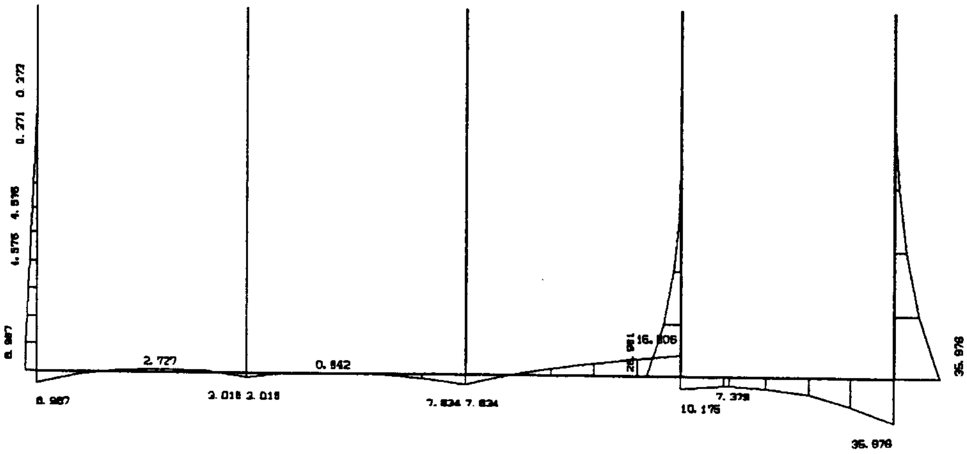


Figure Load and Sectional Force of Opening Section (H=6.2m) Case 3-1

Loads Diagram



Bending Moment Diagram (tf•m)



Shearing Force Diagram (tf)

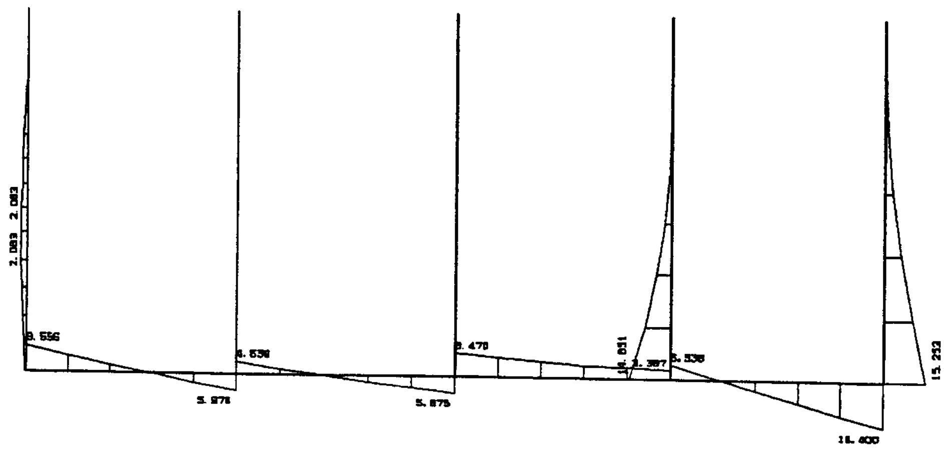
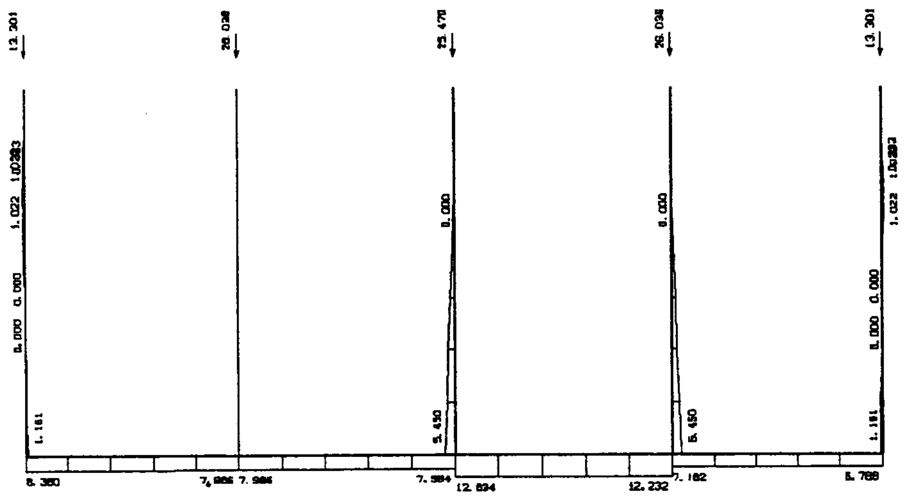
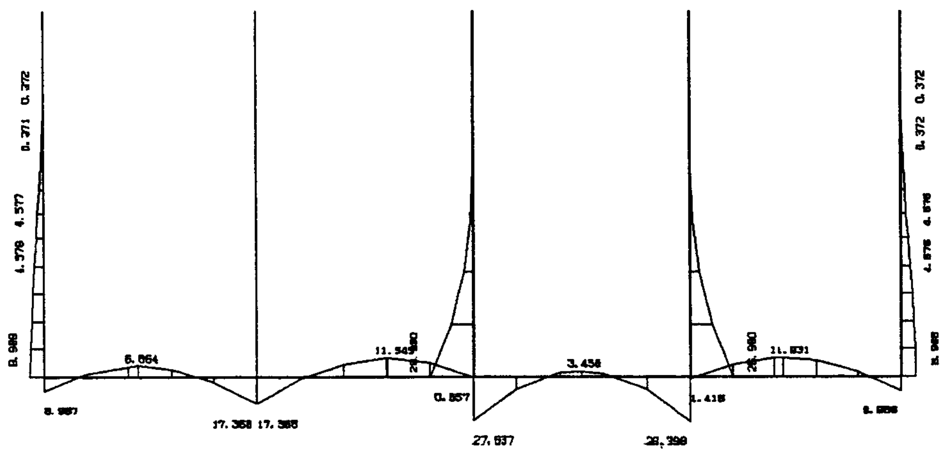


Figure Load and Sectional Force of Opening Section (H=7.2m) Case 2-2

Loads Diagram



Bending Moment Diagram (tf·m)



Shearing Force Diagram (tf)

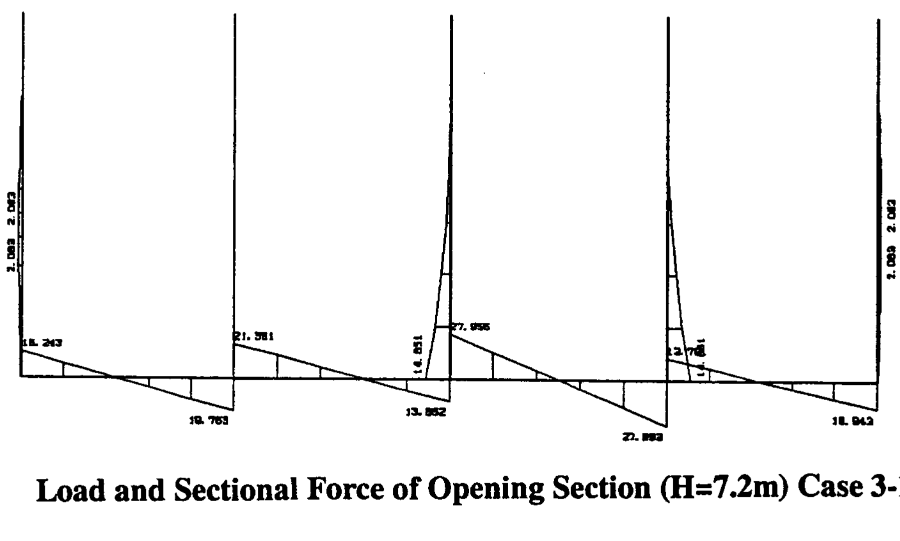


Figure Load and Sectional Force of Opening Section (H=7.2m) Case 3-1

APPENDIX C.4.4-1 Calculation or Detail Procedure of Steel Pipe Wall Thickness

(1) Design condition (summarized)

Steel pipe dimension	Diameter	D = 2400 mm, Dc = 2438.4 mm
		t = 22 mm
Design Inner pressure		P = 12 kgf/cm^2
Earth cover from the top of pipe to the surface of backfill or embankment		H = 1.0 ~ 5.0 m
Vertical load (Truck load)		T - 70
Unit weight of wet soil		γ = 1.8 tf/m^3
Angle of shear resistance		ϕ = 30°
Design support angle		θ = 90°
Reaction modulus of foundation material		E' = 48 kgf/cm^2
Excavation method		Non sheet pile method
Excavation width		B = 23.6/3 = 7.87 m
Material of steel pipe		STPY400
Allowable stress		σa = 1400 kgf/cm^2
Design deflection ratio (%)		3%

(2) Tensile stress by Inner pressure of pipe

$\sigma t = PD/2t$ where, σt : Tensile stress by Inner pressure of pipe (kgf/cm^2)

P : Inner pressure (12 kgf/cm^2)

D : Inner diameter of pipe (Dc–2t= 243.8 – 2 x 2.2 = 239.4 cm)

t : Pipe thickness (t = 2.2cm)

σt = 12 x 239.4 / (2 x 2.2) = 653 kgf/cm^2 < σa = 1400 kgf/cm^2 O.K.

(3) Vertical earth pressure

Vertical earth pressure shall be calculated by following equations;

$$\begin{cases} H \leqq 2.0m & Wv = \gamma \cdot H \quad \text{(Vertical Earth Press.F.)} \\ H > 2.0m & Wv = Cd \cdot \gamma \cdot B \quad \text{(Marston's F.)} \end{cases}$$

$H \leqq 2.0m \quad Wv = \gamma \cdot H$

H = 1.0 m Wv = 0.18 (kgf/cm^2)

H = 2.0 m Wv = 0.36 (kgf/cm^2)

$H > 2.0m \quad Wv = Cd \cdot \gamma \cdot B$

$$Cd = (1 - e - 2K \cdot \mu' \cdot H / B) / 2K\mu'$$

$$K = (1 - \sin\phi) / (1 + \sin\phi) = (1 - \sin 30°) / (1 + \sin 30°)$$

$\therefore$K = 0.33

ϕ' : Friction Angle (generally ϕ = ϕ') $\therefore \phi'$ = 30°

μ : Friction coefficient = tan ϕ' $\therefore \mu$ = 0.58

H (m)	K	μ'	B(cm)	$-2K \cdot \mu \cdot H/B$	$e^{-2K \cdot \mu \cdot H/B}$	Cd	γ	Wv(kgf/cm^2)
3.0	0.33	0.58	787	-0.1453	0.865	0.355	0.0018	**0.503**
4.0				-0.1938	0.824	0.462		**0.655**
5.0				-0.2422	0.785	0.564		**0.799**

(4) Wheel Load

$$Wv = \frac{P \cdot \beta}{W} = \frac{P \cdot \beta}{155 + 2H}$$

$$P = \frac{2 \times \left(\left[\text{FrontWheelLoad}\right] + \left[\text{BackWheelLoad}\right]\right)}{\left[\text{VehicleOccupationWidth}\right]} \times (1 + i)$$

where, Ww : Vertical load by wheel load (kgf/cm^2)

P : Back wheel load per unit length (kgf/cm)

β : Decreasing coefficient of sectional force β = 0.9

W : Distribute width (cm)

H : Earth cover from the top of the pipe to the surface of backfill earth (cm)

i : Impact coefficient

Wheel Load and Vehicle occupation Width

Load	Weight (tf)	Front wheel load (kgf)	Back Wheel load (kgf)	Vehicle Occupation Width(cm)
T-70	70	11650	11700	350

