2.7 Gate Structure

2.7.1 Bulkhead Gate

(1) Design Data

Type of Gate	:	Fixed Wheel Gate
Number of Gate	:	1 set
Design water level	:	WL. 149.700 (Normal water surface EL. 148.900 + Wave Height 0.8 m)
Sill Elevation	:	EL. 113.471
Lintel Seal Elevation	:	EL. 114.488
Clear Span	:	2.000 m
Clear Height	:	1.400 m
Gate Height	:	2.000 m
Type of Hoist	:	Electrically driven 1-Motor, 1-Drum Wire Rope Hoist
Operating Speed	:	1.0 $^{m}/_{min}$ ± 10%
Raising Operation	:	Balance
Operation	:	Local Control
Power Source	:	380 V, 50 Hz, 4ϕ, 4 w
Raising Height	:	68.0 m
Seismic intensity for design	:	K = 0.16
Corrosion Allowance	:	1.0 mm (one face, always used fresh water)
Allowable Stress		
For Steel	:	Tension, Compression 1.125 · σy / 2 as a basic shear 1.125 · σy / 2 / $\sqrt{3}$
For Concrete	:	Bearing 60 kgf/cm^2 Shearing 4.0 kgf/cm^2 Bond 7.0 kgf/cm^2

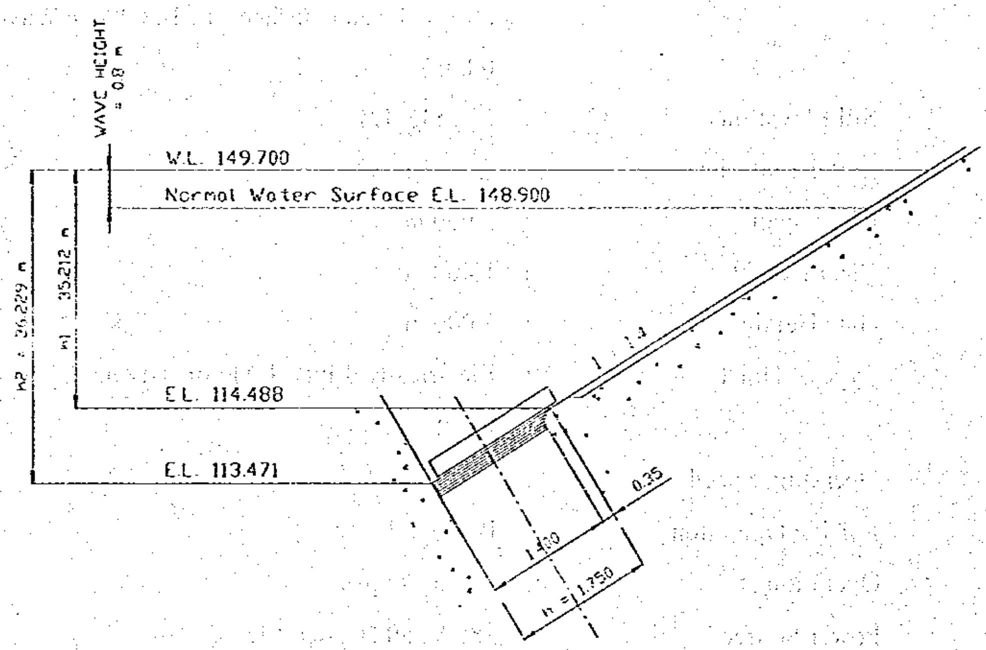
(2) Design Hydraulic Pressure Load

(a) Hydrostatic Pressure Load, Ps

$$Ps = \frac{h_1 + h_2}{2} \times h \times B \times W_o$$

Where,

h_1, h_2, h	:	Shown in figure below
B	:	Seal span = 2.1 m
W_o	:	Unit weight of water = 1.0 tf/m³



$$Ps = \frac{35.212 + 36.229}{2} \times 1.750 \times 2.1 \times 1.0$$

$$= 131.273 \text{ tf}$$

(b) Hydro-Pressure Load in Seismic Period

(i) Hydrostatic Pressure, Ps'

Water level shall be added the wave height due to earthquake.

$$Ps' = \frac{h_1' + h_2'}{2} \times h \times B \times W_o$$

$$Ps' = \frac{35.690 + 36.707}{2} \times 1.750 \times 2.1 \times 1.0$$

$$= 133.030 \text{ tf}$$

($h_1' = h_1 + h_e + 35.212 + 0.478 = 35.690$ m, $h_2' = h_2 + k_e = 36.229 + 0.478$ $= 36.707$ m)

Wave height of earthquake, h_e

$$h_e = \frac{K \cdot \tau}{2 \cdot \pi} \cdot \sqrt{g \cdot H}$$

Where,

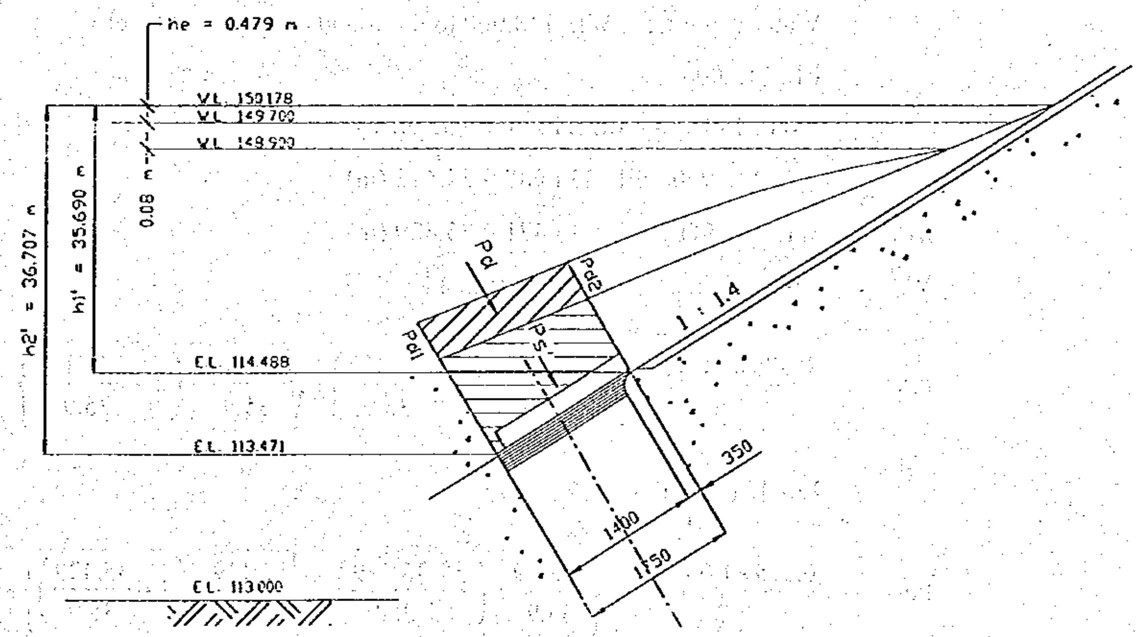
K : Seismic intensity for design = 0.16

τ : Seismic period = 1.0 (s)

g : Gravity acceleration = 9.8 (m/s²)

H : Water depth from WL. 148.9 to the foundation ground Level EL. 113.000 = 35.9 (m)

$$h_e = \frac{0.16 \times 1.0}{2} \times \sqrt{9.8 \times 35.9} = 0.478 \text{ (m)}$$



(ii) Hydrostatic Pressure Load, Pd

Pd is calculated by following Zanger's formula.

$$Pd = \frac{Pd_1 + Pd_2}{2} \times h \times B$$

Where,

$$Pd_1 = \frac{Cm \times W_o \times H \times K}{2} \times \left\{ \frac{h_1''}{H} \times \left(2 - \frac{h_1''}{H}\right) + \sqrt{\frac{h_1''}{H} \times \left(2 - \frac{h_1''}{H}\right)} \right\}$$

$$Pd_2 = \frac{Cm \times W_o \times H \times K}{2} \times \left\{ \frac{h_2''}{H} \times \left(2 - \frac{h_2''}{H}\right) + \sqrt{\frac{h_2''}{H} \times \left(2 - \frac{h_2''}{H}\right)} \right\}$$

Cm : Coefficient due to inclination of gate leaf = 0.375

K : Horizontal seismic coefficient = 0.16

H : Water depth from WL. 148.900 to the foundation ground level EL. 113.000
=WL. 148.900 – EL. 113.000 = 35.9 (m)

h_1'' : WL. 148.900 – EL. 114.488 = 34.412 (m)

h_2'' : WL. 148.900 – EL. 113.471 = 35.429 (m)

W_o : Unit weight of water = 1.0 (tf/m^3)

$$Pd_1 = \frac{0.375 \times 1.0 \times 35.9}{2} \times \left\{ \frac{34.412}{35.9} \times \left(2 - \frac{34.412}{35.9}\right) + \sqrt{\frac{34.412}{35.9} \times \left(2 - \frac{34.412}{35.9}\right)} \right\}$$

= 13.445 (tf/m^2)

$$Pd_2 = \frac{0.375 \times 1.0 \times 35.9}{2} \times \left\{ \frac{35.429}{35.9} \times \left(2 - \frac{35.429}{35.9}\right) + \sqrt{\frac{35.429}{35.9} \times \left(2 - \frac{35.429}{35.9}\right)} \right\}$$

= 13.461 (tf/m^2)

$$Pd = \frac{13.445 \times 13.461}{2} \times 1.75 \times 2.1 = 49.440 \text{ (tf)}$$

(iii) Total Hydraulic Pressure Load in seismic Period

Ps' + Pd = 133.030 + 49.440 = 182.470 (tf)

(c) Design Hydropressure Load

Allowable stress in seismic period are allowed to 1.5 times of the normal case.

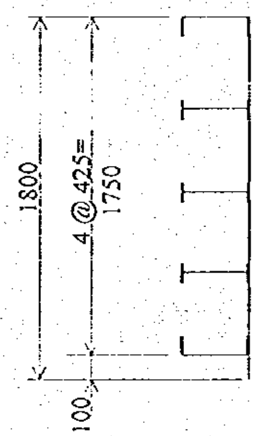
$$\frac{Ps' + Pd}{Ps} = \frac{182.470}{131.273} = 1.390 < 1.5$$

Therefore, design hydropressure load is determined as Ps.

(3) Structural Arrangement of Gate Leaf

(a) Main Girders

In case of high pressure gate, all main girders except top and bottom girders sustain almost the same amount of pressure load even thought were arrange in the same intervals.



The right figure shows general arrangement of main girders. They are provided in the same pitch of 425 mm.

Pressure loads which acts on each main girder can be calculated as follows.

$W_1 = q_1 \times B$

$Wn = (q_n + q_{n+1}) \times B \quad (n = 2\sim8)$

$P_1 = 41.612\ (tf/m^2),\ P_{10} = 42.629\ (tf/m^2)$

$$h_n = \frac{(P_n + 2P_{n+2})}{(P_n + P_{n+2})} \times \frac{(h_n + h_{n+1})}{3} \quad (n = 1\sim7)$$

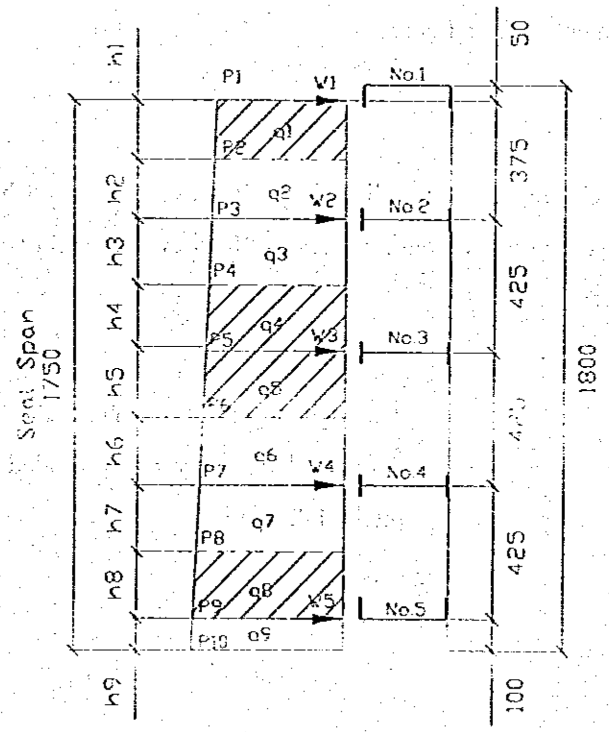
$h_q = 0.1$ m

$Mn = 1/8 \times (2L - B) \times Wn$

$Qn = ½ \times Wn$

Where,

Wn	:	Pressure load (tf)
q_n	:	Unit of pressure load (tf/m)
Mn	:	Bending moment at span center (tf·m)
Qn	:	Shearing force at span end (tf)
B	:	Seal span = 2.1 (m)
L	:	Support span = 2.3 (m)



Calculation results are shown in the following table with pressure loads, bending moments and shearing forces.

No. of Girder	Pressure Load W (tf)	Shearing Force Q (tf)	Bending Moment M (tf·m)
1	13.900	6.950	4.34390
2	27.771	14.886	9.30353
3	31.842	15.921	9.95051
4	32.062	16.031	10.01940
5	23.697	11.849	7.40541

(i) Section Properties

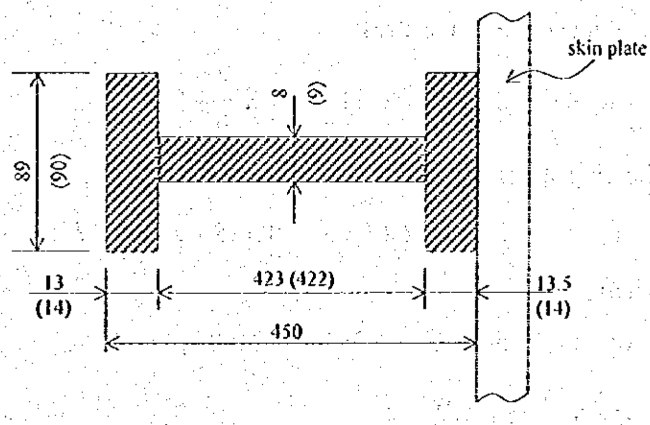
Effective section properties shall be calculated by excluding the corrosion allowance 0.5 mm (one face).

Figure bellow shows the main girder section.

No.1, No. 5

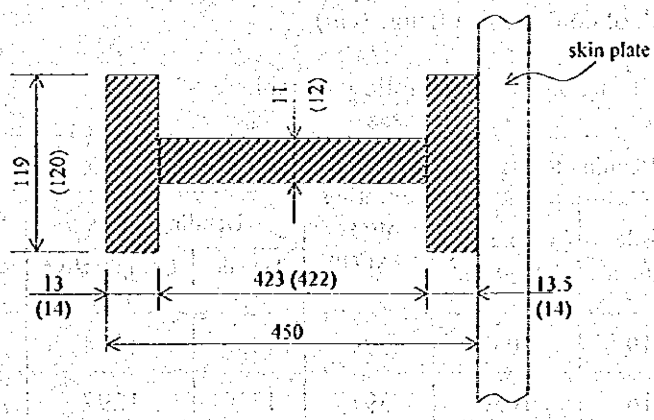
As used in the section for main girders No. 1 or No. 5, Just only about No. 5 girder, which sustain larger load than No. 5 girder may be considered.

I	=	16269	cm^4
Zt	=	729	cm^3
Zc	=	719	cm^3
A	=	57.425	cm^2
Aw	=	21.84	cm^2 (End of Girder)



No.2 – No. 4

As used in the section for main girders No. 2 – No. 4, Just only about No. 4 girder, which the largest load among others may be considered.



I	=	21945	cm^4
Zt	=	983	cm^3
Zc	=	971	cm^3
A	=	78.065	cm^2
Aw	=	21.84	cm^2
			(End of Girder)

(ii) Stress

Bending tensile stress

$$\sigma t = \frac{M}{Zt} \text{ (kgf/cm}^2\text{)}$$

Bending compressive stress

$$\sigma c = \frac{M}{Zc} \text{ (kgf/cm}^2\text{)}$$

Shearing stress

$$\tau = \frac{Q}{Aw} \text{ (kgf/cm}^2\text{)}$$

Allowable stress

Bending tensile stress

$$\sigma ta = 1.125 \times \sigma y / 2 = 1.125 \times 2400/2 = 1350 \text{ kgf/cm}^2$$

Bending compressive stress

$$\sigma tc = 1.125 \times \sigma y / 2 - 12 \times (K \times \frac{\ell}{b} - 9)$$

Shearing stress

$$\tau a = 1.125 \times \sigma y / 2 / \sqrt{3} = 1.125 \times 2400 / 2 / \sqrt{3} = 779 \text{ kgf/cm}^2$$

Where,

σy : Yield stress of SS400 = 2400 kgf/cm²

K : $\sqrt{3 + \frac{Aw}{2Ac}}$

Aw : Gross sectional area of web plate (cm²)

Ac : Gross sectional area of compressive flange (cm²)

ℓ : Distance between fixed points of compressive flange = 80.0 cm

b : Width of compressive flange (cm)

Calculation results are shown in the following table

No. of Girder	Bending Stress		Shearing Stress τ kgf/cm²	Allowable Stress		
				Bending Stress		Shearing Stress τa
	Tensile σt kgf/cm²	Compressive σc kgf/cm²		Tensile σta	Compressive σca	
No.4	1019	1032	529	1350	1234	779
No.5	1016	1030	391	1350	1297	779

(iii) Deflection of Main Girder

$$\frac{\delta}{L} = \frac{W}{48 \cdot E \cdot I} \cdot (L^3 - \frac{B^2}{2} + \frac{B^3}{8L})$$

Where, E : Young's modulus of steel = 2.1 x 10^6 kgf/cm^2

Calculation results are shown in the following table

No. of Girder	W (kgf)	I (cm³)	L (cm²)	B (cm²)	δ (cm)	δ/L	Allowable deletion
No.4	32062	21945	230	210	0.140	1/1638	1/800
No.5	23697	16269	230	210	0.140	1/1643	1/800

(b) Vertical Sub-beam

Vertical sub-beam shall be provided as shown in figure below. These beams shall be analyzed in a manner simple beams supported at the web of main girders.

Load shall be computed from the average pressure of the span. Maximum bending moment and maximum shearing force will be obtained by following formula.

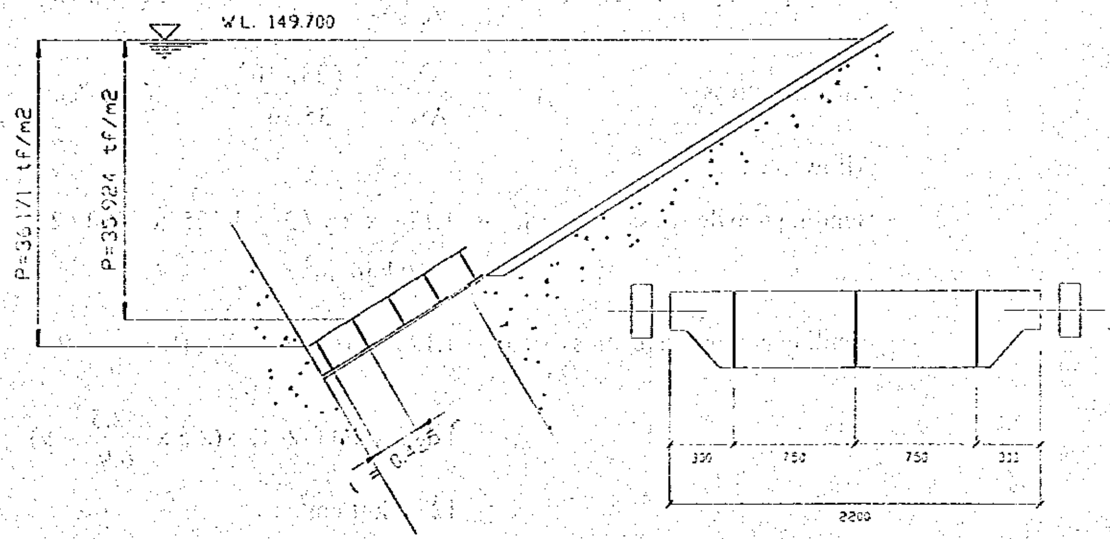
$$M_{max} = \frac{P \cdot \ell^3}{12}$$

$$Q_{max} = \frac{P \cdot \ell^2}{4}$$

Where,

P : Average pressure = 36.048 tf

ℓ : Support span = 0.425 m



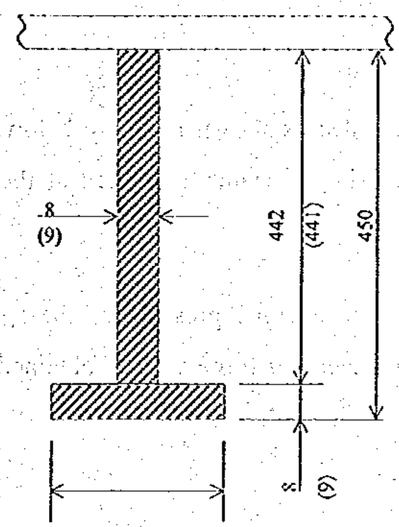
$$M_{max} = \frac{36.048 \times 0.425^3}{12} = 0.23060 \text{ tf·m}$$

$$Q_{max} = \frac{36.048 \times 0.425^2}{4} = 1.628 \text{ tf}$$

(i) Section Properties

Efficient section properties shall be calculated by excluding the corrosion allowance 1.0 mm (one face).

Figure below shows the vertical sub-beams section.



I	=	8174	cm^4
Zt	=	325	cm^3
Zc	=	412	cm^3
A	=	40.88	cm^2
Aw	=	35.36	cm^2

(ii) Stress

Bending tensile stress $\sigma t = \frac{M}{Zt} = \frac{0.23060 \times 10^5}{325} = 71 \text{ kgf/cm}^2$

Bending compressive stress $\sigma c = \frac{M}{Zc} = \frac{0.23060 \times 10^5}{412} = 56 \text{ kgf/cm}^2$

Shearing stress $\tau = \frac{Q}{Aw} = \frac{1.628 \times 10^3}{35.36} = 46 \text{ kgf/cm}^2$

Allowable Stress

Bending tensile stress $\sigma ta = 1.125 \times \sigma y / 2 = 1.125 \times 2400 / 2$

$= 1350 \text{ kgf/cm}^2$

Bending compressive stress $\sigma ca = 1.125 \times \sigma y / 2 - 12 \times (K \times \frac{\ell}{b} - 9)$

$= 1.125 \times 2400/2 - 12 \times (2.5 \times \frac{42.5}{6.9} - 9)$

$= 1273 \text{ kgf/cm}^2$

Where,

σy	:	Yield stress of steel = 2400 kgf/cm^2
K	:	$\sqrt{3 + \frac{Aw}{2Ac}}$
Aw	:	Gross sectional area of web plate = 35.36 cm^2
Ac	:	Gross sectional area of compressive flange = 5.52 cm^2
ℓ	:	Distance between fixed points of compressive flange = 42.5 cm
b	:	Width of compressive flange = 6.9 cm

Shearing Stress

$$\tau a = 1.125 \times \sigma y / 2 / \sqrt{3}$$

$$= 1.125 \times 2400 / 2 / \sqrt{3}$$

$$= 779 \ kgf/cm^2$$

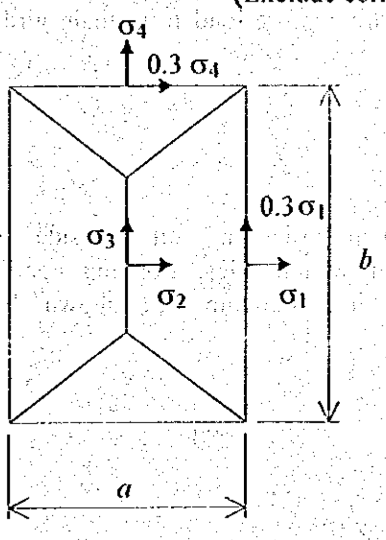
(c) Skin Plate

Flat plates which are subject to bending stress, shall be computed in accordance with DIN 19704, clause 6.5.2.2

$$\sigma = \frac{1}{100} \cdot K \cdot \frac{p \cdot a^2}{t^2}$$

Where,

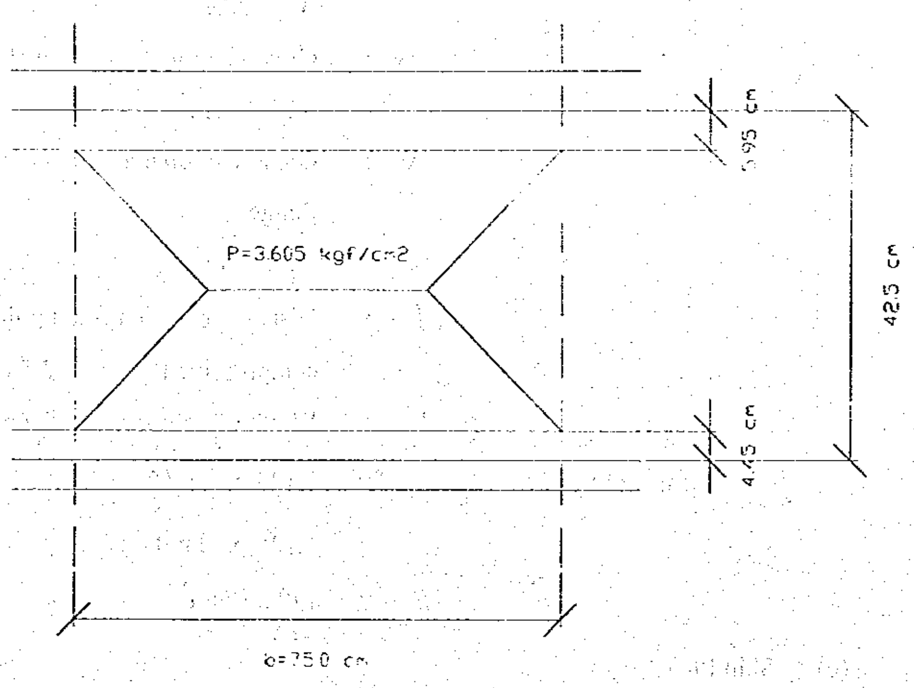
σ	:	Bending stress in kgf/cm^2
K	:	Non-dimensional factor as shown in table
p	:	Water pressure relative to the plate center in kgf/cm^2
a·b	:	Support length of plate pane, a b in cm
t	:	Efficient thickness of skin plate in cm (Exclude corrosion allowance)



b/a	σ_1	σ_2	σ_3	σ_4
1.00	30.9	13.7	13.7	30.9
1.25	40.3	18.8	13.5	33.9
1.50	45.5	22.1	12.2	34.3
1.75	48.4	23.9	10.8	34.3
2.00	49.9	24.7	9.5	34.3
2.50	50.0	25.0	8.0	34.3
3.00	50.0	25.0	7.5	34.3
∞	50.0	25.0	7.5	34.3

" K "

According to the figure, the skin-plate panel dimension are 32.2 cm x 80.0 cm. Thus, the bottom part panel has to be checked.



$b/a = 75.0/32.1 = 2.337 > 2.0,\ K = 50$

$$\sigma = \frac{1}{100} \times 50 \times 32.1^2 \times \frac{3.605}{(1.4-0.1)^2} = 1099 \text{ kgf/cm}^2$$

Skin plate shall be used plate thickness 14 mm (quality SS400).

Allowable stress

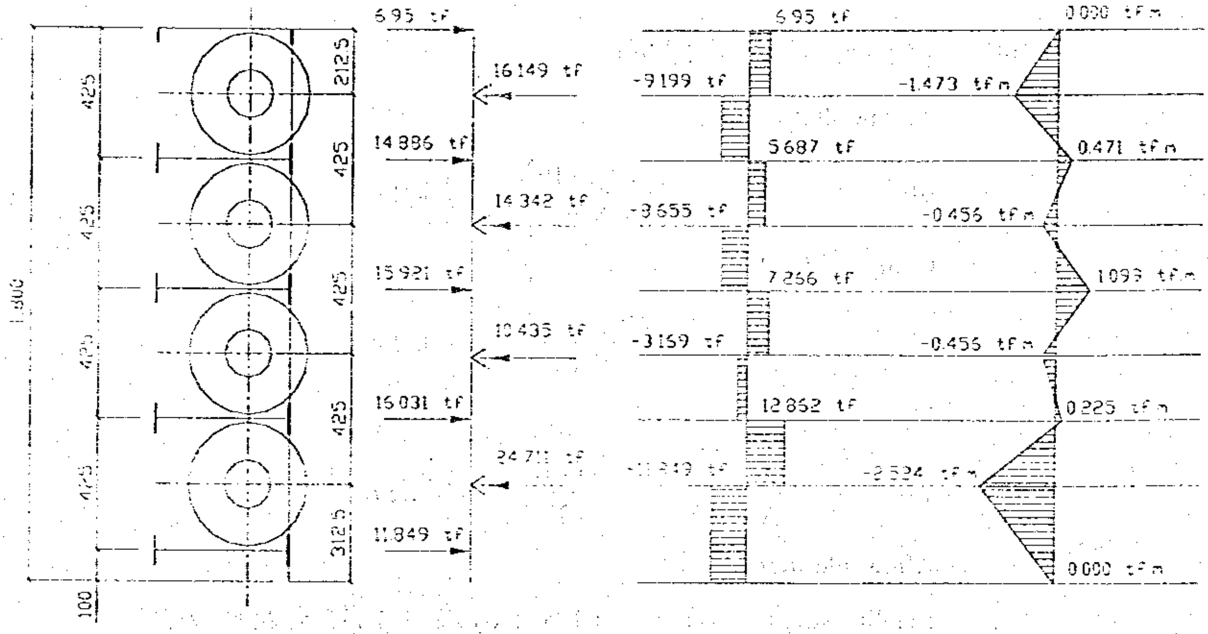
$\sigma a = 1.125 \times \sigma y / 2 = 1.125 \times 2400 / 2 = 1350 \text{ kgf/cm}^2$

(d) Side Beam

Side beam shall have to transfer the hydropressure load from main girder to wheel axles safe and sound.

(i) Loading Condition

Shearing force at the span of main girders act on the side beam. Supporting points are locations of wheel axles. Loading condition, bending moment and shearing force diagram are shown below respectively.

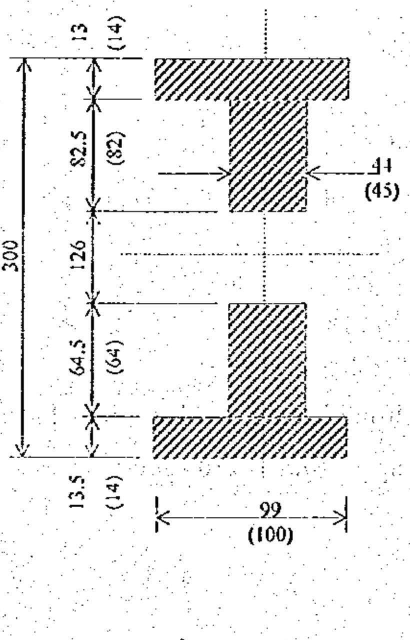


L.C.D S.F.D B.M.D

Q_{max}	=	12.862	tf	(point of main girder)
Q	=	11.849	tf	(point of wheel)
M_{max}	=	2.524	tf·m	(point of wheel)
M	=	1.099	tf	(point of main girder)

(ii) Section Properties

Wheel section of side beam is shown below. The calculated section properties are as follows.



I	=	12040	cm^4
Zt	=	829	cm^3
Zc	=	778	cm^3
A	=	90.915	cm^2
Aw	=	36.3	cm^2

(iii) Bending and Shearing Stress

Tensile stress

$$\sigma bt = \frac{M}{Zt} = \frac{2.524 \times 10^5}{829} = 305 \ \text{kgf/cm}^2$$

Compressive stress

$$\sigma bc = \frac{M}{Zc} = \frac{2.524 \times 10^5}{778} = 324 \ \text{kgf/cm}^2$$

Shearing stress

$$\tau = \frac{Q}{Aw} = \frac{24.711 \times 10^3}{36.3} = 681 \ \text{kgf/cm}^2$$

Allowable stress

Bending stress $\sigma a = 1.125 \times \sigma y / 2 = 1.125 \times 2400 / 2$

$= 1350 \ \text{kgf/cm}^2$

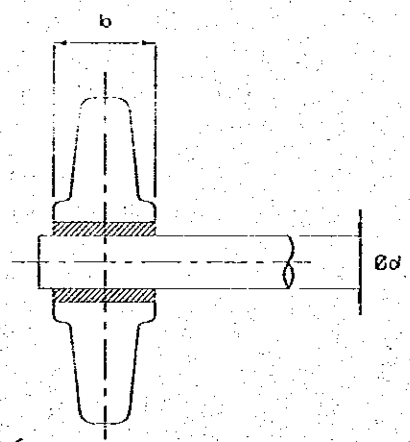
Shearing stress $\tau a = 1.125 \times \sigma y / 2 / \sqrt{3} \times 0.92 \ (t \geqq 40 \text{ mm})$

$= 1.125 \times 2400 / 2 / \sqrt{3} \times 0.92$

$= 717 \ \text{kgf/cm}^2$

(4) Wheel Mounting

(a) Wheel bushing



Bearing Pressure

$$\sigma bp = \frac{R}{b \cdot d}$$

Where,

R : Wheel load = 24.711 tf

d : Inner diameter of bushing = 12.6 cm

b : Breadth of bushing = 9.0 cm

$$\sigma bp = \frac{24.711 \times 10^3}{9.0 \times 12.6} = 218 \ \text{kgf/cm}^2$$

Bearing material is self-lubricating bushing, oilles Industry Company, L.t.d. Japan. Allowable bearing pressure is 230 kgf/cm^2.

(b) Wheel axle

Schematic drawing of wheel mounting is shown in figure next page.