Standard Value of *i*

Road Condition	H < 1.5m	1.5m≦H<2.5m	2.5 m ≦ H
Non-Pavement	0.4	0.3	0.2

Vertical Pressure by Wheel Load

H(m)	Back Wheel Loads (kgf)	Vehicle Occupation width (cm)	i	P (kgf/cm)	β	Wt (kgf/cm^2)
1.0			0.4	187		**0.474**
2.0			0.3	173		**0.281**
3.0	11700	350	0.2	160	0.9	**0.191**
4.0			0.2	160		**0.151**
5.0			0.2	160		**0.125**

(5) Calculation of Deflection

$$\Delta X = \frac{2Kx \cdot (Wv + Wt) \cdot R^4}{EI + 0.061E' \cdot R^3}$$

Coefficient by Support Angle of Foundation

Support Angle	Kb	Kx	0.061Kb - 0.083Kx
90°	0.157	0.096	0.00171

R : Mean radius of the pipe R = (243.8 - 2.2) / 2 = 120.8 cm

E : Modulus of elasticity of the pipe E = 2100000 kgf/cm^2

I : Moment of inertia per unit length of cross-section of the pipe wall

$I = t^3 / 12 = 2.2^3 / 12 = 0.887$ cm^4

E' : Modulus of Soil Reaction E' = 48kgf/cm^2

Calculation of Deflection

H(m)	Wv	Wt	ΔX	Design Deflection Ratio ΔX/D×100 (%)			Judge
1.0	0.180	0.474	3.804	**1.6%**	<	3%	O.K.
2.0	0.360	0.281	3.732	**1.5%**	<	3%	O.K.
3.0	0.503	0.191	4.036	**1.7%**	<	3%	O.K.
4.0	0.655	0.151	4.688	**1.9%**	<	3%	O.K.
5.0	0.799	0.125	5.378	**2.2%**	<	3%	O.K.

(6) Flexural Stress

$$\sigma_b = \frac{2(Wv + Wt)}{f \cdot Z} \times \frac{Kb \cdot R^2 \cdot EI + (0.061Kb - 0.083Kx) \cdot E' \cdot R^5}{EI + 0.061E' \cdot R^3}$$

σ_b : Bending stress at the bottom of pipe

f : Coefficient by shape =1.5

Z: Section modulus $Z = t^2 / 6 = 2.2^2 / 6 = 0.81$ (cm³/cm)

Kb : Coefficient for bending moment at the bottom of pipe Kb = 0.157

Calculation of Flexural Stress

H(m)	Wv	Wt	σ_b		σ_a	Judge
1.0	0.180	0.474	**977**	<	1400	O.K.
2.0	0.360	0.281	**959**	<	1400	O.K.
3.0	0.503	0.191	**1037**	<	1400	O.K.
4.0	0.655	0.151	**1204**	<	1400	O.K.
5.0	0.799	0.125	**1382**	<	1400	O.K.

Following table shows in case 1m to 5m earth cover and 15 mm to 22 mm pipe wall thickness based on 70 ton truck load as an example.

D=2400mm
Dc=2438mm

Upper : Deflection ratio (%)
Lower : Bending stress (kgf/cm²)

H(m) \ t	15	16	19	22
1.0	**1.9% 1386 O.K.**	**1.9% 1297 O.K.**	**1.7% 1111 O.K.**	**1.6% 977 O.K.**
2.0	**1.9% 1360 O.K.**	**1.8% 1273 O.K.**	**1.7% 1090 O.K.**	**1.5% 958 O.K.**
3.0	2.0% 1470 OUT!	**2.0% 1377 O.K.**	**1.8% 1179 O.K.**	**1.7% 1037 O.K.**
4.0	2.4 1708 OUT!	2.3% 1599 OUT!	**2.1% 1369 O.K.**	**1.9% 1204 O.K.**
5.0	2.7% 1959 OUT!	2.7% 1835 OUT!	2.5% 1571 OUT!	**2.2% 1382 O.K.**

Notes : Hatched thickness is minimum required thickness for each earth cover.

APPENDIX C.4.4-2 Required Length for Thrust Load and Restriction Force

The horizontal force P_1 and axial force P_2 for discharged pipes will act at the bending part of the pipes and deflection δ_1 by P_1 and expansion δ_2 by P_2 will be occurred at the bending part of the pipes. The relationship between balance of forces and deflection by P_1 and P_2 can be respectively developed as follows :

$$P_1 \cos\theta + P_2 \sin\theta = P/2,$$

$$\delta = \frac{\delta_1}{\cos\theta} = \frac{\delta_2}{\sin\theta} \quad \text{and} \quad \delta_1 = \frac{P_1 \cdot \beta}{D_c \cdot K}, \quad \delta_2 = \frac{P_2{}^2}{2\alpha D_c}$$

From the above equation, P_1, P_2 and l_1, l_2 can be developed as follows :

Effective required length for the bending force and axial force shall be longer than l_1 and l_2 which can be calculated by the following equations:

$$l_1 = \pi/\beta$$

$$l_2 = P_2 / \mu \cdot w \cdot H_c \cdot \pi \cdot D_c$$

Then, $$P_1 = \frac{P_h}{2 \cdot \cos\theta} - P_2 \cdot \tan\theta$$

$$P_2 = -\frac{\alpha \cdot \beta}{K} \cdot \tan^2\theta + \sqrt{\left(\frac{\alpha \cdot \beta}{K} \cdot \tan^2\theta\right)^2 + \frac{\alpha \cdot \beta \cdot P_h \cdot \tan\theta}{K \cdot \cos\theta}}$$

$$\alpha = A_s \cdot E \cdot \mu \cdot w \cdot H_c \cdot \pi$$

$$\beta = \sqrt[4]{\frac{K \cdot D_c}{4E \cdot I}}$$

Where, l_1 : Required effective length of straight pipeline against bending force (kgf)

l_2 : Required effective length of straight pipeline against axial force (kgf)

P_h : Thrust force (kgf)

P_1 : Right angle force to axial of pipeline (kgf)

P_2 : Axial force at A point (kgf)

A_s: Real sectional area of pipe (cm^2) $\quad A_s = \frac{v}{4}\left(244^2 - 240^2\right) = 1520\,cm^2$

E : Young's modulus $\quad E = 2.1 \times 10^6$ (kg/cm^3)

I : Geometrical moment of inertia (cm^4)

$$I = \frac{\pi}{64}\left(D_c{}^4 - D^4\right) = \frac{3.14}{64}\left(244^4 - 240^4\right) = 1.11 \times 10^7\,cm^4$$

D_c: Outside diameter of pipe (cm)

2θ : Intersection angle (°)

K : Soil repulsive modulus at horizontal direction.(kgf/cm^3)

$K = 0.691 \cdot N^{0.406}$ (kgf/cm^3) by Hukuoka, and Udo

μ : Friction factor $\quad \mu = \tan\phi \quad \phi$: Angle of shearing resistance. (°)

w : Unite weight of soil. (kgf/cm^3)

H_c: Height of ground surface above top of pipe. (cm)

t : Pipe wall thickness. (cm)

Result of Required length calculation

Location	Intersection angle θ(°)	Inner Pressure H (tf/m^2)	Vertical thrust force Ph (kg)	Axial force at A P2(kg)	Effective length L1 (cm)	Effective length L2 (cm)	**Applied effective length (cm)**
IP.16	34.83	120	335432	258155	2124	1407	**2124**
IP.17'-1	10.92	80	71094	107537	2124	586	**2124**
IP.17	21.83	80	141479	152744	2124	832	**2124**
IP.18'-1	26.42	80	170744	163833	2124	893	**2124**
IP.19'	12.17	80	79203	114794	2124	626	**2124**
IP.20'	9.67	80	62976	99514	2124	542	**2124**
IP.21'-1	10.00	60	48840	83209	2124	454	**2124**
IP.22'	30.02	20	48377	46666	2124	255	**2124**

Soil repulsive modulus at horizontal direction : $K = 0.691 \cdot N^{0.406} = 1.76 kgf/cm^3$ (N : Assumed N value : 10)

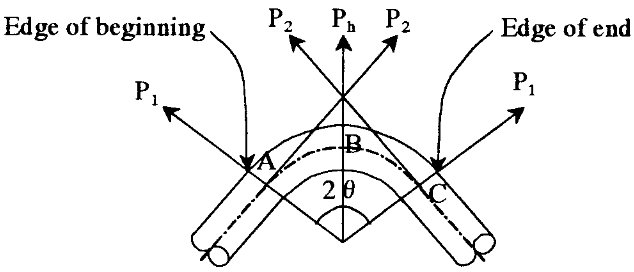


Diagram of thrust force

As shown above calculation, if there is structurally continuous length more than 21.3m of steel pipeline without any joint in case 1m earth cover, no thrust block is requested. it is generally accepted in the steel pipeline without provision of any thrust block as a common knowledge.

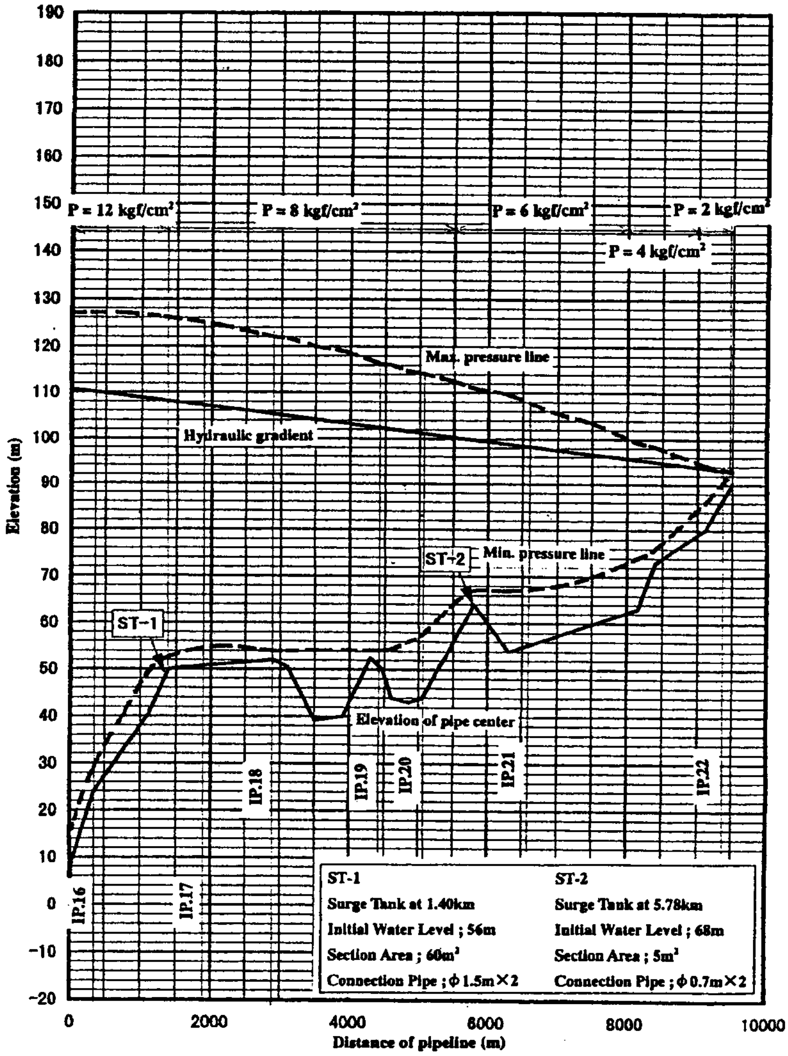


Figure 1 Proposed Design Pressure by Each Block

APPENDIX C.4.4-3 Necessary and Unnecessary of Flexible Pipe Joint

Flexible pipe joint may not be necessary in the steel pipeline and following estimations of pipe settlement and stress are also shown unnecessary of flexible pipe joint.