Bending moment

M = 24.711 x 0.100 = 2.4711 tf·m

Shearing force

Q = 24.711 tf

Material of wheel axle shall be chrome molybdenum steel (JIS G 4105) SCM 435, $\sigma y = 5000$ kgf/cm^2)

Bending stress

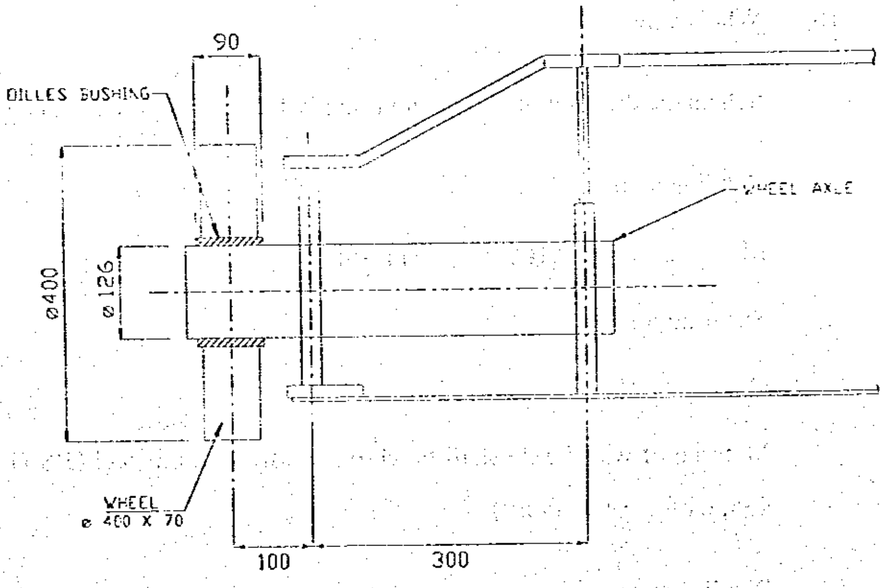
$$\sigma b = \frac{M}{Z} = \frac{2.4711\times 10^5}{\left(\frac{\pi\times 12.6^3}{32}\right)} = 1258 \text{ kgf/cm}^2 < \frac{\sigma y}{2} = \frac{5000}{2}$$

$$= 2500 \text{ kgf/cm}^2$$

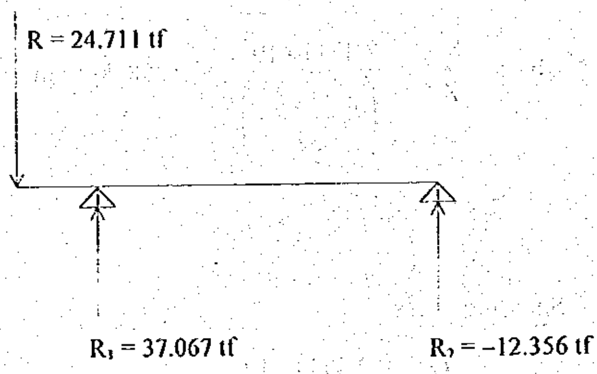
Shearing stress

$$\tau = \frac{Q}{A} = \frac{2.4711\times 10^3}{\left(\frac{\pi\times 12.6^3}{4}\right)} = 198 \text{ kgf/cm}^2 < \frac{\sigma y}{2\cdot\sqrt{3}} = \frac{5000}{2\cdot\sqrt{3}}$$

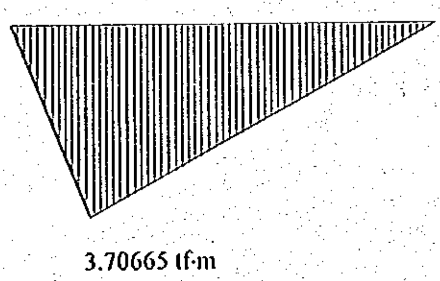
$$= 1443 \text{ kgf/cm}^2$$


90
DILLES BUSHING
WHEEL AXLE
ø400
ø126
WHEEL
ø 400 X 70
100
300

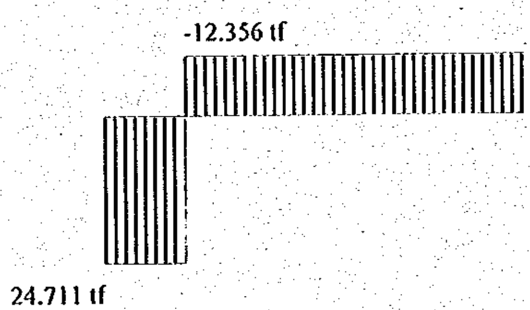
L.C.D


R = 24.711 tf
R_1 = 37.067 tf
R_2 = –12.356 tf

B.M.D


3.70665 tf·m

S.F.D


-12.356 tf
24.711 tf

(c) Wheel

Wheel shall have to be crowned. The ratio (diameter of crown in a section through the axis of the wheel divided by wheel diameter) shall be equal to 15.

Contact Herztian pressure between wheel and wheel track is calculated by following formula.

$$p = \frac{3}{2 \cdot \pi} \cdot \frac{P}{a \cdot b}$$

$$a = 1.109 \cdot m \cdot \sqrt[3]{\frac{P}{(A+B) \cdot E}}$$

$$b = 1.109 \cdot n \cdot \sqrt[3]{\frac{P}{(A+B) \cdot E}}$$

$$A + B = ½ \cdot \left(\frac{1}{R} + \frac{1}{R'}\right)$$

$$z = \beta \cdot b$$

Where,

p : Herztian contact pressure in kgf/cm^2
P : Wheel load = 24711 kgf
2R : Wheel diameter = 40.0 cm
R′ : Wheel crown = 15 x R = 15 x ½ x 40 = 300 cm
m : 2.813 (in case of R'/R = 15)
n : 0.485 (in case of R'/R = 15)
E : Young's Modulus of Material = 2.1×10^6 kgf/cm^2
Z : Depth of maximum shearing stress occurred (cm)
β : Coefficient of a/b

Calculated results are shown in the following table.

R (cm)	R′ (cm)	A + B	a	b	a/b	β	Z (cm)	p (kgf/cm^2)	HB	pa (kgf/cm^2)
20.0	300.0	0.027	2.375	0.409	5.8	0.775	0.317	12132	250	12500

Quality of wheel SSW-Q1S, HB = 250

Allowable pressure

$$pa = \frac{100}{2 \cdot \nu} \cdot HB$$

Where, pa : Allowable Herztion contact pressure in kgf/cm^2
ν : Coefficient of safety = 1.0
HB : Hardness of wheel = 250 (HB)

(5) Wheel Track Frame

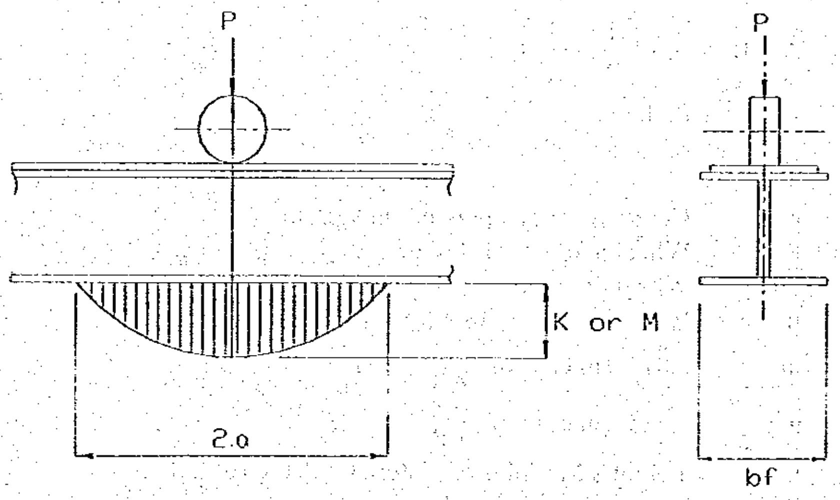
Strength of wheel track frame shall be computed in accordance with following Andree's formula.

$$Mx = \frac{K \cdot bf}{a^2} \cdot \left(\frac{a^4}{4} - \frac{2a^3}{3} \cdot x + \frac{a^2}{2} \cdot x^2 - \frac{1}{12} \cdot x^4 \right)$$

$$Kx = K \cdot \left\{ 1 - \left(\frac{x}{a} \right)^2 \right\}$$

$$K = 0.0588 \cdot \frac{P}{\sqrt[3]{bf^2 \cdot I}}$$

$$a = 0.75 \cdot \frac{P}{K \cdot bf}$$



Where,

Mx : Bending moment of track frame in kgf·cm

Kx : Bearing pressure of concrete just beneath the bottom flange in kgf/cm^2

K : Bearing pressure of concrete just beneath the bottom flange at loading point in kgf/cm^2

P : Wheel load

Top wheel	P_1	=	16149	kgf
No.2 wheel	P_2	=	14342	kgf
No.3 wheel	P_3	=	10435	kgf
Bottom wheel	P_4	=	24711	kgf

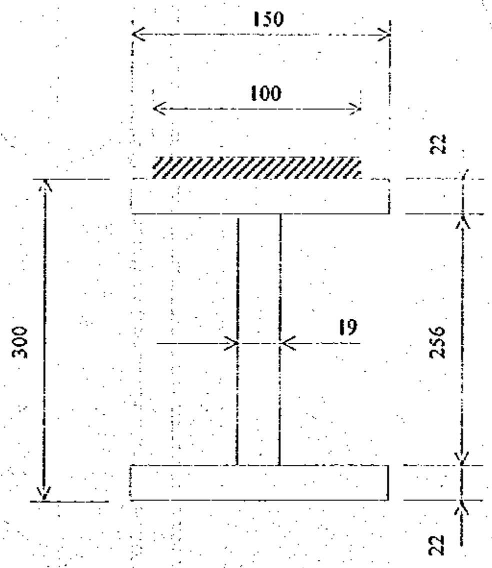
bf : Bottom flange breadth of track frame = 15.0 cm

I : Moment of inertia of track frame = 15435 cm^4

a : Half of the bearing pressure distribution length along the bottom flange of track frame in cm.

(a) Track frame properties

Figure below shows the typical section of track frame. The section properties are the values excluding the wheel track surface plate.



$I = 15435\ cm^4$

$Z = 1029\ cm^3$

$A = 114.64\ cm^2$

$Aw = 48.64\ cm^2$

(b) Bearing Concrete Pressure

Calculated results are shown in the figure next page.

$K_{max} = 21.4\ kgf/cm^2$

Allowable bearing concrete pressure

$Ka = 60\ kgf/cm^2$

(c) Bending Stress of Wheel Track Frame

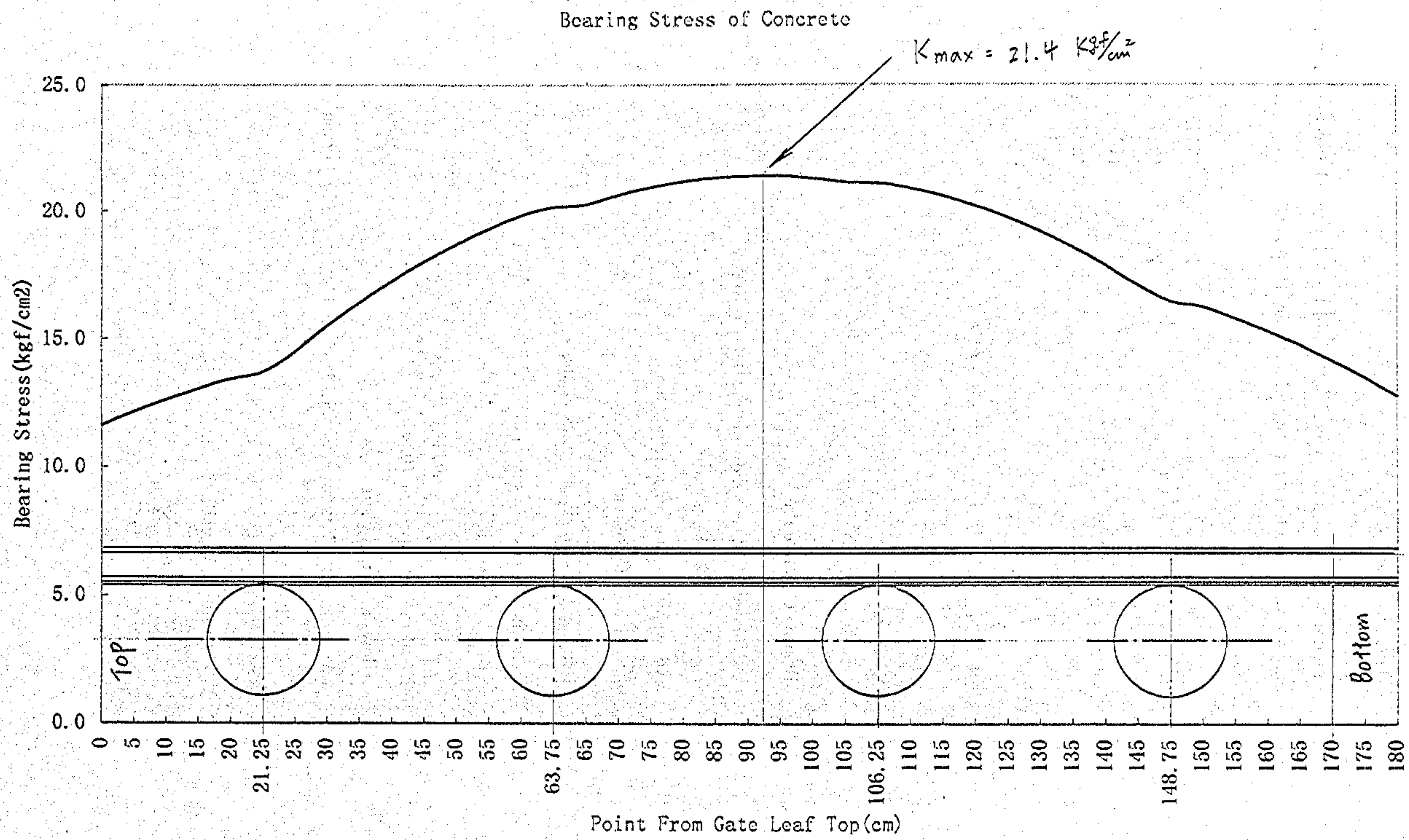
Calculated results are shown in the figure next page.

$M_{max} = 697335\ kgf{\cdot}cm$

$$\gamma = \frac{M_{max}}{Z} = \frac{697335}{1029} = 678\ kgf/cm^2$$

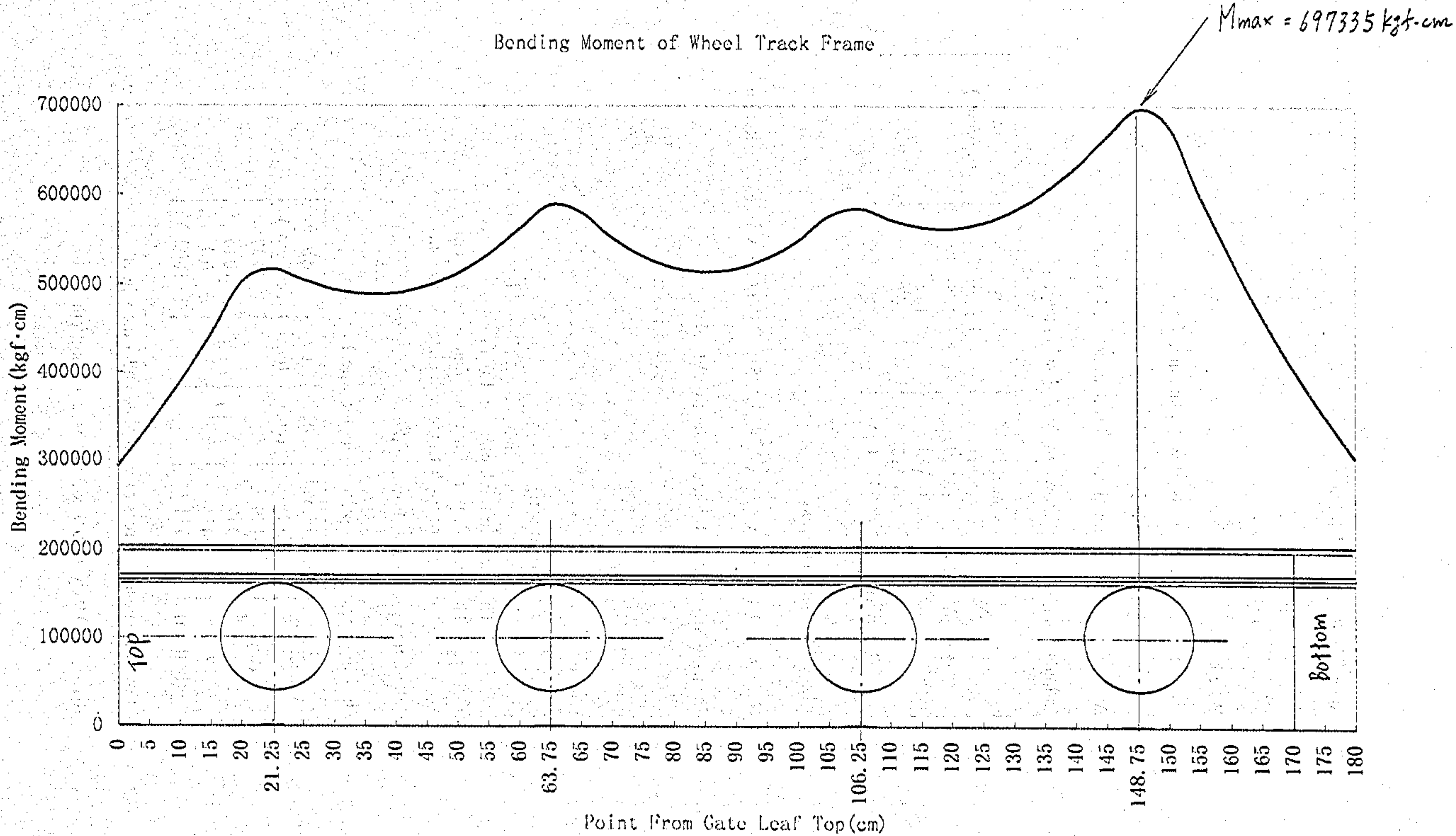
Allowable bending stress

$\sigma a = 1.125 \times \sigma y / 2 = 1.125 \times 2400 / 2 = 1350\ kgf/cm^2$



Bearing Stress of Concrete
Kmax = 21.4 Kgf/cm²
Bearing Stress (kgf/cm2)
25.0
20.0
15.0
10.0
5.0
0.0
Top
Bottom
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180
21.25
63.75
106.25
148.75
Point From Gate Leaf Top (cm)

Bending Moment of Wheel Track Frame



(d) Shearing Stress of Web Plate

$$\tau w = \frac{P}{2Aw}$$

Where,

τw : Shearing stress of web plate in kgf/cm^2

P : Wheel load in kgf

Aw : Gross sectional area of web plate = 48.64 cm^2

Calculation results are shown in the following table.

Wheel No.	Wheel Load (Kgf)	τw (kgf/cm^2)	τa (kgf/cm^2)
1 (top)	16149	166	779
2	14342	147	
3	10435	107	
4 (bottom)	24711	254	

Allowable shearing stress

$$\tau a = 1.125 \times \sigma y / 2 / \sqrt{3} = 1.125 \times 2400 / 2 / \sqrt{3} = 779 \ kgf/cm^2$$

(e) Shearing Stress of Web Plate Under the Wheel

$$\sigma b = \frac{P}{b_b \cdot tw}$$

Where,

b_b : 2 x (b + tr + tf)
b : Short radius of herztian contact ellipsoid = 0.409 cm
tr : Thickness of track plate = 1.0 m
tf : Thickness of track frame top flange = 2.2 cm
tw : Thickness of track frame web plate = 1.9 cm

Calculation results are shown in the following table.

Shearing stress of web plate under the wheel

Wheel No.	Wheel Load (Kgf)	b_b (cm)	tw (cm)	σb (kgf/cm^2)
1 (top)	16149	7.219	1.9	1177
2	14342			1046
3	10435			761
4 (bottom)	24711			1802

Allowable shearing stress of web plate under the wheel.

$$\sigma ba = 0.9 \ \sigma y = 0.9 \times 2400 = 2160 \ kgf/cm^2$$

(f) Bending Stress of Bottom Flange of Track Frame

Bending moment

$$Mf = \frac{K \cdot bf^2}{8}$$

$$= \frac{21.4 \times 15.0^2}{8}$$

$$= 601.875 \text{ kgf·cm}$$

Bending stress

$$\sigma = \frac{6 \cdot Mf}{t'f^2}$$

Where,

t'f : Thickness of bottom flange of track frame

= 2.2 cm

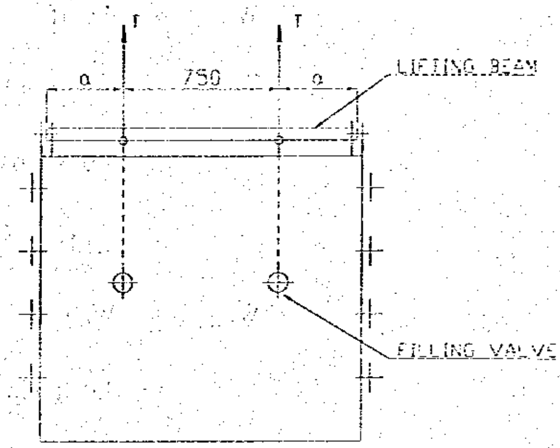
$$\sigma = \frac{6 \times 601.785}{2.2^2} = 746 \text{ kgf/cm}^2$$

Allowable bending stress

$$\gamma a = 1.125 \times \sigma y / 2 = 1.125 \times 2400 / 2 = 1350 \text{ kgf/cm}^2$$

(6) Lifting beam

Lifting beam is regarded as a simply supported beam as shown in the figure.



The maximum bending moment M is

M = T x a

Where,

T : Half a raising load = ½ x 4.0 tf

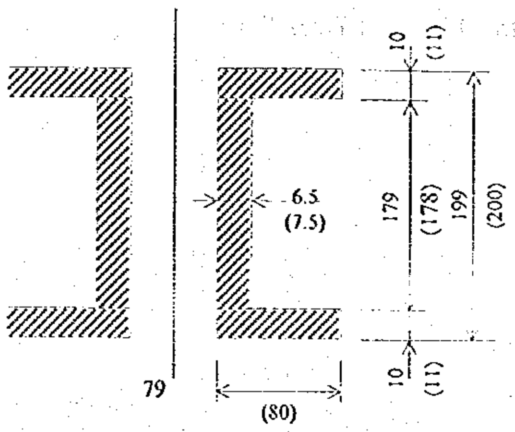
a : Distance from side beam to rope sheave

= 0.675 m

M = ½ x 4.0 x 0.675

= 1.35 tf·m

Lifting beam consists of two (2) rolled channels, C200 x 80 x 7.5/11 (SS400) and the effective section properties, which has already eliminate the corrosion allowance of 0.5 mm (one face) are.



I = 3446 cm^4

Z = 346 cm^3

A = 54.87 cm^2

Aw = 23.27 cm^2

Bending stress

$$\sigma = \frac{M}{Z} = \frac{1.35 \times 10^5}{346} = 390 \text{ kgf/cm}^2 < \sigma a = 1.125 \text{ x } \sigma y/2 = 1.125 \text{ x } 2400/2$$

$= 1350$ gf/cm^2

Shearing stress

$$\tau = \frac{I}{Aw} = \frac{2.0 \times 10^2}{23.27} = 86 \text{ kgf/cm}^2 < \tau a = \sigma a / \sqrt{3} = \frac{1350}{\sqrt{3}} = 779 \text{ kgf/cm}^2$$

(7) Calculation for hoist

(a) Hoisting Load

Gate self weight

W_G = 4.0 tf

W_{GV} = $W_G \cdot \cos\theta$

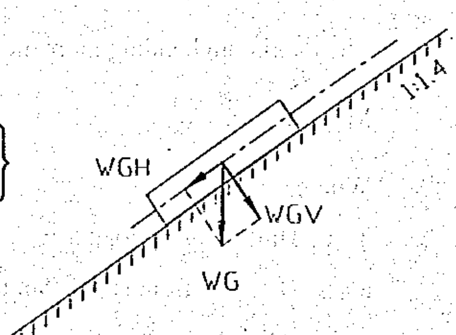
= $4.0 \text{ x } \cos\left\{\tan^{-1}\left(\frac{1}{1.4}\right)\right\}$

= 3.131 tf

W_{GH} = $W_G \cdot \sin\theta$

= $4.0 \text{ x } \sin\left\{\tan^{-1}\left(\frac{1}{1.4}\right)\right\}$

= 2.237 tf



Wire – Rope weight (JIS 6 x 37 – A Type, ϕ 20)

W_R = 1.44 (kg/m) x 70.0 (m) x 2

= 201.6 (kgf)

0.3 tf

Wheel friction

$$Fw = \frac{\left(\mu_1 + \mu_2 \cdot \frac{d}{2}\right) \cdot P}{D/2}$$

Where,

μ_1 : Rolling resistance = 0.1 cm

μ_2 : Friction coefficient on wheel axle Self-rubricating oiles bushing = 0.2 cm

d : Wheel axle diameter = 12.6 cm

D : Wheel diameter = 40.0 cm

P : W_{GV} = 3.131 tf

$$Fw = \frac{\left(0.1 + 0.2 \times {}^{12.6}/_{2}\right) \times 3.131}{40/2}$$

$= 0.410$ tf

Seal rubber friction

$$Fr = q \cdot \mu \cdot \ell$$

Where,

q : Precompression force of rubber = 0.03 tf/m

μ : Friction coefficient rubber on stainless steel
= 0.7 (wet)
= 1.2 (dry)

ℓ : Seal rubber length = 2.1 + 2 x 1.75 = 5.6 m

$Fr_{(wet)}$ = 0.03 x 0.7 x 5.6
= 0.118 tf

$Fr_{(dry)}$ = 0.03 x 1.2 x 5.6
= 0.202 tf

(b) Sum of Load

(tf)

Item	Wet Condition		Dry Condition	
	Raising	Lowering	Raising	Lowering
W_{GH}	↓2.237	↓2.237	↓2.237	↓2.237
W_W	↓0.300	↓0.300	↓0.300	↓0.300
F_W	↓0.410	↑0.410	↓0.410	↑0.410
Fr	↓0.118	↑0.118	↓0.202	↑0.202
Sum	↓3.064	↓2.009	↓3.148	↓1.925

Thus, the design hoisting load is 3.5 tf, and the gate can be fully lowered by its own weight.

(c) Mechanical Efficiency

Mechanical efficiency of each device is listed below

Helical gear reducer	:	0.80 ~ 0.94
Drum gear & pinion gear	:	0.95
Drum	:	0.95

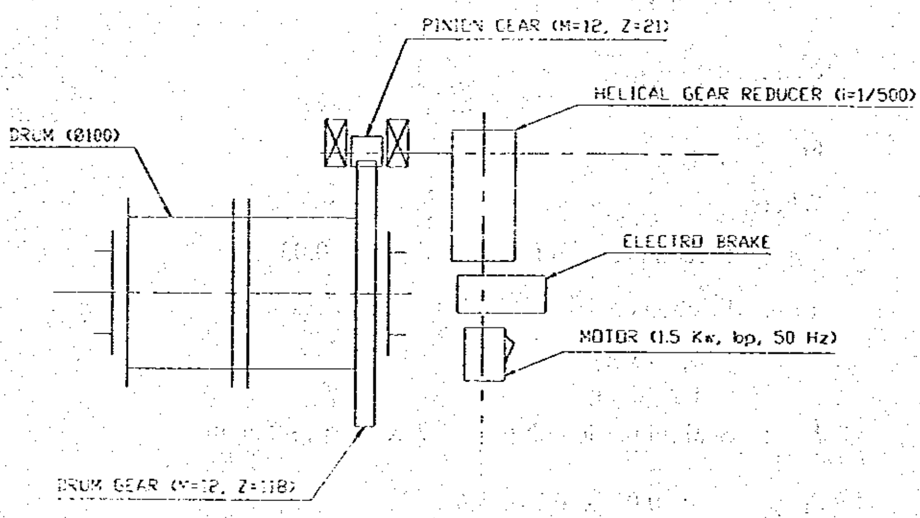
η_m (start) $= 0.8 \times 0.95 \times 0.95$

$= 0.722$

η_m (drive) $= 0.94 \times 0.95 \times 0.95$

$= 0.848$

Schematic arrangement of hoist is shown below



(d) Hoisting Speed

Hoisting speed for gate is calculated as follows.

$$V = N_M \times i_h \times i_G \times \pi \times D_D$$

Where,

N_M	:	Revolution number of motor (50 Hz, bp) = 930 r.p.m
i_h	:	Reducing ratio of Helical gear reducer = 1/500
i_G	:	Number of teeth on Pinion gear / Drum gear = 21/118
D_D	:	Diameter of drum = 1.0 m

$$V = 930 \times \frac{1}{500} \times \frac{21}{118} \times \pi \times 1.0 = 1.040 \ ^{m}/_{min}$$

(e) Motor Output

$$Pm = \frac{1}{6.12} \cdot \frac{W \cdot V}{\eta_m}$$

Where,

W : Hoisting Load = 3.5 tf

V : Actual hoisting speed = 1.040 $^m/_{min}$

η_m : Mechanical efficiency = 0.722

$$Pm = \frac{1}{6.12} \cdot \frac{3.5 \times 1.040}{0.722}$$

$$= 0.824 \text{ kw} \rightarrow 1.5 \text{ kw}$$

Therefore, 1.5 kw induction motor should be used.

(f) Torque of Each Shaft

Torque moments, which shall be transferred through each shaft, are computed in two cases.

(i) At Rated Motor Torque

Motor output torque

$$T_1 = 97400 \times \frac{1.5}{930} = 157.1 \text{ kgf·cm}$$

Pinion gear torque

$$T_2 = T_1 \times \frac{500}{1} \times 0.94 = 73835.5 \text{ kgf·cm}$$

Drum gear torque

$$T_3 = T_2 \times \frac{118}{21} \times 0.95 = 394140.8 \text{ kgf·cm}$$

(ii) At Maximum Motor Torque

Maximum motor torque shall be 300 % of rated motor torque. Each torque value is 3.0 times as calculated 7.6.1.

T_1' = 471.3 kgf·cm

T_2' = 221506.5 kgf·cm

T_3' = 1182422.5 kgf·cm

(g) Strength of Wire Rope

(i) Applied Wire Rope

JIS G 3525 6 x 37 – A type wire rope

Diameter : d = 20 mm

Breaking strength : T = 21700 kgf

(ii) Safety Factor

Safety factor to breaking strength calculated from hoisting load and from maximum motor torque shall be at least 8 and 1.7 respectively.

Wire rope tension per one rope for hoisting load is

$$F = \frac{3.5}{2} = 1.75 \text{ tf}$$

Safety factor is

$$S = \frac{21700}{1.75 \times 10^3} = 12.4 > 8$$

Wire rope tension per one rope for maximum motor torque is

$$F' = \frac{2 \times T_3'}{D_D \times 2} = \frac{2 \times 1182422.5}{100 \times 2} = 11824.2 \text{ kgf}$$

Safety factor is

$$S' = \frac{21700}{11824.2} = 1.8 > 1.7$$

(h) Strength of Gear

Strength of gear teeth shall be examined as regards bending and bearing. Bending strength factor to ultimate tensile strength calculated from rated motor torque shall be more than 5. And be less than 90 % of yield strength for the maximum motor torque.

Bearing strength shall be more than the actual bearing load calculated from rated motor torque.

Calculation results are summarized in table next page

$P < Pa, Pba$

$P' < Pa'$

for Pinion gear and Drum gear.

CALCULATION TABLE FOR STRENGTH OF TEETH

		Pinion Gear	Drum Gear
Module m (mm)		12	
Number of teeth z		21	118
Width of teeth b (mm)		130	120
Pitch circle dia P·C·D = m·z (mm)		252	1416
Material Ultimate σ_B / Yield σy (kgf/mm^2)		SCM 440 90 / 70	SCM 435 75 / 55
Allowable stress	$\sigma a = \sigma_B/5$	18	15
	$\sigma a' = 0.9\ \sigma y$	63	49.5
Revolution n (r·p·m)		1.86	0.331
Pitch line velocity $V = \pi \cdot n \cdot D/1000$ ($^m/_{min}$)		1.473	1.473
Coefficient of velocity $fv = 3.05/(3.05 + v)$		0.674	0.674
Coefficient of tooth profile y		0.34	0.464
Coefficient of bearing stress K		0.116	
Torque kg·cm	Rated T	73835.5	394140.8
	Maximum T'	221506.5	1182422.5
Actual load $\frac{T or T'}{D/2}$ kg	Rated P	586.0	556.7
	Maximum P'	1758.0	1670.1
Allowable load in bending kg $m \cdot b \cdot fv \cdot y \cdot (\sigma a$ or $\sigma a')$ kg	Rated Pa	6438.7	6759.1
	Maximum Pa'	22535.3	22305.1
Allowable load in bearing $fv \cdot K \cdot D2 \cdot b_1 \cdot \frac{2Z_1}{Z_1 + Z_2}$ (kg) Pba		774.4	
D2 : Pitch circle of Pinion b1 : Teeth width of Pinion gear		Z_1 : Pinion Z_2 : Drum Gear	

2.7.2 Emergency Gate

(1) Design Data

Type of Gate	:	Steel Made Slide Gate
Number of Gate	:	1 set
Design Water Level	:	W.L. 130.800
		(W.L. 130.000 + Wave Height 0.8 m)
Sill Elevation	:	E.L. 115.000
Lintel Seal Elevation	:	E.L. 115.900
Clear Span	:	2.000 m
Clear Height	:	1.400 m
Gate Height	:	1.650 m
Type of Hoist	:	Electrically Driven 1 – Motor, 2 – Drum Wire Rope Hoist and Lifting beam.
Operating Speed	:	1.0 $^{m}/_{min}$ ± 10 %
Raising Operation	:	Balance (water level L.W.L 136.000 ~ W.L 131.000)
Operation	:	Local Control
Power Source	:	380 V, 50 Hz, 3 ϕ, 4 W
Raising Height	:	Normal 2.0 m
		Maintenance 67.0 m
Seismic intensity for design	:	k = 0.16
Corrosion Allowance	:	One face 1.0 mm (always used fresh water)
Allowable Stress		
for Steel	:	Tension, Compression 1.125 · σy/2 as a basic shear 1.125 · σy/ 2 / $\sqrt{3}$
for Concrete	:	Bearing 60 kgf/cm^2
		Shearing 4.0 kgf/cm^2
		Bond 7.0 kgf/cm^2