(1) Assume unequal settlement (Type A)

Immediate settlement at high embankment, at highly sand deposition or at truck load will be anticipated unequal settlement, but consolidation settlement due to poor ground will not be anticipated in these site. It will be estimated at those occasions that longitudinal stress in pipe may be caused.

Immediate settlement at certain condition may be estimated by the following equation.

$$S=(1-v^2)\times q\times H\times B\times I/Es$$

where, S :Immediate settlement after load increase

H :Height of embankment =5m (assumed)

q : Unit weight of soil = 1.8 t/m^3

v : Poisson ratio = 0.3

B :Width of structure = 12m

Es: Young's modulus of soil $28N \doteqdot 28\times 5=140kg/cm^2=1400t/m^2$

Assumed N value; 5

I : Coefficient of settlement =1.05

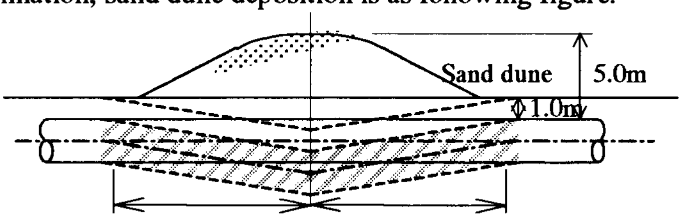
$$S = (1-0.3^2)\times 1.8\times 5\times 12\times 1.05\times 1/1400 = 0.07m$$

Then in case Type A (refer to attached Figure 1), longitudinal stress of pipe may be estimated approx.500kg/cm^2 $<$1,400kg/cm^2 (allowable stress of pipe) OK

(2) Assume unequal settlement (Type B)

Continuous unequal settlement may also be anticipated at highly sand deposition, or at truck load passing.

Condition of estimation; sand dune deposition is as following figure.



$H = 1$ m to $H = 5.0m$ $\Delta H = 4m$

Then, $S = (1-0.3^2)\times 1.8\times 4\times 12\times 1.05\times 1/1400 = 0.06m$

$a = -0.06m/30m = -0.002$, $b = 0.06m/30m = 0.002$ $b-a = 0.004$

Then in case Type B (refer to attached Figure 2) longitudinal stress of pipe may be estimated approx.525 kg/cm^2 ---------- O.K

(3) Places need flexible pipe joint

The following places need flexible pipe joint:

Both front and back sides of valve chamber, air valve chamber and other same structural places as shown above reasons.

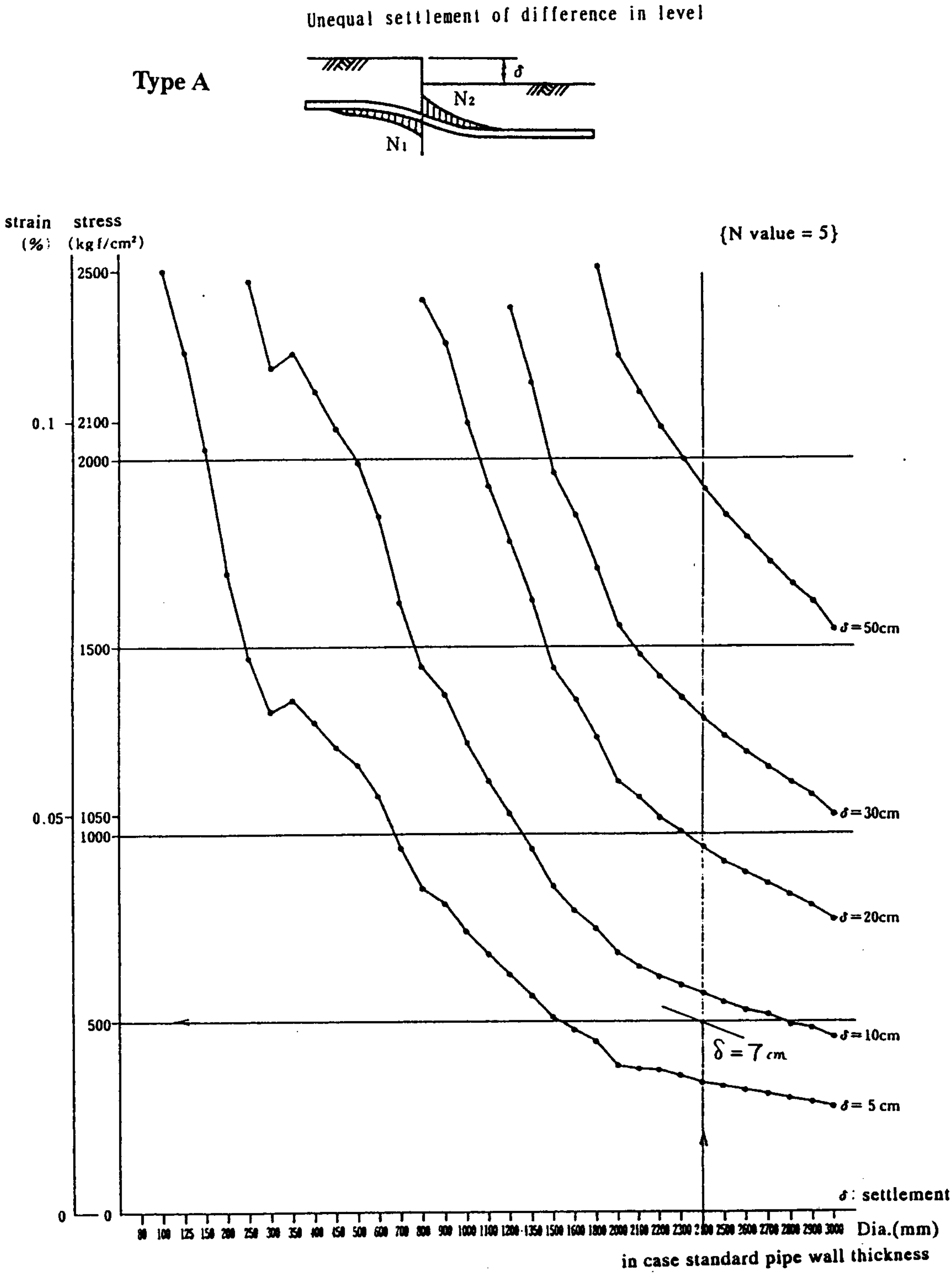


Figure 1 Relation Between Unequal Settlement (Type A) and Stress

Type B

Unequal settlement for long line as zigzag

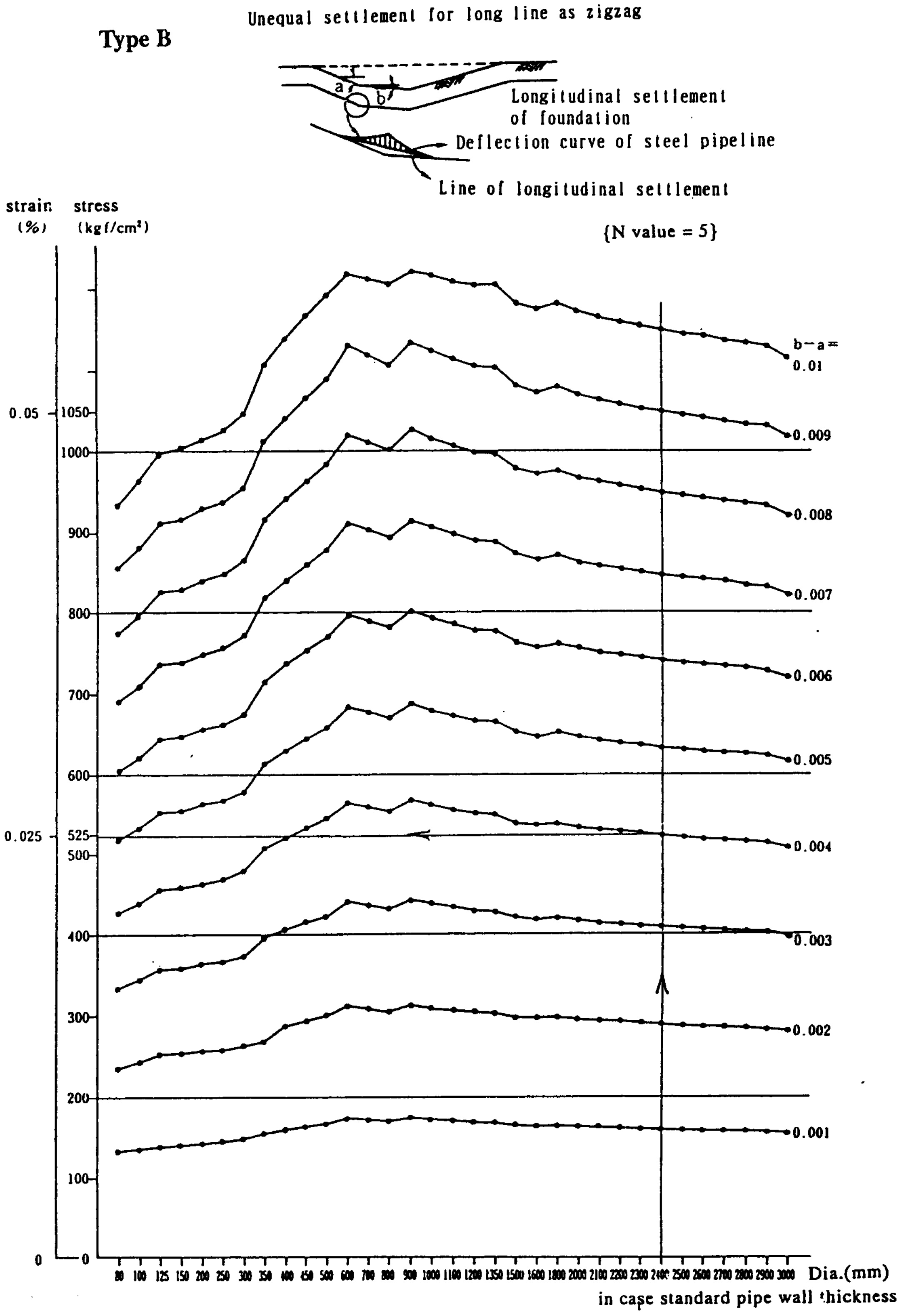


Figure 2 Relation Between Unequal Settlement (Type B) and Stress

APPENDIX C.4.4-4 Design of Cathodic Protection System

(1) General

This specification covers the design of the cathodic protection system for the underground pipelines in Egypt.

(2) Codes and Standards

The following standards and codes shall be used as guidance for design and materials for the cathodic protection system:

・BS7361 Cathodic Protection Part 1 Code of practice for land and marine applications (formerly CP 1021)

・NACE RP0169-96 "Control of External Corrosion on Underground or Submerged Metallic Piping system"

・International Electro Technical Commission (IEC)

・Japanese Industrial Standard (JIS)

(3) Basic Requirement

(a) Protection Method

The impressed current system shall be employed considering pipeline diameter and soil resistively.

(b) Electrical Insulation

To prevent electrical connection with any foreign metallic structure, (such as concrete reinforcing steel bar, earthing, casing, cable rack, other underground piping, heat exchangers and existing pipeline) insulating flanges shall be installed at the underground protected pipelines. Also electrical insulation should be taken for instrument cable conduit, if required.

(4) Structures to be Protected

Underground Piping Description

Classification	Pipe Nominal Size (mm)	Pipe Outer Diameter (m)	Pipe Length (m)	Protected Area (m^2)
Water supply pipe	2400	–	9400	70838

quantity of line 3 lines

Pipe Service Condition

Material	Fluid	Operation temp	Coating
	Fresh water mixed with seawater	40℃	Asphalt vinilon cloth

(5) Design Conditions

- Soil Resistively of Anode Ground bed Design

4000 ohm-cm(Assumed)

- Criteria of Cathodic Protection

The pipe-to-soil potential should be more negative than -0.85 volt with respect to a copper/copper sulfate reference electrode at all test stations when the protective current is applied.

- Protective Current Density

1.0mA/m2

- Design Life of Anode

20 years

(6) Design Calculation

Impressed current system for underground piping

Service	Water
Protective Current Requirement	213A
Transformer-rectifier 50V×50A	6unit
Quantity of High Silicon Iron Anode	96pcs
Width of Ground bed	70m/groundbed
Diameter of anode	0.16m
Depth of bore hole	Approx. 6.0m

・Design calculation of impressed Current System For Underground Piping (Phase1)

Protective current requirement are calculated by the following formula;

$Ip = S \times i$

where,

Ip : protective current requirement (mA)

S : Protective area (m2)

I : Current density (mA/ m2)

thus; Ip=70838(m2)×1.0(mA/ m2)×3line=213A

・Ground bed Conditions

Approx. 6m deep ground bed will be applied to this design.

・Earthing Resistance of Ground bed

Earthing resistance of ground bed (Ra) is calculated by the following formula ;

$$Ra = \frac{\rho}{2\pi Lnp}\left\{\log_e\left(\frac{4L}{a}\right) - 1 + \frac{2L}{I_a}\log_e(0.656 \times np)\right\}$$

where,

Ra	:	Earthing resistance of ground bed	(ohm)
ρ	:	Soil resistively at ground bed	(ohm-m)
L	:	Length of ground bed	(m)
a	:	Radius of ground bed	(m)
Ia	:	Space of anode to anode	(m)
np	:	Quantity of anode in ground bed	(pcs)

when, ρ=40 ohm-m , L=2.0m ,a=0.08m ,np=8pcs ,Ia=10m.

then, Ra=1.73 ohm/ground bed

2 ground bed are required.

・DC Output Voltage Required

DC output voltage requirement (E) is calculated by the following formula,

E = Io (Ra + Rc + Rw) + Ew

where,

E	:	Output voltage required	(V)
Io	:	Design output current of transformer-rectifier	(A)
Ra	:	Earthing resistance of groundbed	(ohm)
Rc	:	Earthing resistance of protective structures	Negligible (ohm)
Rw	:	Resistance of wiring	Max. 0.2 (ohm)
Ew	:	Back Voltage	2.0 (V)

when, Io = 35.5A, Ra = 1.73 ohm/groundbed 0.87

Rw = 0.2 ohm

Ew = 2.0 V

then, E = 40V (≦50V)

Thus, output rating of 50 volts is sufficient to current required.

・Design Life of Anode

The design life of Anode is calculated by the following formula;

$$T = \frac{W}{C \times Ia} \times 0.6$$

Where, T : Design life of anode (Year)

W	:	Net weight of anode	22.7 (kg)
C	:	Consumption rate of anode	0.25 (kg/A・year)
la	:	Maximum output current of anode	2.3 (A)
0.6	:	Utilization factor	

Thus, $$T = \frac{22.7}{0.25 \times 2.3} \times 0.6 = 24\,years(> 20\,years)$$

(7) Required capacity of transformer rectifier

Capacity of transformer rectifier will be calculated by the following formula;

$P = f \cdot A \cdot E$

where, P : Required capacity of the electricity (kw)

A : 213A÷6units = 35.5A

E : 40V

f : Coefficient 1/0.7

Thus; $P = (1/0.7) \times 35.5 \times 40 \fallingdotseq 2.1$ kw

Then; Capacity of the transformer recitifier = $2.1 / 0.75 \fallingdotseq 3$ KVA

(8) Comparison study on power source for substation or solar generation system

There is no power source entirely along the pipeline. There are two alternatives of power source, one is to get from substation of No.7 pumping station and the other is to get from solar and battery generation system. The comparison of these two alternatives is tabulated he following table and proposed source of electricity for the cathodic protection system shall obviously be from the substation of No.7 pumping station.

Comparison study on power source from substation or solar generation

Items	Substation supply	Solar cell generation
Construction cost	Cost for cable Steel tape armor cable (4-cv cable 66-V $70mm^2$) 9,400mm × 10LE=950,000LE Labor installation 500m × 200LE = 100,000LE Total **1,050,000 LE**	Cost for solar generation and battery solar cell 300,000LE Controller 100,000 Battery 200,000 × 10 = 2,000,000 (300AH × 4sets 3year life cycle Then 10 times renewal for 30 year) Sub-total 2,400,000/unit Total for 6 units **14,400,000LE**
Conclusion	◎	

APPENDIX C.4.4-5 Structural Design of Surge Tank

(1) Pipe wall thickness of surge tank

(a) ϕ1500 (Surge tank No.1)

(i) Design condition (summarized)

Steel pipe dimension	Diameter	D = 1500 mm, Dc = 1524 mm
		t = 12 mm
Design Inner pressure		P = 12 kgf/cm^2
Earth cover from the top of pipe to the surface of backfill or embankment		
		H = 4.0 m
Vertical load (Truck load)		T - 70
Unit weight of wet soil		γ = 1.8 tf/m^3
Angle of shear resistance		ϕ = 30°
Design support angle		θ = 90°
Reaction modulus of foundation material		E' = 48 kgf/cm^2
Excavation method		Non sheet pile method
Excavation width		B = 23.6/3 = 7.87 m
Material of steel pipe		STPY400
Allowable stress		σa = 1400 kgf/cm^2
Design deflection ratio (%)		3%

(ii) Tensile stress by Inner pressure of pipe

$\sigma t = PD/2t$ D : Inner diameter of pipe (Dc – 2t = 152.4 – 2 x 1.3 = 150 cm)

$\therefore \sigma t$ = 12 x 150 / (2 x 1.3) = 691 kgf/cm^2 < σa = 1400 kgf/cm^2 O.K.

(iii) Vertical earth pressure

Vertical earth pressure shall be calculated by following equation;

$H > 2.0m \quad Wv = Cd \cdot \gamma \cdot B$

$$Cd = (1 - e - 2K \cdot \mu' \cdot H / B) / 2K\mu'$$

H (m)	K	μ'	B(cm)	$-2K \cdot \mu \cdot H/B$	$e^{-2K \cdot \mu \cdot H/B}$	Cd	γ	Wv(kgf/cm^2)
4.0	0.33	0.58	787	-0.1938	0.824	0.462	0.0018	0.655

(iv) Wheel Load

$$Wv = \frac{P \cdot \beta}{W} = \frac{P \cdot \beta}{155 + 2H}$$

$$P = \frac{2 \times ([\text{FrontWheelLoad}] + [\text{BackWheelLoad}])}{[\text{VehicleOccupationWidth}]} \times (1 + i)$$

H(m)	Back Wheel Loads (kgf)	Vehicle Occupation width (cm)	i	P (kgf/cm)	β	Wt (kgf/cm^2)
4.0	11700	350	0.2	160	0.9	0.151

(v) Calculation of Deflection

$$\Delta X = \frac{2Kx \cdot (Wv + Wt) \cdot R^4}{EI + 0.061E' R^3}$$

H(m)	Wv	Wt	ΔX	Design Deflection Ratio ΔX/D×100 (%)	Judge
4.0	0.655	0.151	3.223	**2.1%** < 3%	O.K.

(vi) Flexural Stress

$$\sigma_b = \frac{2(Wv + Wt)}{f \cdot Z} \times \frac{Kb \cdot R^2 \cdot EI + (0.061Kb - 0.083Kx) \cdot E' R^5}{EI + 0.061E' R^3}$$

H(m)	Wv	Wt	σ_b		σ_a	Judge
4.0	0.655	0.151	**1353**	<	1400	O.K.

(b) ϕ 700 (Surge tank No.2)

(i) Design condition (summarized)

Steel pipe dimension   Diameter   D = 700 mm, Dc = 711.2 mm

t = 6 mm

Design Inner pressure   P = 12 kgf/cm^2

Earth cover from the top of pipe to the surface of backfill or embankment

H = 4.0 m

Vertical load (Truck load)   T - 70

(ii) Tensile stress by Inner pressure of pipe

$\sigma t = PD/2t$ D : Inner diameter of pipe (Dc – 2t = 71.2 – 2 x 0.6 = 69.9 cm)

$\therefore \sigma t = 12 \times 69.9 / (2 \times 0.6) = 699$ kgf/cm^2 < $\sigma a = 1400$ kgf/cm^2 O.K.

(iii) Vertical earth pressure

H (m)	K	μ'	B(cm)	$-2K \cdot \mu \cdot H/B$	$e^{-2K \cdot \mu \cdot H/B}$	Cd	γ	Wv(kgf/cm^2)
4.0	0.33	0.58	787	-0.1938	0.824	0.462	0.0018	0.655

(iv) Wheel Load

H(m)	Back Wheel Loads (kgf)	Vehicle Occupation width (cm)	i	P (kgf/cm)	β	Wt (kgf/cm^2)
4.0	11700	350	0.2	160	0.9	0.151

(v) Calculation of Deflection

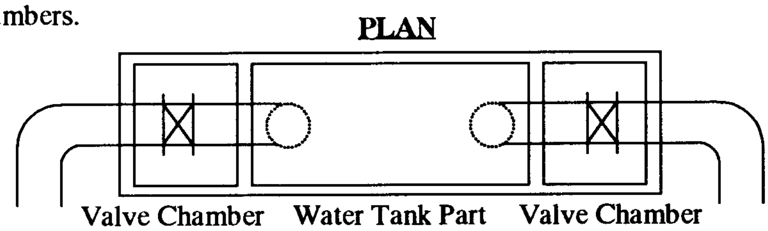
H(m)	Wv	Wt	ΔX	Design Deflection Ratio ΔX/D×100 (%)	Judge
4.0	0.655	0.151	1.439	**2.0%** < 3%	O.K.

(vi) Flexural Stress

H(m)	Wv	Wt	σ_b		σ_a	Judge
4.0	0.655	0.151	**1277**	<	1400	O.K.

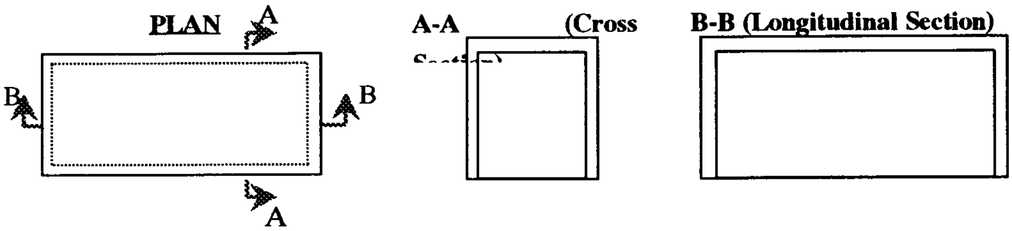
(2) Structural calculation of Surge Tank

There are two surge tanks, No.1 and No.2, and each of them consist of water tank part and two valve chambers.