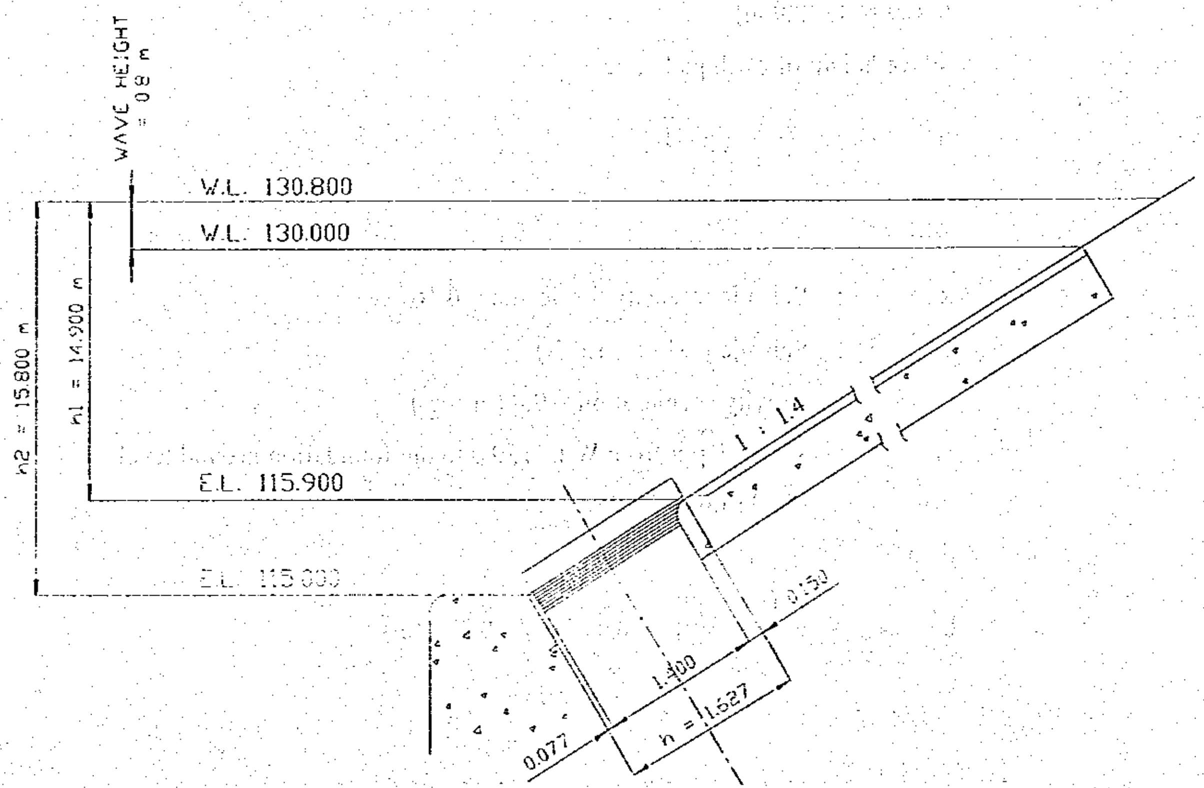
(2) Design hydraulic pressure load

(a) Hydrostatic Pressure Load, Ps

$$Ps = \frac{h_1 + h_2}{2} \times h \times B \times W_0$$

where,

h_1, h_2, h_3,	:	Shown in figure below
B	:	Seal span = 2.300 m
W_0	:	Unit weight of water = 1.0 tf/m^3



$$Ps = \frac{14.900 + 15.800}{2} \times 1.627 \times 2.300 \times 1.0$$

$$= 57.442 \text{ tf}$$

(b) Hydro – Pressure Load in Seismic Period

(i) Hydrostatic Pressure, Ps'

Water level shall be added the wave height due to earthquake.

$$Ps' = \frac{h_1' + h_2'}{2} \times h \times B \times W_0$$

$$= \frac{15.229 + 16.129}{2} \times 1.627 \times 2.300 \times 1.0$$

$$= 58.803 \text{ (tf).}$$

($h_1' = h_1 + he$ = 15.800 + 0.329 = 16.129 m, $h_2' = h_2 + he$ = 14.900 + 0.329 = 15.229 m)

Wave height of earthquake, he

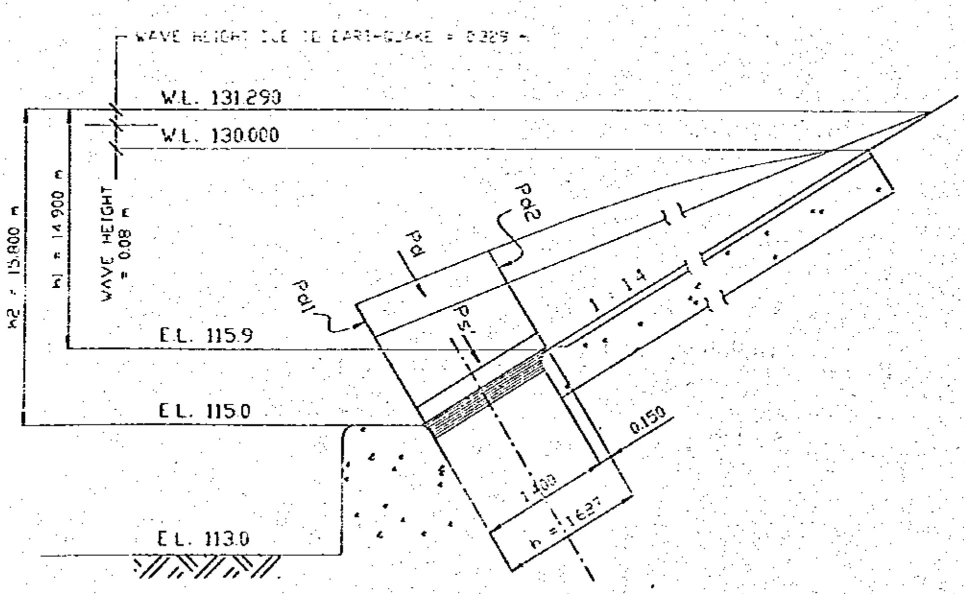
$$he = \frac{k \cdot \tau}{2 \cdot \pi} \cdot \sqrt{g \cdot H}$$

where,

k	:	Seismic intensity for design = 0.16
τ	:	Seismic period = 1.0 (s)
g	:	Gravity acceleration = 9.8 (m/sec^2)
H	:	Water depth from W.L. 130.0 to the foundation ground level EL. 113.0 = 17.0 (m)

then,

$$he = \frac{0.16 \times 1.0}{2 \times \pi} \times \sqrt{9.8 \times 17.0} = 0.329 \text{ (m)}$$



(ii) Hydrodynamic Pressure Load, Pd

Pd is calculation by following Zanger's formula.

$$Pd = \frac{Pd_1 + Pd_2}{2} \times h \times B$$

where,

$$Pd_1 = \frac{Cm \times W_0 \times H \times k}{2} \times \left\{ \frac{h_1''}{H} \times \left(2 - \frac{h_1''}{H}\right) + \sqrt{\frac{h_1''}{H} \times \left(2 - \frac{h_1''}{H}\right)} \right\}$$

$$Pd_2 = \frac{Cm \times W_0 \times H \times k}{2} \times \left\{ \frac{h_2''}{H} \times \left(2 - \frac{h_2''}{H}\right) + \sqrt{\frac{h_2''}{H} \times \left(2 - \frac{h_2''}{H}\right)} \right\}$$

Cm : Coefficient due to inclination of gate leaf = 0.375

k : Horizontal seismic coefficient = 0.16

H : Water depth from W.L. 130.0 to the foundation ground level E.L. 113.0 = W.L. 130.0 – E.L.113.0 = 17.0 m

h_1'' : W.L. 130.0 – E.L. 115.9 = 14.1 m

h_2'' : W.L. 130.0 – E.L. 115.0 = 15.0 m

W_0 : Unit weight of water = 1.0 tf/m^3

then,

$$Pd_1 = \frac{0.375 \times 1.0 \times 17.0 \times 0.16}{2} \times \left\{ \frac{14.1}{17.0} \times \left(2 - \frac{14.1}{17.0}\right) + \sqrt{\frac{14.1}{17.0} \times \left(2 - \frac{14.1}{17.0}\right)} \right\}$$

$$= 0.998 \text{ tf/m}^2$$

$$Pd_2 = \frac{0.375 \times 1.0 \times 17.0 \times 0.16}{2} \times \left\{ \frac{15.0}{17.0} \times \left(2 - \frac{15.0}{17.0}\right) + \sqrt{\frac{15.0}{17.0} \times \left(2 - \frac{15.0}{17.0}\right)} \right\}$$

$$= 1.009 \text{ tf/m}^2$$

$$Pd = \frac{0.998 \times 1.009}{2} \times 1.627 \times 2.3$$

$$= 3.756 \text{ tf}$$

(iii) Total Hydraulic Pressure Load in Seismic Period

$Ps' + Pd$ = 58.803 + 3.756 = 62.559 tf

(c) Design Hydropressure Load

Allowable stresses in seismic period are allowed to 1.5 times of the normal case.

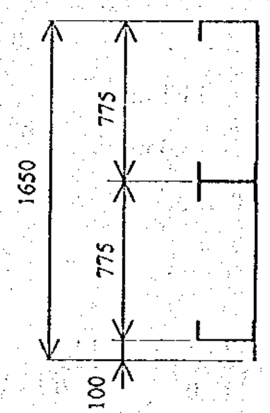
$$\frac{Ps' + Pd}{Ps} = \frac{62.559}{57.442} = 1.089 < 1.5$$

Therefore, design hydropressure load is determined as Ps.

(3) Structural Arrangement of Gate Leaf

(a) Main Girders

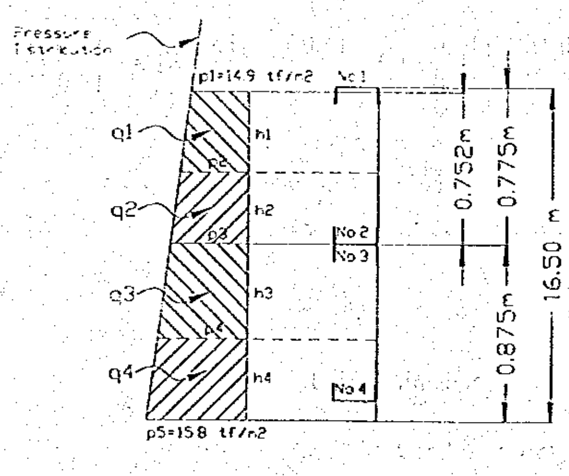
In case of high pressure gate, all main girders except top and bottom girders sustain almost the same amount of pressure load even though were arrange in the same intervals.



The right figure shows general arrangement of main girders.

They are provided in the same pitch of 775 mm.

Pressure loads, which acts on each main girder, can be calculated as follows.



$$Wn = q_n \times B$$

$$q_n = ½ \times (p_n + p_{n+1}) \times h_n$$

$$h_n = \frac{p_n + 2 \times p_{n+2}}{p_n + p_{n+2}} \times \frac{h_n + h_{n+1}}{3} \quad (n=1\sim3)$$

$$h_4 = \frac{2 \times p_3 + p_4}{p_3 + p_4} \times \frac{h_3 + h_4}{3} \quad (n=4)$$

$$Mn = {}^1/_8 \times (2L - B) \times Wn$$

$$Qn = ½ \times Wn$$

where,

Wn	:	Pressure load (ft)
q_n	:	Unit of pressure load (tf/m)
Mn	:	Bending moment at span center (tf.m)
Qn	:	Shearing force at span end (tf)
B	:	Seal span = 2.300 (m)
L	:	Support span = 2.500 (m)

Calculation results are shown in the following table with pressure loads, bending moments and shearing forces.

No. of Girder	Pressure Load W (tf)	Shearing Force Q (tf)	Bending Moment M (tf.m)
1	13.045	6.522	4.403
2	13.086	6.543	4.416
3	15.623	7.812	5.273
4	15.688	7.844	5.295

As used in the section for main girders No.1 – No.4, just only about No. 4 girder which sustain the largest load among others may be considered.

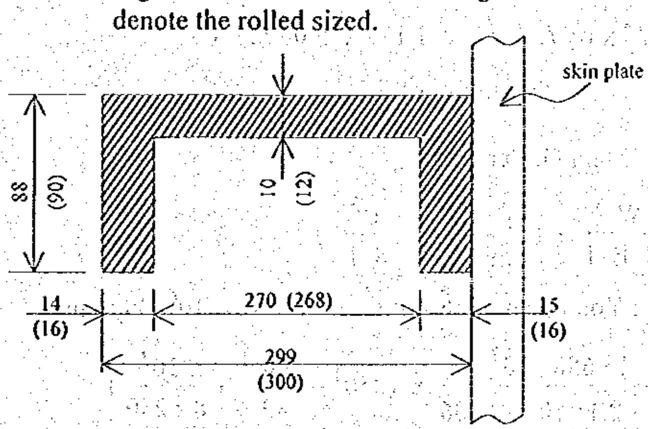
(i) Section Properties

Sections of main girders are chosen from the series of C shaped rolled section. (JIS G 3101)

⊏ 300 x 90 x $^{12}/_{16}$ steel quality SS400.

Effective section properties shall be calculated by excluding the corrosion allowance 1.0 mm (one face).

Figure below shows the main girder section. The figures in parenthesis denote the rolled sized.



I	=	6806	(cm^4)
Zt	=	461	(cm^3)
Zc	=	449	(cm^3)
A	=	52.52	(cm^2)
Aw	=	27.0	(cm^2)

(ii) Stress

Bending tensile stress

$$\sigma t = \frac{M}{Zt} = \frac{5.29465 \times 10^5}{461} = 1149 \ (kgf/cm^2)$$

Bending compressive stress

$$\sigma c = \frac{M}{Zc} = \frac{5.29465 \times 10^5}{449} = 1179 \ (kgf/cm^2)$$

Shearing stress

$$\tau = \frac{Q}{Aw} = \frac{7.844 \times 10^3}{27.0} = 291 \ (kgf/cm^2)$$

Allowable stress

Bending tensile stress

$\sigma ta = 1.125 \times \sigma y/2 = 1.125 \times 2400/2 = 1350 \ (kgf/cm^2)$

Bending compressive stress

$$\sigma ca = 1.125 \times \sigma y/2 - 12 (K \times \frac{\ell}{b} - 9)$$

$$= 1.125 \times 2400/2 - 12 \times (2.024 \times \frac{70.0}{8.8} - 9)$$

$$= 1265 \ (kgf/cm^2)$$

Where σy : Yield stress of SS400 = 2400 (kgf/cm^2)

K : $\sqrt{3 + \frac{Aw}{2 \cdot Ac}}$

Aw : gross sectional area of web plate = 27.0 (cm^2)

Ac : gross sectional area of compressive flange = 12.32 (cm^2)

ℓ : distance between fixed points of compressive flange = 62.5 (cm)

b : width of compressive flange = 8.8 (cm)

Shearing stress

$$\tau a = 1.125 \times \sigma y/2/\sqrt{3} = 1.125 \times 2400/2/\sqrt{3}$$

$$= 779 \ (kgf/cm^2)$$

(iii) Deflection of Main Girder

$$\frac{\delta}{L} = \frac{W}{48 \cdot E \cdot I} \cdot (L^2 - \frac{B^2}{2} + \frac{B^3}{8 \cdot L})$$

where, E : Young's modulus of steel = $2.1 \times 10^6 \ (kgf/cm^2)$

$$\frac{\delta}{L} = \frac{15.688 \times 10^3}{48 \times 2.1 \times 10^6 \times 6806} \times (250^2 - \frac{230^2}{2} + \frac{230^3}{8 \times 250})$$

$$= \frac{1}{1037} < \frac{1}{800}$$

(b) Vertical Sub-beam

Vertical Sub-beam shall be provided as shown in figure next page. These beams shall be analyzed in a manner simple beams supported at the web of main girders.

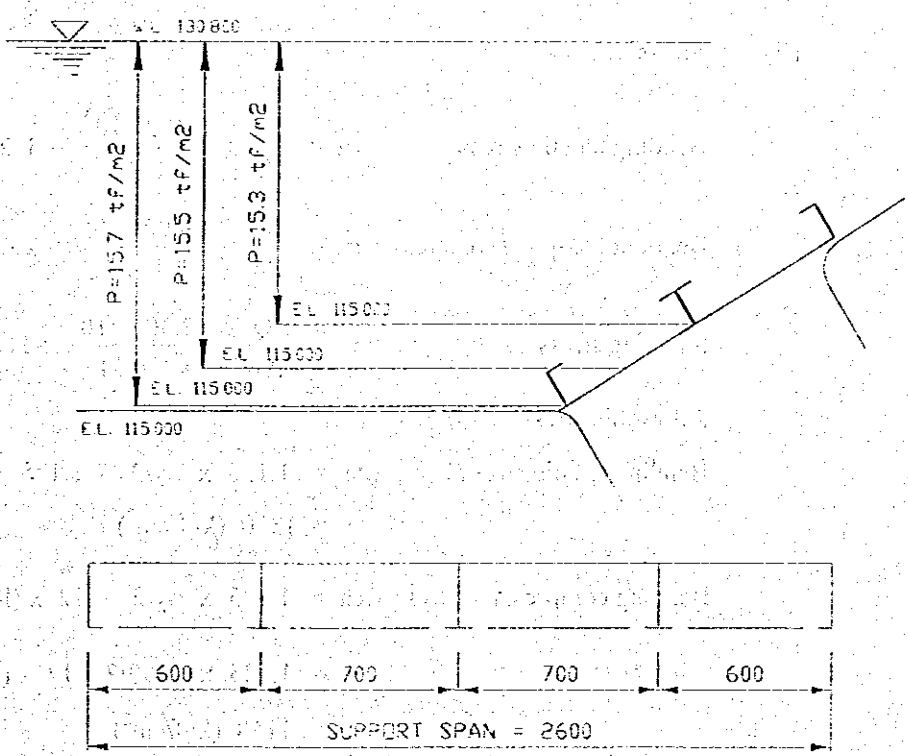
Load shall be computed from the average pressure of the span. Maximum shearing force and maximum bending moment will be obtained by following formula.

$$Q_{max} = \frac{p \cdot m}{2} \cdot \left(\ell - \frac{m}{2}\right)$$

$$M_{max} = \frac{p \cdot m}{24} \cdot (3 \cdot \ell^2 - m)$$

where,

p	:	Average pressure = 15.5 (tf/m^2)
m	:	Vertical sub-beam interval = 0.7 (m)
ℓ	:	Support span = 0.775 (m)



All sub-beams have the same span, so the one, which locates at the bottom part, shall be checked.

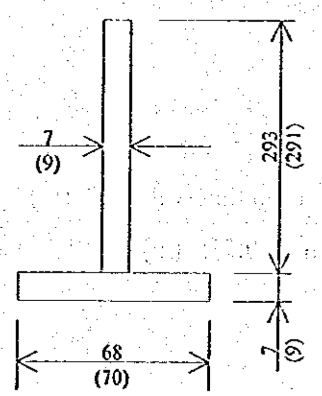
$$Q = \frac{15.5\times0.7}{2} \times (0.775 - \frac{0.7}{2}) = 2.306 \text{ (tf)}$$

$$M = \frac{15.5\times0.7}{24} \times (3 \times 0.775^2 - 0.7) = 0.499 \text{ (tf.m)}$$

(i) Section Properties

BT 300 x 75 x 12 (SS400) shall be used for vertical sub-beams. Efficient section properties shall be calculated by excluding the corrosion allowance 1.0 mm (one face).

Figure below shows the vertical sub-beams section.



I	=	2337	(cm^4)
Zt	=	134	(cm^3)
Zc	=	187	(cm^3)
A	=	25.27	(cm^2)
Aw	=	20.51	(cm^2)

(ii) Stress

Bending tensile stress $\sigma t = \frac{M}{Zt} = \frac{0.499\times10^5}{134} = 372$ (kgf/cm^2)

Bending compressive stress $\sigma c = \frac{M}{Zc} = \frac{0.499\times10^5}{187} = 267$ (kgf/cm^2)

Shearing stress $\tau = \frac{Q}{Aw} = \frac{2.306\times10^3}{20.51} = 112$ (kgf/cm^2)

Allowable stress

Bending tensile stress $\sigma ta = 1.125 \times \sigma y/2 = 1.125 \times 2400/2$

$= 1350$ (kgf/cm^2)

Bending compressive stress $\sigma ca = 1.125 \times \sigma y/2 - 12 \times (K \times \frac{\ell}{b} - 9)$

$= 1.125 \times 2400/2 - 12 \times (2.270 \times \frac{77.5}{6.8} - 9)$

$= 1148$ (kgf/cm^2)

where,

σy	:	Yield stress of SS400 = 2400 (kgf/cm^2)
K	:	$\sqrt{3+\dfrac{Aw}{2\cdot Ac}}$
Aw	:	gross sectional area of web plate =20.51 (cm^2)
Ac	:	gross sectional area of compressive flange =4.76 (cm^2)
ℓ	:	distance between fixed points of compressive flange = 77.5 (cm)
b	:	width of compressive flange = 6.8 (cm)

Shearing stress τa : $1.125 \times \sigma y /2/\sqrt{3}$
$=1.125 \times 2400 /2/\sqrt{3} = 779$ (kgf/cm^2)

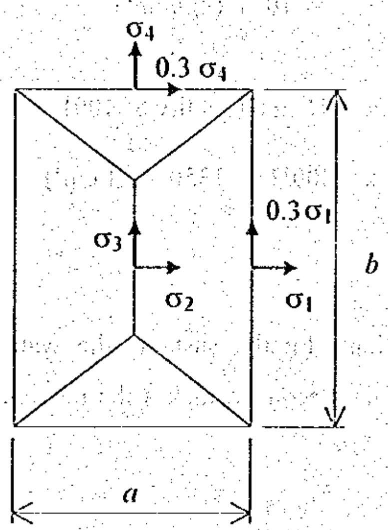
(c) Skin Plate

Flat plates which are subject to bending stress, shall be computed in accordance with DIN 19704, clause 6.5.2.2

$$\sigma = \frac{1}{100}\cdot K \cdot \frac{p\cdot a^2}{t^2}$$

where,

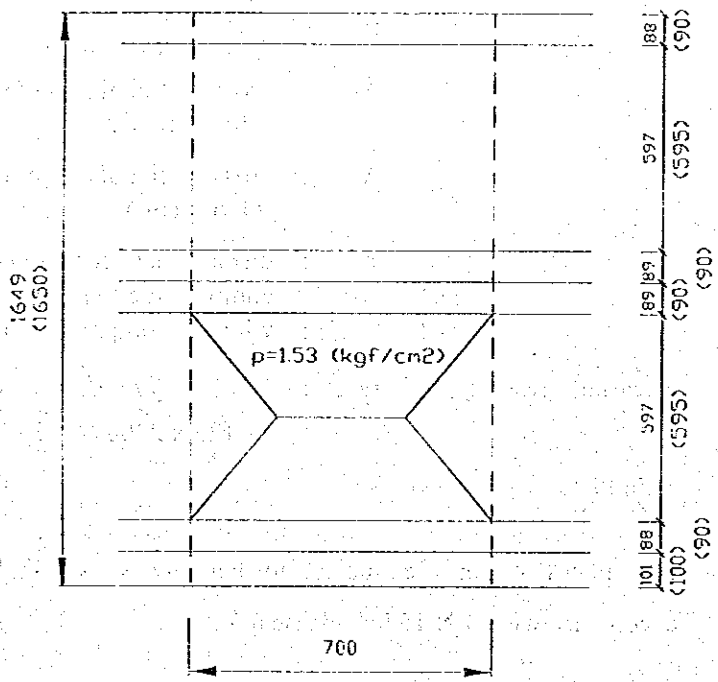
σ	:	Bending stress in kgf/cm^2
p	:	Water pressure relative the plate center in kgf/cm^2
K	:	Non-dimensional factor as shown in table.
a,b	:	Support length of plate pane. $a \le b$ in cm.
t	:	Efficient thickness of skin plate in cm (Exclude corrosion allowance)



b/a	σ1	σ2	σ3	σ4
1.00	30.9	13.7	13.7	30.9
1.25	40.3	18.8	13.5	33.9
1.50	45.5	22.1	12.2	34.3
1.75	48.4	23.9	10.8	34.3
2.00	49.9	24.7	9.5	34.3
2.50	50.0	25.0	8.0	34.3
3.00	50.0	25.0	7.5	34.3
∞	50.0	25.0	7.5	34.3

" K "

According to the figure, the skin plate panel dimension are 59.7 cm x 70.0 cm. Thus, the part panel has to be checked.



$$\frac{b}{a} = \frac{70.0}{59.7} = 1.173$$

$$K_1 = -33.6 \times \left(\frac{b}{a}\right)^2 + 113.2 \times \left(\frac{b}{a}\right) - 48.7 \quad \left(1.0 \leqq \frac{b}{a} \leqq 1.5\right)$$

$$= -33.6 \times 1.173^2 + 113.2 \times 1.173 - 48.7 \fallingdotseq 37.9$$

$$\sigma = \frac{1}{100} \times 37.9 \times \frac{59.7^2 \times 1.53}{(1.6 - 0.2)^2} = 1054 \ (\text{kgf/cm}^2)$$

Skin plate shall be used plate thickness 16 mm (quality SS400)

$$\sigma a = 1.125 \times \sigma y / 2 = 1.125 \times 2400/2 = 1350 \ (\text{kgf/cm}^2)$$

(d) Bearing Plate

The bearing plate has two functions. Firstly, sustains the water load and transfers it to embedded guide frame. Secondly, makes the movement of gate leaf smooth in operation.

Leaded tin bronze casting. LBC–3 (JIS H–5115) shall be used for bearing plate material.

Bearing stress (Gate Leaf)

$$\sigma b = \frac{p \cdot Ls}{2 \cdot Lc}$$

where,

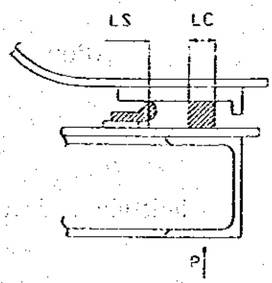
σb : Bearing Stress (kgf/cm^2)

p : Design hydro-pressure at the gate leaf bottom

= 1.58 (kgf/cm^2)

Ls : Seal span = 230 (cm)

Lc : Width of bearing plate = 5.0 (cm)



$$\sigma b = \frac{1.58 \times 230}{2 \times 5.0} = 36.34 \ (kgf/cm^2)$$

Allowable bearing stress

σba = 180 (kgf/cm^2) (static)

Bending stress (Guide Flame/concrete)

$$K = \frac{p \cdot Ls}{2 \cdot LB}$$

where,

K : Bearing stress of concrete (kgf/cm^2)

p : Design hydro-pressure at the gate leaf bottom

= 1.58 (kgf/cm^2)

Ls : Seal span = 230 (cm)

L_B : Width of pressure received = 11.8 (cm)

$$K = \frac{1.58 \times 230}{2 \times 11.8} = 15.4 \ (kgf/cm^2)$$

Allowable bending stress of concrete

Kq = 60 (kgf/cm^2)

Shearing stress of concrete

$$\tau c = \frac{p \cdot Ls}{2 \cdot \sqrt{2} \cdot \ell}$$

where,

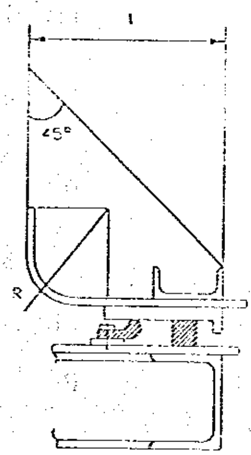
τc : Shearing stress of concrete (kgf/cm^2)

p : Design hydro-pressure at the gate leaf bottom = 1.58 (kgf/cm^2)

Ls : Seal span = 230 (cm)

ℓ : Flowing the figure = 40.0 (cm)

$$\tau c = \frac{1.58 \cdot 230}{2 \times \sqrt{2} \times 40} = 3.2 \text{ (kgf/cm}^2\text{)}$$

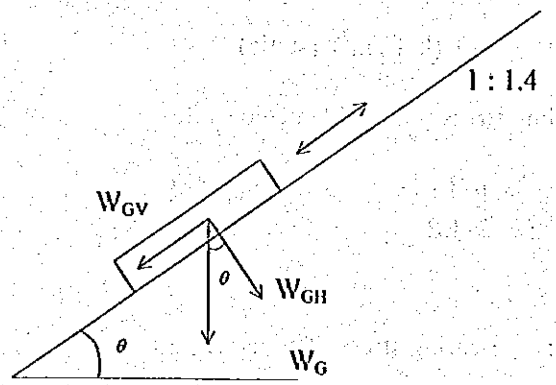


Allowable shearing stress of concrete

τca = 4.0 (kgf/cm^2)

(4) hoisting load (for lifting beam)

Gate Leaf weight : WG = 1.850 (tf)



$$W_{GH} = W_G \times \cos\theta$$

$$= 1.85 \times \cos\left\{\tan^{-1}\left(\frac{1}{1.4}\right)\right\}$$

$$= 1.505 \text{ (tf)}$$

$$W_{GV} = W_G \times \sin\theta$$

$$= 1.85 \times \sin\left\{\tan^{-1}\left(\frac{1}{1.4}\right)\right\}$$

$$= 1.075 \text{ (tf)}$$

Friction due to bearing plate

$Fb = W_H \times \mu b$

where, μ: friction coefficient between bearing plate = 0.4

$Fb = 1.505 \times 0.5 = 0.753$ tf

Friction due to seel rubber

$Fr = \mu r \times q \times L$

where,

μr : Friction coefficient rubber on a stainless steel = 0.7

q : Precompression force of rubber = 0.03 tf/m

L : Seal rubber length = 1.65 x 2 + 2.3 = 5.6 m

Fr = 0.7 x 0.03 x 5.6 = 0.118 tf

(a) Sum of Hoisting Load

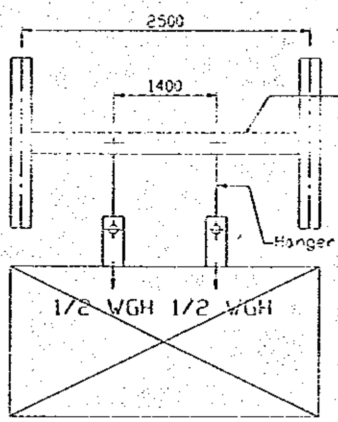
Items	Raising	Lowering	Notes
W_{GV} Fb Fr	↓ 1.075 ↓ 0.753 ↓ 0.118	↓ 1.075 ↑ 0.753 ↑ 0.118	
Sum	↓ 1.828 (tf)	↓ 0.332 (tf)	

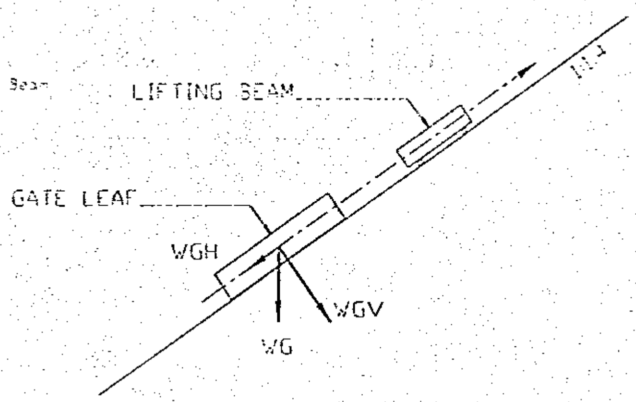
Thus, the design hoisting load is 2.0 tf, and the gate can be fully lowered by its own weight.

(5) Lifting Beam

(a) Lifting Beam

Lifting beam is regarded as a simply supported beam as shown in the figure.



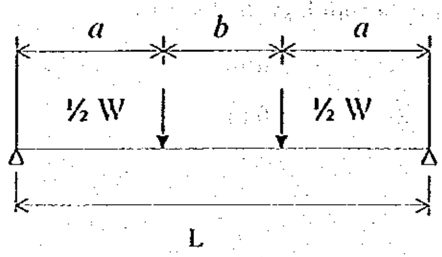


(b) Load

Lifting beam is added to the gate raising load.