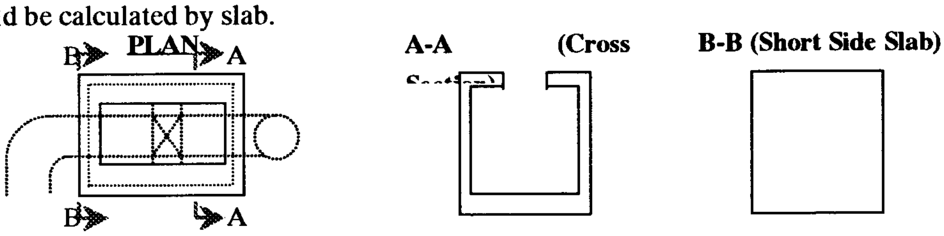
Surge tank No.1 water tank

Two section, cross section (A-A) and longitudinal section (B-B) should be calculated by gate shaped rigid frame.



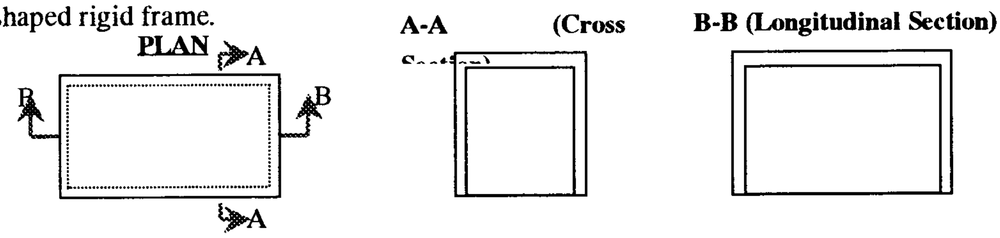
Surge tank No.1 valve chamber

Long side slabs and bottom slab should be calculated by rigid frame. And short side slab should be calculated by slab.



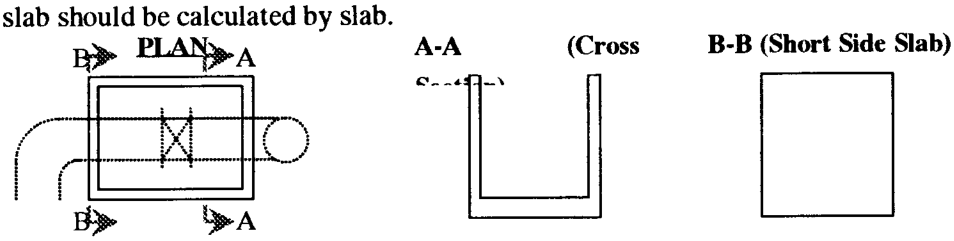
Surge tank No.2 water tank

Two section, cross section (A-A) and longitudinal section (B-B) should be calculated by gate shaped rigid frame.



Surge tank No.2 valve chamber

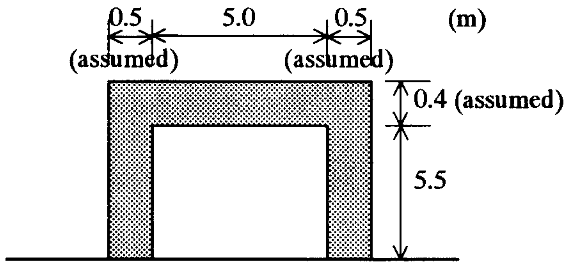
Long side slabs and bottom slab should be calculated by flume (rigid frame). And short side slab should be calculated by slab.

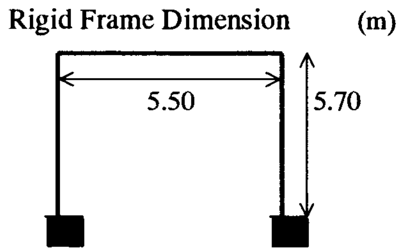


Surge Tank No.1 (Water Tank Part)

(a) Sectional Dimension for Calculation

Surge tank (water tank) should be calculated by Gate Shaped Rigid Frame.



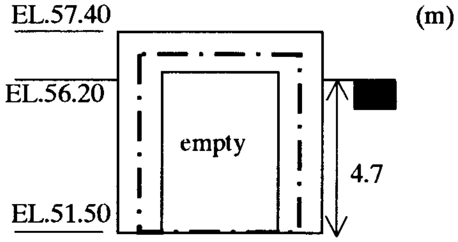


(b) Calculation of Load

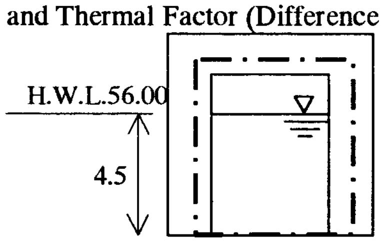
(i)Case of Calculation

Considering condition, following cases should be calculated.

Case 1 5.0m sand covered on the Pipe



Case2 Consider Inner Water Pressure and Thermal Factor (Difference 21℃)

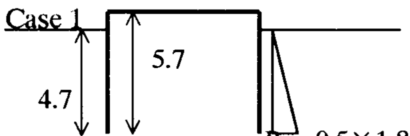


(ii) Own Weight and Earth Weight Applied for Top Slab (W_1)

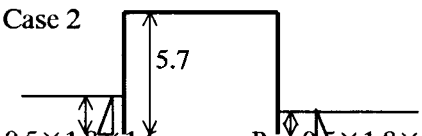
Concrete Weight of Top Slab 0.980 tf/m^2 (= 0.40 * 2.45)

(iii) Side Earth Pressure (P_1)

Side earth pressure should be calculated by following equation; $P = K_0 \times \gamma_t \times H$



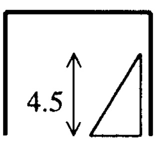
$P_1 = 0.5 \times 1.8 \times 4.7$
$= 4.230$ tf/m^2



$P_1 = 0.5 \times 1.8 \times 1.6$
$= 1.440$ tf/m^2

$P_2 = 0.5 \times 1.8 \times 0.7$
$= 0.630$ tf/m^2

(iv) Inner Water Pressure (P_3)

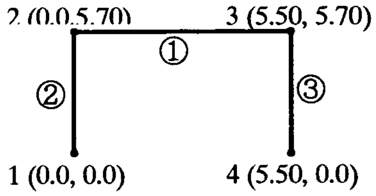


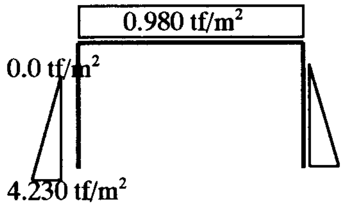
$P_3 = 1.0 \times 4.5 = 4.5$ tf/m^2

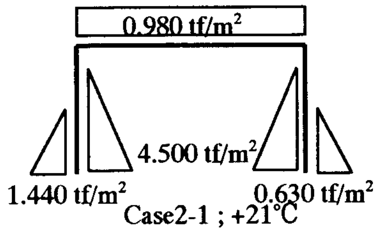
(v) Load Distribution

Load Distribution, Element Number, Contact Point Number and Coordinates are figured as follows.

Element Number, Contact Number and Coordinates **Case1 Load Distribution** **Case2 Load Distribution**







Case2-1 ; +21°C

Case2-2 ; -21°C

(c) Result of Calculation

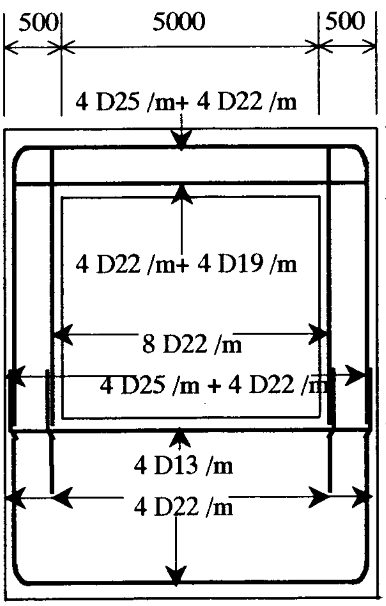
	Top Slab		Side Slab	
	Outside	Inside	Outside	Inside
Case 1	① 2.627 2.625	① 10.790 0.000	②,③ 6.231 2.695	②,③ 2.497 0.000
Case 2-1	① 4.352 6.024	① 13.955 0.634	②,③ 11.349 0.000	②,③ 14.397 7.327
Case 2-2	① 16.590 6.035	① 1.781 0.645	②,③ 16.590 0.630	②,③ 19.947 9.603

Upper : Element Number
Middle: Bending Moment (tf・m)
Lower : Shearing Force (tf)

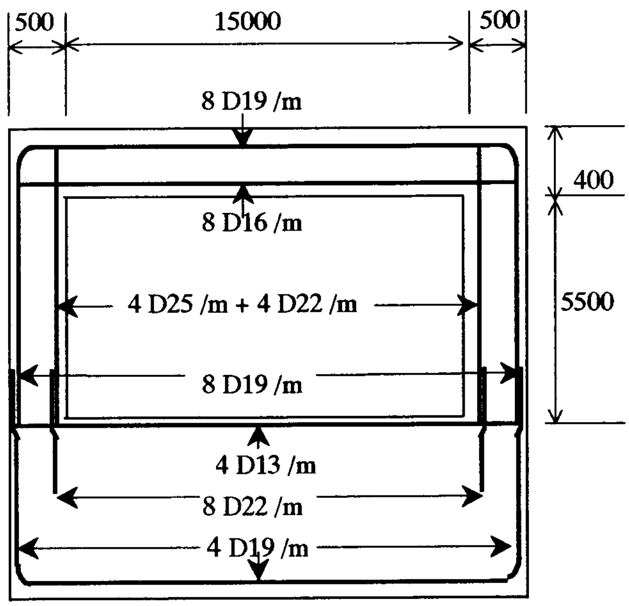
(d) Design of Reinforcement

By using result of calculation reinforcement should be designed as following figure.

<Cross Section>



<Longitudinal Section>



(e) Stress Analysis

Stress analysis will be shown at next page.

Stress Analysis of North Sinai Surge Tank No.1 (Water Tank)

			Top Slab Outside	Top Slab Inside	Side Slab Outside	Side Slab Inside
Bending Moment		M(kgf·cm)	1,659,000	1,395,500	1,659,000	1,994,700
Axial Force		N(kgf)	630	2,578	6,035	645
Shearing Force		S(kgf)	6,035	634	630	9,603
Width		b(cm)	100	100	100	100
Thickness		h(cm)	40.0	40.0	50.0	50.0
Effective Depth		d(cm)	33.0	33.0	43.0	43.0
Cover (Compressive)		d_1(cm)	7.0	7.0	7.0	7.0
Cover (Tensile)		d_2(cm)	7.0	7.0	7.0	7.0
Required Effective Depth		d_0(cm)	30.1	27.8	31.0	33.0
Judge	Axial Direction Force		Compressive	Compressive	Compressive	Compressive
			Case2-A	Case2-A	Case2-A	Case2-A
	Tensile Steel		Required	Required	Required	Required
	Compressive Steel		Not Required	Not Required	Not Required	Not Required
Max. Compressive Stress σ c1			-	-	-	-
Min. Compressive Stress σ c2			-	-	-	-
Area of Tensile Reinforcement As			31.88	26.22	22.94	29.41
Area of Compressive Reinforcement As'(Smaller Area of Tensile Reinforcement, in case Compressive one isn't required)			-	-	-	-
Min. Area of Reinforcement		(cm^2)	5.00	5.00	5.00	5.00
Required Area of Reinforcement		As(cm^2)	31.88	26.22	22.94	29.41
Required Perimeter		U(cm^2)	11.67	1.23	0.93	14.25

Design of Reinforcement

Main Reinforcement 1	Diameter	D_1(mm)	25	22	25	22
	Pitch	$c.to.c$(mm)	250	250	250	250
	Area	As_1(cm^2)	19.64	15.20	19.64	15.20
	Perimeter	U_1(cm)	32.00	28.00	32.00	28.00
Main Reinforcement 2	Diameter	D_2(mm)	22	19	22	22
	Pitch	$c.to.c$(mm)	250	250	250	250
	Area	As_2(cm^2)	15.20	11.34	15.20	15.20
	Perimeter	U_2(cm)	28.00	24.00	28.00	28.00
Area of Reinforcement As(cm2)			34.84	26.54	34.84	30.40
Perimeter of Reinforcement U(cm2)			60.00	52.00	60.00	56.00

Stress Check

Distance form Neutral axis to Compressive Edge x			14.122	12.969	17.479	15.836
$j=1-x/(3d)$			0.857	0.869	0.865	0.877
Reinforcement	Tensile	σ_s	1,684	1,779	1,191	1,726
	Stress	Judge (σ_{sa}=1,840kgf/cm^2)	O.K.	O.K.	O.K.	O.K.
Concrete	Compressive	σ_c	84.0	76.8	54.4	67.1
	Stress	Judge (σ_{ca}=98kgf/cm^2)	O.K.	O.K.	O.K.	O.K.
	Shear Stress	τ	1.8	0.2	0.1	2.2
		Judge (τ_a=9.2kgf/cm^2)	O.K.	O.K.	O.K.	O.K.

Stress Analysis of North Sinai No.1 Surge Tank (Longitudinal Section)

			Top Slab Outside	Top Slab Inside	Side Slab Outside	Side Slab Inside
Bending Moment		M (kgf·cm)	783,800	837,200	1,434,500	2,154,800
Axial Force		N (kgf)	2,436	353	-	-
Shearing Force		S (kgf)	-	-	1	9,772
Width		b (cm)	100	100	100	100
Thickness		h (cm)	40.0	40.0	50.0	50.0
Effective Depth		d (cm)	33.0	33.0	43.0	43.0
Cover (Compressive)		d_1 (cm)	7.0	7.0	7.0	7.0
Cover (Tensile)		d_2 (cm)	7.0	7.0	7.0	7.0
Required Effective Depth		d_0 (cm)	21.0	21.4	27.9	34.2
Judge	Axial Direction Force		Compressive	Compressive	—	—
			Case2-A	Case2-A	—	—
	Tensile Steel		Required	Required	Required	Required
	Compressive Steel		Not Required	Not Required	Not Required	Not Required
Max. Compressive Stress σ c1			-	-	-	-
Min. Compressive Stress σ c2			-	-	-	-
Area of Tensile Reinforcement *As*			14.44	16.08	21.28	31.97
Area of Compressive Reinforcement As'(Smaller Area of Tensile Reinforcement, in case Compressive one isn't required)			-	-	-	-
Min. Area of Reinforcement		(cm^2)	5.00	5.00	5.00	5.00
Required Area of Reinforcement		As (cm^2)	14.44	16.08	21.28	31.97
Required Perimeter		U (cm^2)	-	-	-	14.50

Design of Reinforcement

Main Reinforcement 1	Diameter	D_1 (㎜)	19	16	19	25
	Pitch	c.to.c (㎜)	125	125	125	250
	Area	As_1 (cm^2)	22.68	16.08	22.68	19.64
	Perimeter	U_1 (cm)	48.00	40.00	48.00	32.00
Main Reinforcement 2	Diameter	D_2 (㎜)	-	-	-	22
	Pitch	c.to.c (㎜)	-	-	-	250
	Area	As_2 (cm^2)	-	-	-	15.20
	Perimeter	U_2 (cm)	-	-	-	28.00
Area of Reinforcement As(cm2)			22.68	16.08	22.68	34.84
Perimeter of Reinforcement U(cm2)			48.00	40.00	48.00	60.00

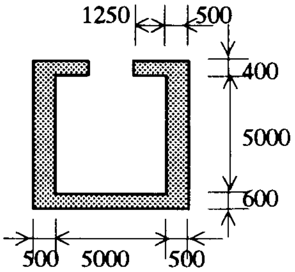
Stress Check

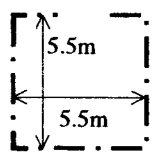
Distance form Neutral axis to Compressive Edge x			12.389	10.486	14.038	16.609
$j = 1 - x/(3d)$			0.875	0.894	0.891	0.871
Reinforcement	Tensile	σ_s	1,138	1,768	1,649	1,652
	Stress	Judge (σ_{sa}=1,840kgf/cm^2)	O.K.	O.K.	O.K.	O.K.
Concrete	Compressive	σ_c	45.6	54.9	53.3	69.3
	Stress	Judge (σ_{ca}=98kgf/cm^2)	O.K.	O.K.	O.K.	O.K.
	Shear Stress	τ	-	-	-	2.3
		Judge (τ_a=9.2kgf/cm^2)			O.K.	O.K.

Surge Tank No.1 (Valve Camber)

(a) Sectional Dimension for Calculation

Valve Chamber should be calculated by Gate Shaped Rigid Frame.



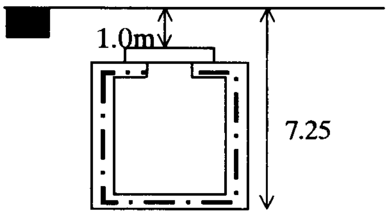


(b) Calculation of Load

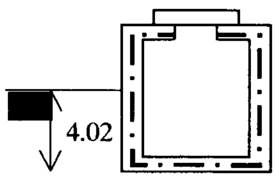
(i) Case of Calculation

Considering condition, following cases should be calculated.

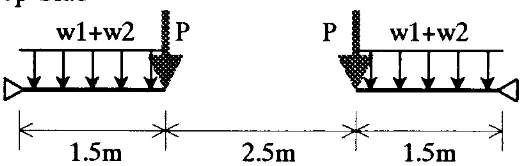
Case 1 1.0m sand covered on the Top slab (m)



Case2 Consider Thermal Factor (Difference 15°C)



(ii) Top Slab



w1: Own Weight of Top Slab

w1= 0.40 × 2.45 = 0.980 tf/m^2

P : Own Weight of Cover

P=0.25 × 2.88 × 2.45 / 2=0.882 tf/m

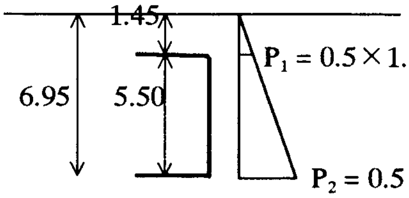
w2:Vertical Soil Pressure(Case1 only)

w2 = 1.8 × 1.25 = 2.250 tf/m^2

(iii) Side Earth Pressure (P_1)

Side earth pressure should be calculated by following equation; $P = K_a \times \gamma_t \times H$

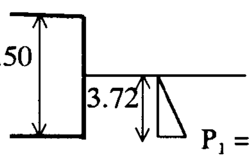
Case 1



$P_1 = 0.5 \times 1.8 \times 1.45 = 1.305$ tf/m^2

$P_2 = 0.5 \times 1.8 \times 6.95 = 6.255$ tf/m^2

Case 2



$P_1 = 0.5 \times 1.8 \times 3.72 = 3.348$ tf/m^2

(iv) Reaction Force of Bottom Slab (W_2)

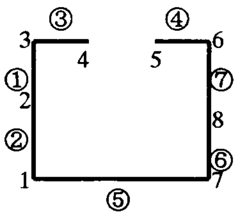
	(tf)
Concrete Weight	183.8
Check Valve φ 1500	9.0
Butterfly Valve φ 1500	5.0
Loose Flange φ 1500	1.1
Pipe Weight φ 1500	2.5

Water Weight ϕ 1500	12.0	
Stop Valve ϕ 200×2	0.5	
Pipe Weight ϕ 200	0.3	
Water Weight ϕ 200	0.3	
+) (Soil Weight	88.9 case1 only)	
Total	303.4 / (5.5×6.5) = 8.5 tf/m²	(Case1)
	214.5 / (5.5×6.5) = 6.0 tf/m²	(Case2)

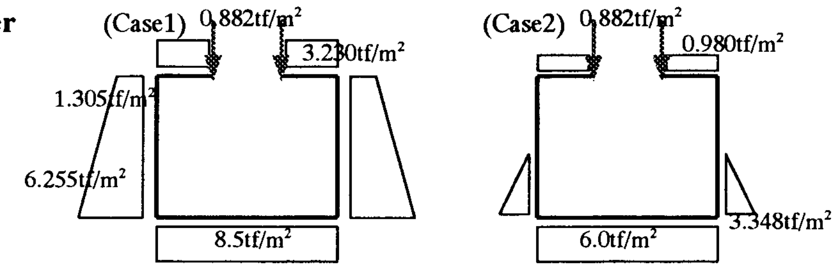
(v) Load Distribution

Load Distribution, Element Number, Contact Point Number and Coordinates are figured as follows.

Element Number and Contact Number



Load Distribution



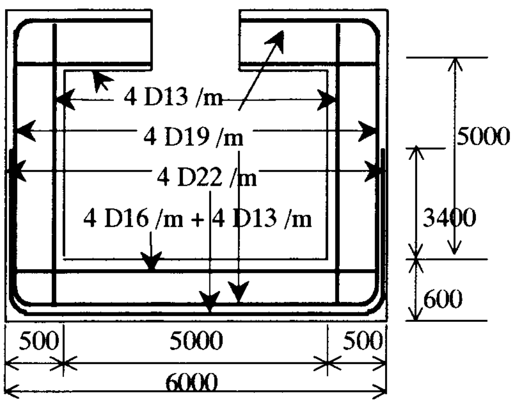
(c) Result of Calculation

Part	Top Slab Outside	Side Slab Outside	Bottom Slab Outside	Bottom Slab Inside
Bending Moment (tf·m)	49.570	17.839	17.839	14.358
Axial Force (tf)	-	5.727	14.942	14.942
Shearing Force (tf)	5.792	14.963	23.396	-

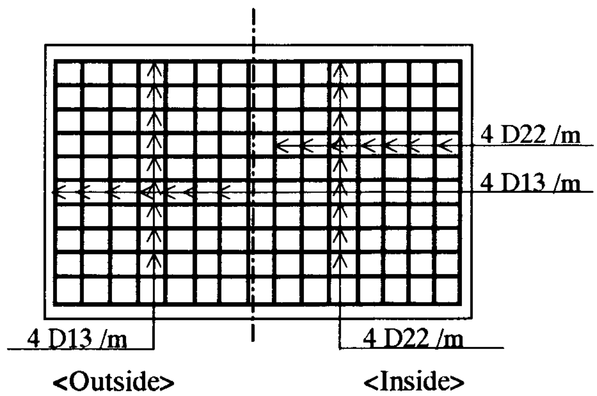
(d) Design of Reinforcement

By using result of calculation reinforcement should be designed as following figure.

Side Slab and Bottom Slab



Side Slab (Long side)



(e) Stress Analysis

Stress analysis will be shown at next page.