Gate Raising Load W = 2.0 tf

(c) Bending Moment and Shearing force



$M = \frac{1}{2} W \cdot a$

where,

W : Horizontal Gate Leaf Weight

W_{GH} = 1.017 tf

a : ½ x (2.5 – 1.4) = 0.55 m

M = ½ x 2.0 x 0.55

= 0.550 tf.m

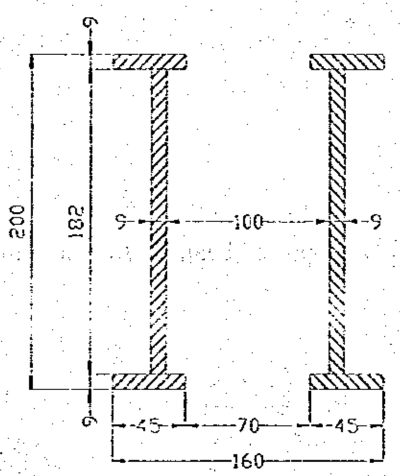
S = ½ W

= ½ x 2.0

= 1.0 tf

(d) Lifting Beam Properties

Point of hanger



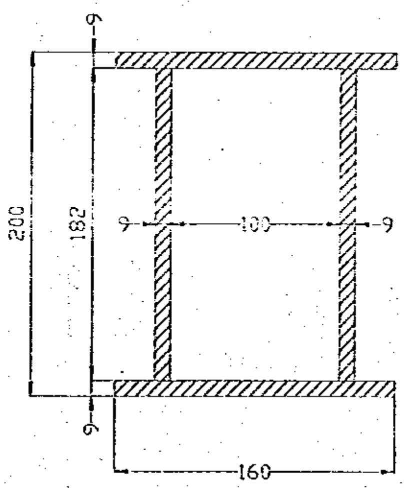
I = 2383 cm^4

Z = 238 cm^3

A = 48.96 cm^2

Aw = 32.76 cm^2

Point of Supporting



$I = 3553\ cm^4$

$Z = 353\ cm^3$

$A = 61.56\ cm^2$

$Aw = 32.76\ cm^2$

Bending Stress and Shearing Stress

$$\sigma = \frac{M}{Z} = \frac{0.55 \times 10^5}{238} = 231\ kgf/cm^2$$

$$\tau = \frac{S}{Aw} = \frac{1.0 \times 10^3}{32.76} = 31\ kgf/cm^2$$

Allowable stress

$\sigma a = 1.125 \times \sigma y/2 = 1.125 \times 2400/2 = 1350\ kgf/cm^2$

$\tau a = 1.125 \times \sigma y/2 / \sqrt{3} = 779\ kgf/cm^2$

(e) Deflection of Lifting Beam

$$\delta_{max} = \frac{\frac{1}{2} \cdot W \cdot a}{24 E I} \times (3L^2 - 4a^2) \quad \text{(center)}$$

where,

W : Gate Raising Load = 2.0 tf

a : 55 cm

E : Young's modulus of steel = 2.1×10^6 kgf/cm^2

I : Inertia of Moment = 3553 cm^4

L : Support Span = 250 cm

$$\delta = \frac{\frac{1}{2} \times 2000 \times 55}{24 \times 2.1 \times 10^6 \times 3553} \times (3 \times 250^2 - 4 \times 55^2)$$

$= 0.054$ cm

$$\frac{\delta}{L} = \frac{0.054}{250} = \frac{1}{4641} < \frac{1}{800}$$

(6) Hoist

(a) Hoisting Load

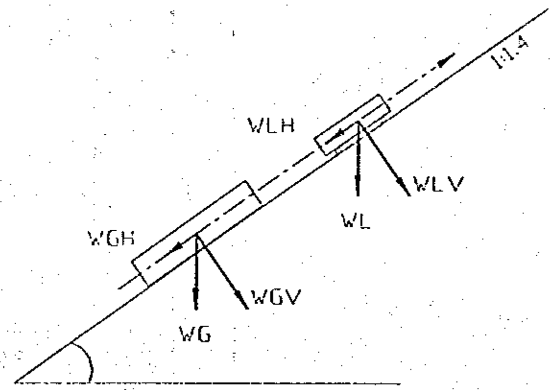
Gate self-weight

$W_G = 1.850$ ton

$W_{GV} = W_G \times \cos\theta$

$= 1.850 \times \cos\left\{\tan^{-1}\left(\frac{1}{1.4}\right)\right\}$

$= 1.505$ ton



$W_{GH} = W_G \times \sin\theta$

$= 1.850 \times \sin\left\{\tan^{-1}\left(\frac{1}{1.4}\right)\right\}$

$= 1.075$ ton

Lifting Beam self-weight

$W_L = 0.6$ ton

$W_{LV} = WL \times \cos\theta$

$= 0.6 \times \cos\left\{\tan^{-1}\left(\frac{1}{1.4}\right)\right\}$

$= 0.488$ ton

$W_{LH} = W_L \times \sin\theta$

$= 0.6 \times \sin\left\{\tan^{-1}\left(\frac{1}{1.4}\right)\right\}$

$= 0.349$ ton

Wripe-Rope weight (JIS 6 x 37 – A Type, ϕ 16)

$W_R = 0.920$ (kg) x 67.0 (m) x 2

$= 123.28$ kg

$\fallingdotseq 0.15$ ton

Bending plate friction

$F_B = \mu \times W_{GV}$

where, μ : Bending plate resistance = 0.4

F_B = 0.5 x 1.505

= 0.753 tf

Seal rubber friction (under water)

Fr = q x L x μ

where, q : Precompression force of rubber = 0.03 tf/m

L : Length of Seal rubber = 2 x 1.65 + 2.3 = 5.6 m

μ : Friction coefficient rubber on stainless steel = 0.7

Fr = 0.03 x 5.6 x 0.7

= 0.118 tf

Seal rubber friction (in the air)

Fr' = q x L x μ'

where, μ' : Friction coefficient rubber on stainless steel = 1.2

Fr' = 0.03 x 5.6 x 1.2

= 0.202 tf

Wheel friction (Lifting Beam)

$$Fw = \frac{(\mu_1 + \mu_2 \times d/2)}{D/2} \times W_{LV}$$

where, μ_1 : Rolling resistance = 0.1

μ_2 : Friction coefficient on wheel axle self-rubricating oils bushing = 0.2

D : Wheel diameter = 9.8 cm

d : Wheel axle diameter = 2.8 cm

$$Fw = \frac{\left(0.1 + 0.2 \times \frac{2.8}{2}\right)}{9.8/2} \times 0.488$$

= 0.038 tf

(b) Sum of Load

Item	Under Water		in the air	
	Raising	Lowering	Raising	Lowering
W_{GH}	1.075 ↓	1.075 ↓	1.075 ↓	1.075 ↓
W_{LH}	0.349 ↓	0.349 ↓	0.349 ↓	0.349 ↓
W_R	0.150 ↓	0.150 ↓	0.150 ↓	0.150 ↓
F_B	0.753 ↓	0.753 ↑	0.753 ↓	0.753 ↑
Fr / Fr'	0.118 ↓	0.118 ↑	0.202 ↓	0.202 ↑
Fw	0.038 ↓	0.038 ↑	0.038 ↓	0.038 ↑
Sum	2.483 ↓	0.665 ↓	2.566 ↓	0.582 ↓

Thus, the design hoisting load is 2.6 tf, and the gate can be fully lowered by its own weight.

(c) Mechanical Efficiency

Mechanical efficiency of each device is listed below.

Reduction gear : 0.8 ~ 0.94

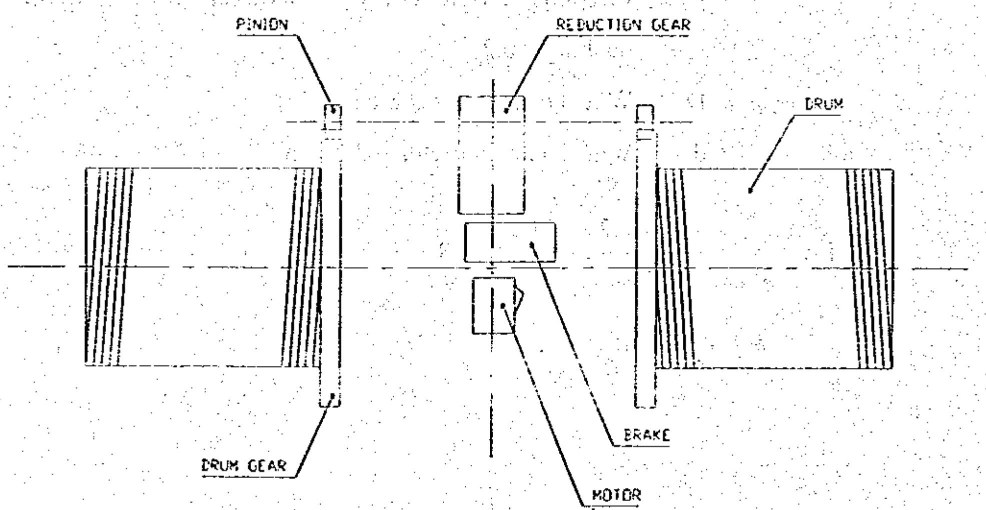
Drum gear and pinion : 0.95

Drum : 0.95

$\eta_m = 0.8 \times 0.95 \times 9.5 = 0.722$ (start)

$\eta_m = 0.94 \times 0.95 \times 9.5 = 0.848$ (drive)

Schematic arrangement of hoist is shown below



(d) Hoisting Speed

Hoisting speed for gate is calculated as follows.

$$V = M_M \times iR \times iG \times \frac{\pi \times D}{N} \quad (^m/_{min})$$

where,

M_M : Revolution number of motor (50 Hz, 6 poles),

= 930 r.p.m (under leaded condition).

iR : Reduction ratio of reducer = $^1/_{500}$

iG : Number of teeth on $^{pinion}/_{Drum\ gear}$ = $^{21}/_{98}$

D : Diameter of drum = 0.86 m

N : Number of wire ropes suspending the gate leaf at each side = 1

$$V = 930 \times {}^1/_{500} \times {}^{21}/_{98} \times \frac{\pi \times 0.86}{1}$$

$$= 1.077 \ ^m/_{min}$$

Motor output

$$Pm = {}^1/_{6.12} \times \frac{W \times V}{\eta}$$

where, W : Hoisting load = 2.6 tf

V : Hoisting speed = 1.077 $^m/_{min}$

η : Mechanical efficiency = 0.722

$$Pm = {}^1/_{6.12} \times \frac{2.6 \times 1.077}{0.722}$$

$$= 0.634 \ kW$$

Therefor, 0.75 kW induction motor should be used.

(e) Torque of Each Shaft

Torque moments, which shall be transferred through each shaft, are computed in two cases.

(i) At Rated Motor Torque

Motor output torque

$$T_1 = \frac{97400}{930} \times 0.75 = 78.5 \text{ kgf·cm}$$

Reducer output shaft

$$T_2 = 78.5 \times \frac{500}{1} \times 0.94 \times ½ = 18458.9 \text{ kgf·cm}$$

Drum gear

$$T_3 = 18458.9 \times \frac{98}{21} \times 0.95 = 81834.3 \text{ kgf·cm}$$

(ii) At Maximum Motor Torque

Maximum motor torque shall be 300% of rated motor torque. Each torque value is 3.0 times as calculated 6.1.

T_1' = 235.5 kgf·cm

T_2' = 55376.6 kgf·cm

T_3' = 245503.0 kgf·cm

(f) Strength Wire Rope

(i) Applied Wire Rope

JIS G3525, 6 x 37 class A wire rope

Diameter : d = 16 mm

Breaking strength : T = 13900 kgf

(ii) Safety Factor

Safety factor to breaking strength calculated from hoisting load and from maximum motor torque shall be at least 8 and 1.7 respectively. Wire rope tension per one rope for hoisting load is

$$F = \frac{2.6}{2} = 1.300 \text{ tf}$$

Safety factor is

$$S = \frac{13900}{1.3 \times 10^3} = 10.7 \geqq 8.0$$

Wire rope tension per one rope for maximum motor torque is

$$F' = \frac{2 \times 245503 \times 0.95}{86} = 5423.9 \text{ tf}$$

$$S = \frac{13900}{5423.9} = 2.56 \geqq 1.7$$

(g) Strength of Gear

Strength of gear shall be examined as regards bending and bearing. Bending strength safety factor to ultimate tensile strength calculated from rated motor torque shall be more than 5. And be less than 90% of yield strength for the maximum motor torque. Bearing strength shall be more than the actual bearing load calculated from rated motor torque.

Calculation result are summarized in table.

$P < Pa$

$P' < Pa'$

for pinion and drum gear

CALCULATION TABLE FOR STRENGTH OF TEETH

		Pinion	Drum Gear
Module m (mm)		16	16
Number of teeth z		21	98
Width of teeth b (mm)		150	160
Pitch circle dia P·C·D = m·z (mm)		336	1568
Material Ultimate σ_B / Yield σy (kgf/mm)		SCM 440 90 / 70	SCM 435 75 / 55
Allowable stress	$\sigma a = \sigma_B/5$	18	15
	$\sigma a' = 0.9\ \sigma y$	63	49.5
Revolution n (r·p·m)		19	0.407
Pitch line velocity $V = \pi \cdot n \cdot D/1000\ (^{m}/_{min})$		2.006	2.006
Coefficient of velocity $fv = 3.05/(3.05 + v)$		0.603	0.603
Coefficient of tooth profile y		0.34	0.464
Coefficient of bearing stress K		0.116	
Torque	Rated T	18458.9	8134.3
	Maximum T'	55376.6	245503.0
Actual load $\frac{T or T'}{D/2}$ kgf	Rated	1098.7	1043.8
	Maximum	3296.2	3131.4
Allowable load in bending kgf m x b x fv x y x (σa or $\sigma a'$)	Rated Pa	10425.1	10839.8
	Maximum Pa'	36487.8	35771.2
Allowable load in bearing $fv \times K \times D2 \times b_1 \times \frac{2Z_1}{Z_1 + Z_2}$ Pba (kgf)		1464.6	
D2 : Pitch circle of pinion b1 : Teeth width of pinion		Z_1 : Pinion Z_2 : Drum Gear	

2.7.3 Trash Rack for Bulkhead Gate

(1) Design Data

Type	:	Steel Made
Quantity	:	1 set
Elevation		
Top of Trash Rack	:	E.L. 152.200
Bottom of Trash Rack	:	E.L. 130.000
Breadth	:	2.0 m
Inclination Angle	:	1 : 1.4
Bar Element		
Thickness	:	12 mm (Include corrosion allowance)
Breadth	:	100 mm
Clear Spacing between Bars	:	88 mm (Include corrosion allowance)
Design Pressure	:	0.2 kgf/cm^2
Corrosion Allowance	:	1.0 mm (one face)
Allowable Stress		
for Steel	:	Tension, Compression 0.5 · σy as a basic shearing 0.5 σy/ $\sqrt{3}$
for Concrete	:	Compression 70.0 kgf/cm^2
		Shearing 4.0 kgf/cm^2
		Bearing 60.0 kgf/cm^2
		Bond 7.0 kgf/cm^2

(2) Strength of Bar Element

Each Trash Rack bar element is regarded simply supported by supporting beams and supporting beams.

(a) Load Exerted on Bar Element

$$q = p \cdot b$$

where, q : Uniform load exerted on bar element

p : Design pressure = 0.2 kgf/cm^2

b : ℄ to ℄ of bar element = 10.0 cm

$q = 0.2 \times 10.0$

$= 2.0$ kgf/cm

(b) Bending Moment and Shearing Force

$$M = \frac{q \cdot L^2}{8}$$

$$Q = \frac{q \cdot L}{2}$$

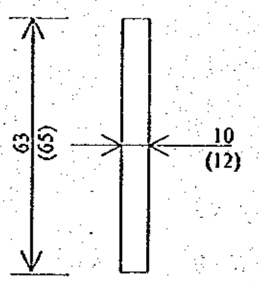
where, L = Span of bat element = 150 cm

$$M = \frac{2.0 \times 150^2}{8} = 5625 \text{ kgf/-cm}$$

$$Q = \frac{2.0 \times 150}{2} = 150 \text{ kgf}$$

(c) Section Properties

Flat bars 12 x 65 (steel quality SS400) shall be used for Trash Rack bar elements.



$I = 20.8 \text{ cm}^4$

$Z = 6.6 \text{ cm}^3$

$A = 6.3 \text{ cm}^2$

Corrosion allowance of 1.0 mm (one face) has already been eliminated for these section properties.