Stress Analysis of North Sinai Surge Tank No.1 (Valve Chamber)

		Top Slab Outside	Side Slab Outside	Bottom Slab Outside	Bottom Slab Inside	side slab outside upper
Bending Moment	M (kgf·cm)	495,700	1,783,900	1,783,900	1,435,800	495,700
Axial Force	N (kgf)	-	5,727	14,942	14,942	5,727
Shearing Force	S (kgf)	5,792	14,963	23,396	-	5,792
Width	b (cm)	100	100	100	100	100
Thickness	h (cm)	40.0	50.0	60.0	60.0	50.0
Effective Depth	d (cm)	33.0	43.0	53.0	53.0	43.0
Cover (Compressive)	d_1 (cm)	7.0	7.0	7.0	7.0	7.0
Cover (Tensile)	d_2 (cm)	7.0	7.0	7.0	7.0	7.0
Required Effective Depth	d_0 (cm)	18.1	35.2	37.4	34.2	19.8
Judge	Axial Direction Force	—	Compressive	Compressive	Compressive	Compressive
		—	Case2-A	Case2-A	Case2-A	Case2-A
	Tensile Steel		Required	Required	Required	Required
	Compressive Steel		Not Required	Not Required	Not Required	Not Required
Max. Compressive Stress σ c1		-	-	-	-	-
Min. Compressive Stress σ c2		-	-	-	-	-
Area of Tensile Reinforcement As		9.68	25.10	17.57	13.34	5.79
Area of Compressive Reinforcement As'(Smaller Area of Tensile Reinforcement, in case Compressive one isn't required)		-	-	-	-	-
Min. Area of Reinforcement	(cm^2)	5.00	5.00	5.00	5.00	5.00
Required Area of Reinforcement	As (cm^2)	9.68	25.10	17.57	13.34	5.79
Required Perimeter	U (cm^2)	12.73	25.23	32.01	-	9.77

Design of Reinforcement

Main Reinforcement 1	Diameter	D_1 (㎜)	19	19	19	16	19
	Pitch	$c.to.c$ (㎜)	250	250	250	250	250
	Area	As_1 (cm^2)	11.34	11.34	11.34	8.04	11.34
	Perimeter	U_1 (cm)	24.00	24.00	24.00	20.00	24.00
Main Reinforcement 2	Diameter	D_2 (㎜)	-	22	22	13	-
	Pitch	$c.to.c$ (㎜)	-	250	250	250	-
	Area	As_2 (cm^2)	-	15.20	15.20	5.32	-
	Perimeter	U_2 (cm)	-	28.00	28.00	16.00	-
Area of Reinforcement As(cm2)			11.34	26.54	26.54	13.36	11.34
Perimeter of Reinforcement U(cm2)			24.00	52.00	52.00	36.00	24.00

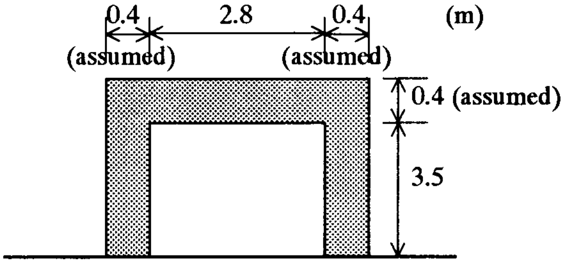
Stress Check

Distance form Neutral axis to Compressive Edge x			9.030	15.676	19.801	15.780	12.780
$j=1-x/(3d)$			0.909	0.878	0.875	0.901	0.901
Reinforcement	Tensile Stress	σ_s	1,457	1,665	1,164	1,670	858
		Judge(σ_{sa}=1,800kgf/cm^2)	O.K.	O.K.	O.K.	O.K.	O.K.
Concrete	Compressive Stress	σ_c	36.6	63.7	46.3	47.2	24.2
		Judge(σ_{ca}=85kgf/cm^2)	O.K.	O.K.	O.K.	O.K.	O.K.
	Shear Stress	τ	1.8	3.5	4.4	-	1.3
		Judge(τ_a=8.0kgf/cm^2)	O.K.	O.K.	O.K.		O.K.

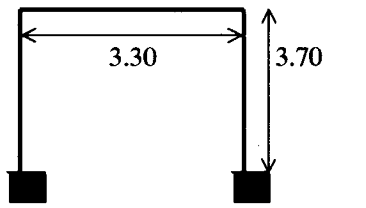
Surge Tank No.2 (Water tank part)

(a) Sectional Dimension for Calculation

Surge tank (water tank) should be calculated by Gate Shaped Rigid Frame.



Rigid Frame Dimension (m)

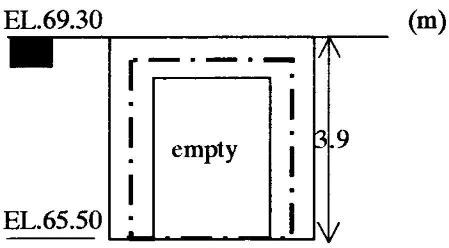


(b) Calculation of Load

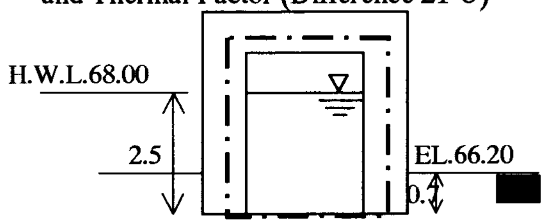
(j)Case of Calculation

Considering condition, following cases should be calculated.

Case 1 5.0m sand covered on the Pipe



Case2 Consider Inner Water Pressure and Thermal Factor (Difference 21℃)



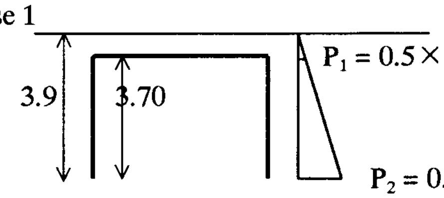
(ii) Own Weight and Earth Weight Applied for Top Slab (W_1)

Concrete Weight of Top Slab 0.980 tf/m^2 (= 0.40 * 2.45)

(iii) Side Earth Pressure (P_1)

Side earth pressure should be calculated by following equation; $P = K_0 \times \gamma_t \times H$

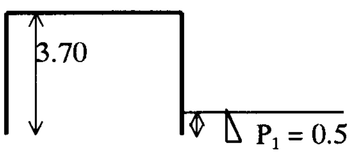
Case 1



$P_1 = 0.5 \times 1.8 \times 0.20 = 0.180$ tf/m^2

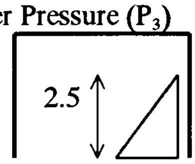
$P_2 = 0.5 \times 1.8 \times 3.9 = 3.510$ tf/m^2

Case 2



$P_1 = 0.5 \times 1.8 \times 0.7 = 0.630$ tf/m^2

(iv) Inner Water Pressure (P_3)



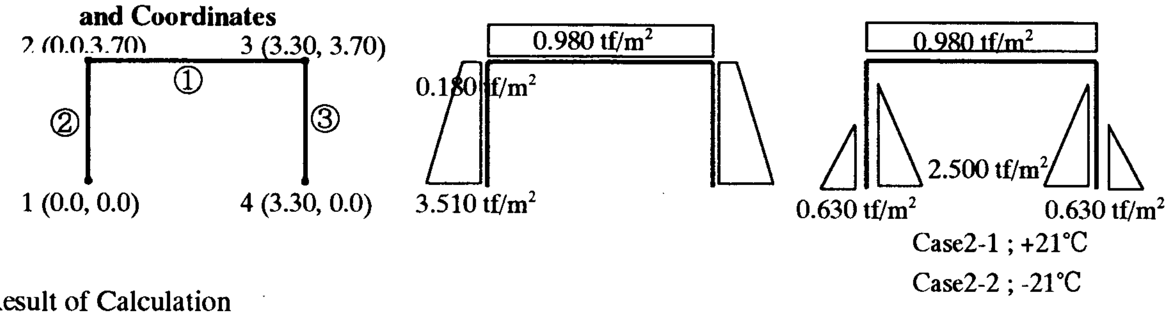
$P_3 = 1.0 \times 2.5 = 2.5$ tf/m^2

(v) Load Distribution

Load Distribution, Element Number, Contact Point Number and Coordinates are figured as follows.

Element Number, Contact Number Case1 Load Distribution Case2 Load Distribution

and Coordinates



(c) Result of Calculation

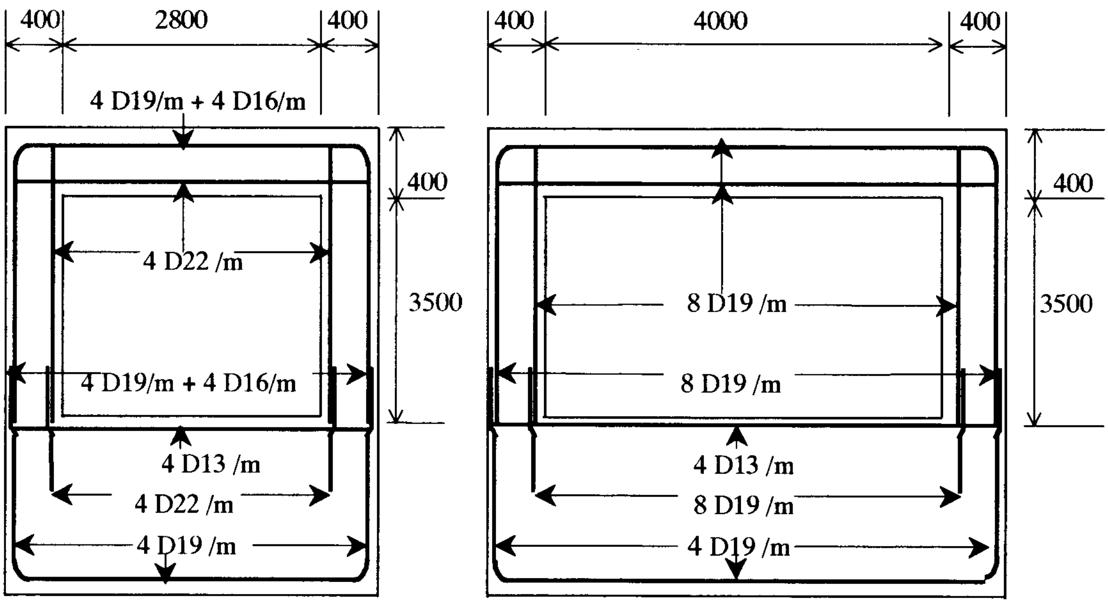
	Top Slab		Side Slab	
	Outside	Inside	Outside	Inside
Case 1	① 0.995 1.568	① 0.259 0.000	②,③ 2.772 4.867	②,③ 1.189 0.001
Case 2-1	① 3.666 5.141	① 7.770 2.005	②,③ 6.166 0.001	②,③ 7.770 1.156
Case 2-2	① 8.916 5.141	① 2.519 2.005	②,③ 8.716 3.903	②,③ 8.916 0.998

Upper : Element Number
Middle: Bending Moment (tf • m)
Lower : Shearing Force (tf)

(d) Design of Reinforcement

By using result of calculation reinforcement should be designed as following figure.

<Cross Section> <Longitudinal Section>



(e) Stress Analysis

Stress analysis will be shown at next page.

Stress Analysis of North Sinai No.2 Surge Tank

		Top Slab Outside	Top Slab Inside	Side Slab Outside	Side Slab Inside	Top Slab Outside Long Side	Top Slab Inside Long Side	Side Slab Outside Long Side	Side Slab Inside Long Side
Bending Moment	M(kgf·cm)	891,600	777,000	891,600	777,000	1,170,600	1,202,700	778,600	1,202,700
Axial Force	N(kgf)	998	1,156	5,141	2,005	1,808	2,589	2,925	2,925
Shearing Force	S(kgf)	5,141	2,005	998	1,156	2,925	2,925	-	2,589
Width	b(cm)	100	100	100	100	100	100	100	100
Thickness	h(cm)	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Effective Depth	d(cm)	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0
Cover (Compressive)	d_1(cm)	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Cover (Tensile)	d_2(cm)	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Required Effective Depth	d_0(cm)	22.1	20.7	22.8	20.9	25.4	25.9	21.0	25.9
Judge	Axial Direction Force	Compressive	Compressive	Compressive	Compressive	Compressive	Compressive	Compressive	Compressive
		Case2-A	Case2-A	Case2-A	Case2-A	Case2-A	Case2-A	Case2-A	Case2-A
	Tensile Steel	Required	Required	Required	Required	Required	Required	Required	Required
	Compressive Steel	Not Required	Not Required	Not Required	Not Required	Not Required	Not Required	Not Required	Not Required
Max. Compressive Stress $\sigma c1$		-	-	-	-	-	-	-	-
Min. Compressive Stress $\sigma c2$		-	-	-	-	-	-	-	-
Area of Tensile Reinforcement As		16.94	14.68	15.73	14.43	22.10	22.49	14.20	22.39
Area of Compressive Reinforcement As'(Smaller Area of Tensile Reinforcement, in case Compressive one isn't required)		-	-	-	-	-	-	-	-
Min. Area of Reinforcement	(cm^2)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Required Area of Reinforcement	As(cm^2)	16.94	14.68	15.73	14.43	22.10	22.49	14.20	22.39
Required Perimeter	U(cm^2)	9.94	3.88	1.93	2.23	5.65	5.65	-	5.00

Design of Reinforcement

Main Reinforcement 1	Diameter	D_1(mm)	19	22	22	22	19	19	19	19
	Pitch	c.to.c (mm)	250	250	250	250	250	250	250	250
	Area	As_1(cm^2)	11.34	15.20	15.20	15.20	11.34	11.34	11.34	11.34
	Perimeter	U_1(cm)	24.00	28.00	28.00	28.00	24.00	24.00	24.00	24.00
Main Reinforcement 2	Diameter	D_2(mm)	16	-	-	-	19	19	19	19
	Pitch	c.to.c (mm)	250	-	-	-	250	250	250	250
	Area	As_2(cm^2)	8.04	-	-	-	11.34	11.34	11.34	11.34
	Perimeter	U_2(cm)	20.00	-	-	-	24.00	24.00	24.00	24.00
Area of Reinforcement As(cm2)			19.38	15.20	15.20	15.20	22.68	22.68	22.68	22.68
Perimeter of Reinforcement U(cm2)			44.00	28.00	28.00	28.00	48.00	48.00	48.00	48.00

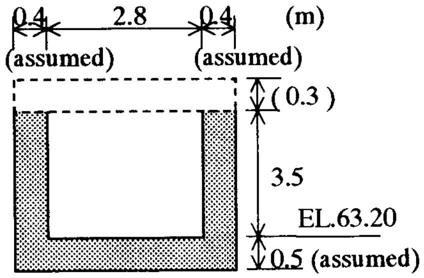
Stress Check

Distance form Neutral axis to Compressive Edge x			11.393	10.382	10.929	10.519	12.174	12.257	12.479	12.295
$j=1-x/(3d)$			0.885	0.895	0.890	0.894	0.877	0.876	0.874	0.876
Reinforcement	Tensile	σ_s	1,548	1,686	1,811	1,661	1,737	1,772	1,117	1,766
	Stress	Judge (σ_{sa}=1,840kgf/cm^2)	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.
Concrete	Compressive	σ_c	54.4	51.6	59.8	51.8	67.7	69.8	45.3	69.9
	Stress	Judge (σ_{ca}=98kgf/cm^2)	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.
	Shear Stress	τ	1.6	0.6	0.3	0.4	0.9	0.9	-	0.8
		Judge (τ_a=9.2kgf/cm^2)	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.		O.K.

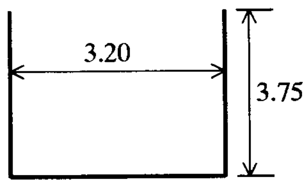
Surge Tank No.2 (Valve Camber)

(f) Sectional Dimension for Calculation

Valve Chamber should be calculated by Gate Shaped Rigid Frame.



Rigid Frame Dimension (m)



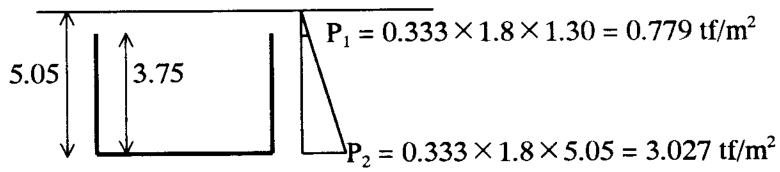
(b) Calculation of Load

(i) Side Earth Pressure (P_1)

Side earth pressure should be calculated by following equation;

$$P = K_a \times \gamma_t \times H$$

Where, K_a : Earth Pressure Coefficient $K_a = 0.333$ ($\phi = 30°$)



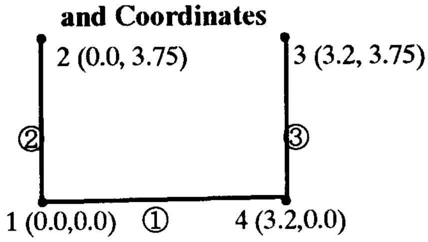
(ii) Reaction Force of Bottom Slab (W_2)

Earth Weight of Top Slab	34.992 tf (= 1.0m * 1.8 * 3.6 * 5.4)
Concrete Weight of Top Slab	14.288 tf (= 0.30 *3.6*5.4* 2.45)
Concrete Weight of Side Slab	51.979 tf (= (3.6 * 5.4 - 2.8 * 5.0) * 3.9 * 2.45)
Pipe Weight (Inside Chamber)	0.285 tf (= 2.34 * 0.122 tf/m)
Water Weight (Inside Pipe)	2.078 tf (= 5.4m * π * 0.7^2 / 4 * 1.0)
Valve Weight	3.237 tf (= 0.870 + 0.209 + 0.258 +1.900)
+) Foundation Concrete (under Valve)	1.323 tf (= 0.3 * 1.0 * 0.9 * 2.45 * 2)
	108.182 tf / (3.6*5.4) ≒ **5.6** tf/m²

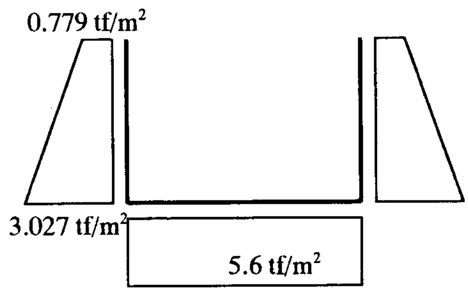
(iii) Load Distribution

Load Distribution, Element Number, Contact Point Number and Coordinates are figured as follows.

Element Number, Contact Number and Coordinates



Load Distribution



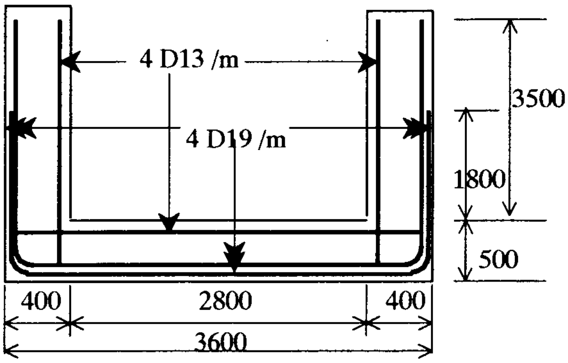
(c) Result of Calculation

Part	Side Slab Outside	Bottom Slab Outside
Bending Moment (tf・cm)	10.746	10.746
Axial Force (tf)	0.000	7.136
Shearing Force (tf)	7.136	8.960

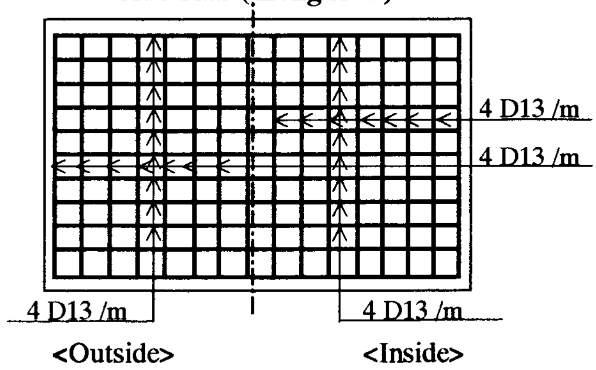
(d) Design of Reinforcement

By using result of calculation reinforcement should be designed as following figure.

Side Slab and Bottom Slab



Side Slab (Long side)



(e) Stress Analysis

Stress analysis will be shown at next page.

Stress Analysis of North Sinai Surge Tank No.2 (Valve Chamber)

		Side Slab Outside	Bottom Slab Outside	Side Slab Inside x	Side Slab Inside y
Bending Moment	M (kgf·cm)	1,074,600	1,074,600	220,800	189,500
Axial Force	N (kgf)	-	7,136	-	-
Shearing Force	S (kgf)	7,136	8,960	4,181	4,375
Width	b (cm)	100	100	100	100
Thickness	h (cm)	40.0	50.0	40.0	40.0
Effective Depth	d (cm)	33.0	43.0	33.0	33.0
Cover (Compressive)	d_1 (cm)	7.0	7.0	7.0	7.0
Cover (Tensile)	d_2 (cm)	7.0	7.0	7.0	7.0
Required Effective Depth	d_0 (cm)	25.0	26.1	11.6	11.4
Judge	Axial Direction Force	—	Compressive	Compressive	Compressive
		—	Case2-A	Case2-A	Case2-A
	Tensile Steel	Required	Required	Required	Required
	Compressive Steel	Not Required	Not Required	Not Required	Not Required
Max. Compressive Stress σ c1		-	-	-	-
Min. Compressive Stress σ c2		-	-	-	-
Area of Tensile Reinforcement As		18.51	16.57	2.20	1.84
Area of Compressive Reinforcement As'(Smaller Area of Tensile Reinforcement, in case Compressive one isn't required)		-	-	-	-
Min. Area of Reinforcement	(cm^2)	5.00	5.00	5.00	5.00
Required Area of Reinforcement	As (cm^2)	18.51	16.57	Min.	Min.
Required Perimeter	U (cm^2)	14.20	22.50	-	-

Design of Reinforcement

Main Reinforcement 1	Diameter	D_1 (㎜)	19	19	13	13
	Pitch	$c.to.c$ (㎜)	250	250	250	250
	Area	As_1 (cm^2)	11.34	11.34	5.32	5.32
	Perimeter	U_1 (cm)	24.00	24.00	16.00	16.00
Main Reinforcement 2	Diameter	D_2 (㎜)	19	19	-	-
	Pitch	$c.to.c$ (㎜)	250	250	-	-
	Area	As_2 (cm^2)	11.34	11.34	-	-
	Perimeter	U_2 (cm)	24.00	24.00	-	-
Area of Reinforcement As(cm2)			22.68	22.68	5.32	5.32
Perimeter of Reinforcement U(cm2)			48.00	48.00	16.00	16.00

Stress Check

Distance form Neutral axis to Compressive Edge x			11.246	11.315	8.597	9.176
$j = 1 - x/(3d)$			0.886	0.886	0.913	0.907
Reinforcement	Tensile Stress	σ_s	1,671	1,794	668	557
		Judge(σ_{sa}=1,800kgf/cm^2)	O.K.	O.K.	O.K.	O.K.
Concrete	Compressive Stress	σ_c	57.6	62.4	15.7	14.3
		Judge(σ_{ca}=85kgf/cm^2)	O.K.	O.K.	O.K.	O.K.
	Shear Stress	τ	2.0	3.1	-	-
		Judge(τ_a=8.0kgf/cm^2)	O.K.	O.K.		