(d) Bending and Shearing Stress

$$\sigma = \frac{M}{Z} = \frac{5625}{6.6} = 852 \text{ kgf/cm}^2$$

$$\tau = \frac{Q}{A} = \frac{150}{6.3} = 24 \text{ kgf/cm}^2$$

(e) Allowable Stress

Allowable stress for bending shall be calculated by succeeding formula, which considers the lateral bucking.

$$\sigma a = 0.6 \cdot \sigma y \cdot (1.123 - 0.0153 \cdot \ell / t)$$

where, σy : Yield strength of bar = 2400 kgf/cm² (SS400)

ℓ : Bending bolt pitch = 30 cm

t : Thickness of bar = 1.0 cm

σa = 0.6 x 2400 x (1.123 – 0.0153 x 30/1.0)

= 956

τ = 0.5 x $\sigma y / \sqrt{3}$

= 0.5 x 2400/ $\sqrt{3}$

= 693 kgf/cm²

(3) Flow induced vibration of bar element

Trash rack bar elements shall be design to prevent vibration induced by the flow through the Trash Rack. The design criteria for this problem are expressed as follows.

$$\frac{fn}{f} > 2.5$$

where, fn : Natural frequency of bar element

$= (\alpha / 2\pi) \times \sqrt{(E \times I \times g)/(W + \ell^3)}$

d : Coefficient of bar supporting condition

Simple support = 9.87

Fixed support = 22.7

E : Young's modulus of steel = 2.1×10^6 kgf/cm²

I : Inertia of moment

$$I_{max} = \frac{t \cdot B^3}{12} = \frac{1.0 \times 6.3^3}{12} = 20.8 \text{ cm}^4$$

$$I_{min} = \frac{t^3 \cdot B}{12} = \frac{1.0^3 \times 6.3}{12} = 0.525 \text{ cm}^4$$

g : Gravity acceleration = 980 cm/s²

W : Weight of bar per unit length and added weight of water per unit length

= ν x (r + b x rf/t)

v : $t \cdot B \cdot \ell$

t : Thickness of bar element = 1.0 cm

B : Width of bar element = 6.3 cm

ℓ : Supporting distance of bar element = 27.5 cm

r : Weight of bar unit = 0.00785 kgf/cm^3

rt : Weight of water unit = 0.001 kgf/cm^3

b : Clear spacing between bar elements = 9.0 cm

f : Karman's vortex frequency of bar element

= St x u / t

St : Strouhal number = 0.2

u : Mean flow velocity passing through Trash Rack

$$= \frac{Q}{A} = \frac{6.0\,m^3/s}{2.0m \times \frac{1}{3} \times (WL.136.0 - EL.130.0)m} = 1.5\ m/s = 150\ cm/s$$

fn = 209.6 Hz (I_{min} = 0.525 cm^4)

fn' = 1320.2 Hz (I_{max} = 20.8 cm^4)

f = 30 Hz

$$\frac{fn}{f} = 7.0 > 2.5$$

$$\frac{fn'}{f} = 44.0 > 2.5$$

(4) Strength of supporting frame

(a) Load Exerted on Supporting Frame

$q = p \cdot \ell$

where, q : Uniform load exerted in supporting frame

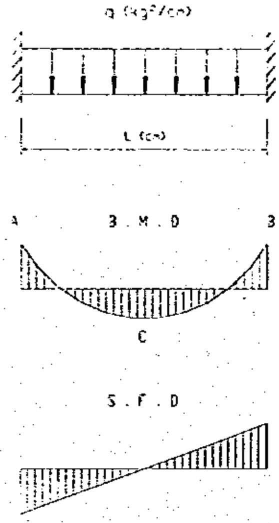
p : Design pressure = 0.2 kgf/cm^2

ℓ : Pitch of supporting frame = 150 cm

q = 0.2 x 150

= 30 kgf/cm

(b) Bending Moment and Shearing Force



$$M_A = M_B = -\frac{q \cdot L^2}{12}$$

$$M_C = \frac{q \cdot L^2}{24}$$

$$Q = \frac{q \cdot L}{2}$$

Where, L : Span of supporting frame = 200 cm

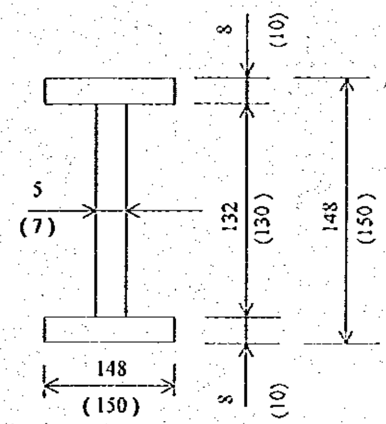
$$M_A = M_B = -\frac{30 \times 200^2}{12} = -\ 100000 \text{ kgf·cm}$$

$$M_C = \frac{30 \times 200^2}{24} = 50000 \text{ kgf·cm}$$

$$Q = \frac{30 \times 200}{2} = 3000 \text{ kgf}$$

(c) Section Properties

H 150 x 150 x 7/10 (steel quality SS400)



$I = 1257$ cm^4

$Z = 170$ cm^3

$A = 30.28$ cm^2

$A_W = 6.6$ cm^2

(d) Bending and Shearing Stress

$$\sigma = \frac{M}{Z} = \frac{100000}{107} = 588 \text{ kgf/cm}^2$$

$$\tau = \frac{Q}{A_W} = \frac{3000}{6.6} = 455 \text{ kgf/cm}^2$$

(e) Allowable Stress

$$\sigma ta = 0.5 \cdot \sigma y = 0.5 \times 2400 = 1200 \text{ kgf/cm}^2$$

$$\sigma ca = 1200 - 11 \left(K \cdot \frac{\ell}{b} - 9\right)$$

where, K : Coefficient = 2

ℓ : Distance between fixed points of compressive flange = 200 cm

b : Width of compressive flange = 14.8 cm

$$\sigma ca = 1200 - 11 \times (2 \times \frac{200}{14.8} - 9)$$

$$= 1002 \text{ kgf/cm}^2$$

$$\tau = 0.5 \cdot \tau / \sqrt{3} = 0.5 \times 2400 / \sqrt{3} = 693 \text{ kgf/cm}^2$$

(f) Deflection of Supporting Frame

$$\delta = \frac{q \cdot L^4}{384 \cdot E \cdot I}$$

$$= \frac{30 \times 200^4}{384 \times 2.1 \cdot 10^6 \times 1257}$$

$$= 0.0474 \text{ cm}$$

$$\frac{\delta}{L} = \frac{0.0474}{200} = \frac{1}{4219} < \frac{1}{800}$$

2.7.4 Trash Rack for Emergency Gate

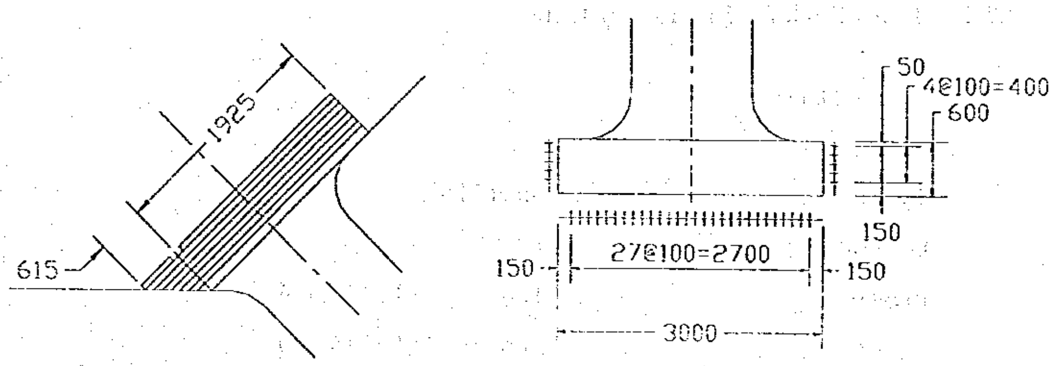
(1) Design Data

Type	:	Steel Made
Quantity	:	1 set
Elevation	:	Top EL. 116.476
		Bottom EL. 115.000
Breadth	:	3.0 m
Depth	:	0.6 m
High	:	2.54 m
Inclination Angle	:	1 : 1.4
Bar Element		
Thickness	:	9 mm
Breath	:	100 mm
Clear spacing between Bars	:	91 mm (Include corrosion allowance)
Design pressure	:	0.2 kgf/cm^2
Corrosion Allowance	:	1.0 mm (one face)
Allowable Stress		
Main Girder	:	Tension, Compression $1.125 \times \sigma y / 2$
		as a basic shear $1.125 \times \sigma y / 2 / \sqrt{3}$
Bar Element	:	$0.6 \times \sigma y \times (1.23 - 0.0153 \times \ell / t)$
		where,
		σy : Yield stress of SS400 = 2400 kgf/cm^2
		ℓ : Binding bold pitch = 33.5 cm
		t : Thickness of bar = 0.9 cm (Include corrosion allowance)
For concrete	:	Bearing 60 kgf/cm^2
		Bearing 4.0 kgf/cm^2
		Bearing 7.0 kgf/cm^2

(2) Strength of bar element

Each Bar element is regarded simply supported by supporting frames and supporting beams.

As shown in figure, Bar support distance is 1.925 m.



(a) Load Exerted on Bar Element

$q = p \times b$

where,

q : Uniform load exerted on bar element

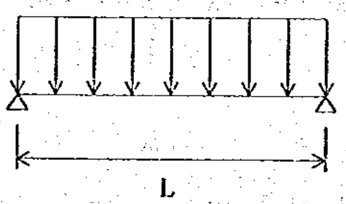
p : Design pressure = 0.2 kgf/cm^2

b : ℄ to ℄ of bar element = 10.0 cm

$q = 0.2 \times 10.0$

$= 2.0 \ kgf/cm^2$

(b) Bending Moment and Shearing Force



$M = \frac{1}{8} \times q \times L^2$

$Q = \frac{1}{2} \times q \times L$

where,

L : Span of bar element

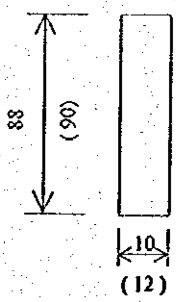
= 192.5 cm

$M = \frac{1}{8} \times 2.0 \times 192.5^2 = 9.264 \ kgf \cdot cm$

$Q = \frac{1}{2} \times 2.0 \times 192.5 = 192.5 \ kgf$

(c) Section properties

Flat bar 9 x 90 (steel quantity SS400) shall be used for Bar elements.



$I = 56.8 \ cm^4$

$Z = 12.9 \ cm^3$

$A = 8.8 \ cm^2$

Corrosion allowance of 1.0 mm (one face) has already been eliminated for these section properties.

(d) Bending and Shearing Stress

$$\sigma b = \frac{M}{Z} = \frac{9.264}{12.9} = 718 \quad kgf/cm^2$$

$$\tau = \frac{Q}{A} = \frac{192.5}{8.8} = 21.9 \quad kgf/cm^2$$

(e) Allowable Stresses

Allowable stress for bending shall be calculated shall by succeeding formula, which considers the lateral buckling.

$$\sigma a = 0.6 \times \sigma y \times (1.23 - 0.0153 \ \ell / t)$$

where,

σy : Yield stress of SS400 = 2400 kgf/cm^2

ℓ : Binding bolt pitch = 35.5 cm

t : Thickness of bar = 1.0 cm

$$\sigma a = 0.6 \times 2400 \times (1.23 - 0.0153 \times 35.5/1.0)$$
$$= 989 \ kgf/cm^2$$

$$\tau a = 1.125 \times \sigma y / 2 / \sqrt{3}$$
$$= 1.125 \times 2400 / 2 / \sqrt{3}$$
$$= 779 \ kgf/cm^2$$

(3) Flow induced vibration of bar element

Trash rack bar elements shall be designed to prevent vibration induced by the flow through the trash rack. The design criteria for this problem is expressed as following:

$$\frac{fn}{f} \geqq 2.5$$

where,

fn ; Natural frequency of bar element

$$= (\alpha / 2\pi) \times \sqrt{(E \times I \times g)/(W \times \ell^3)}$$

α	:	Coefficient of bar supporting condition
		Simple support : 9.87
		Fixed support : 22.7
E	:	Young's modulus of steel = 2.10×10^6 kgf/cm^2
I	:	Inertia of movement

$$I_{max} = \frac{tB^3}{12} = \frac{0.7 \times 8.8^3}{12} = 39.8 \ \text{cm}^4$$

$$I_{min} = \frac{t^3B}{12} = \frac{0.7^3 \times 8.8}{12} = 0.252 \ \text{cm}^4$$

g	:	Gravity acceleration = 980 cm/s^2
W	:	Weight of bar per unit length and added weight of water per unit length.
		= $\nu \times (\gamma + b \times \gamma_f / t)$
ν	=	$t \cdot B \cdot \ell$
t	:	Thickness of bar element = 0.7 (cm)
B	:	Width of bar element = 8.8 (cm)
ℓ	:	Supporting distance of bar element = 35.5 (cm)
γ	:	Weight of bar unit = 0.00785 kgf/cm^3
γ_f	:	Weight of water unit = 0.001 kgf/cm^3
b	:	clear spacing between bar elements = 9.3 cm
f	:	Karman's vortex frequency of bar element
		= St x u / t
St	:	Strouhal number = 0.2
u	:	Mean flow velocity passing through trash rack

$$= \frac{Q}{A} = \frac{3.0 \ \text{m}^3/\text{s}}{2.0\,\text{m} \times 1.4\,\text{m}} = 1.071 \ \text{m/s} = 107.1 \ \text{cm/s}$$

$$fn = \{9.87 / (2 \times \pi)\} \times \sqrt{(2.1 \times 10^6 \times 0.252 \times 980) / [\{0.7 \times 8.8 \times 35.5 \times (0.00785 + 9.3 \times 0.001 / 0.7)\} \times 35.5^3]}$$

$$= 78.669$$

$$f = 0.2 \times 107.1 / 0.7 = 30.6$$

$$\frac{fn}{f} = \frac{78.669}{30.6} = 2.571 \geqq 2.5$$

(4) Strength of supporting frame

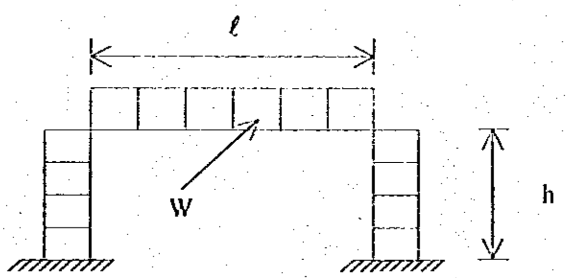
Supporting frames installed inside of solid trash rack are supposed rigid rahmen frames. These frames sustain the uniform distribution load W, coming from trash rack bar elements.

(a) General Formulae for Structural Analysis

Figure shows structural conditions, loading conditions, and diagrams for each section froze.

According to the results of analysis, each section force value is expressed as follows.

(i) Structural Conditions



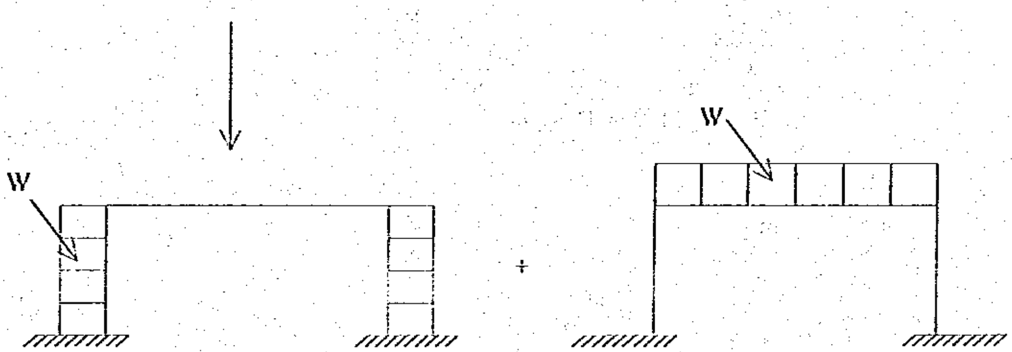
ℓ = 3.1 m

h = 0.62 m

W = 2.0 tf/m^2 x 1.54 m

= 3.08 tf/m

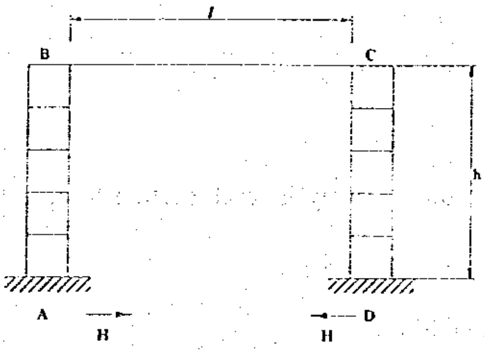
$$K = \frac{h}{\ell} = \frac{0.62}{3.1} = 0.2$$



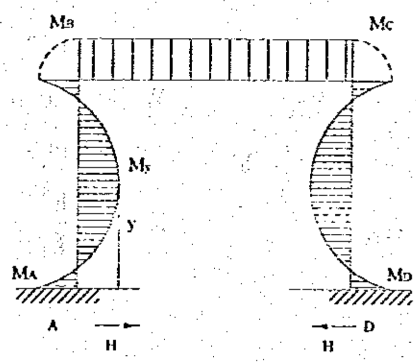
Case A

Case B

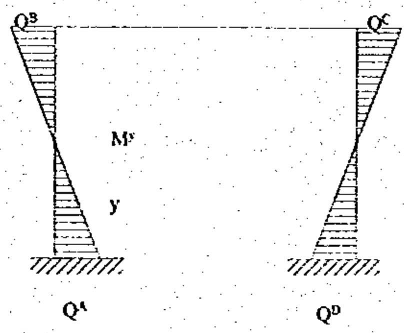
Case A

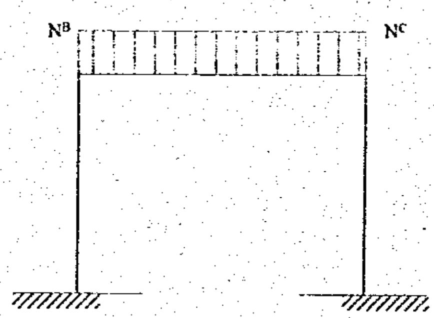


Structural and Loading Condition

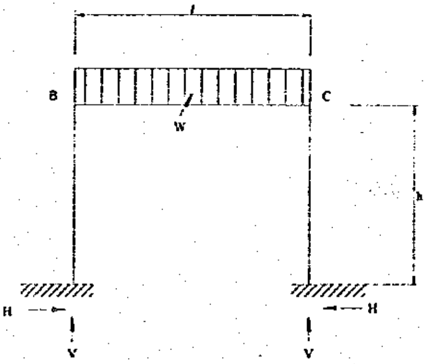


Bending Moment Diagram

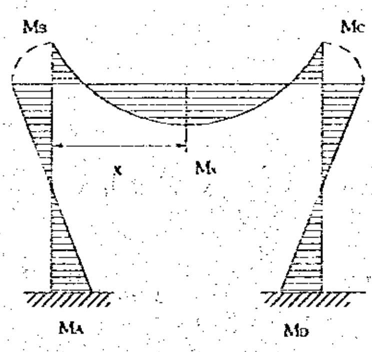




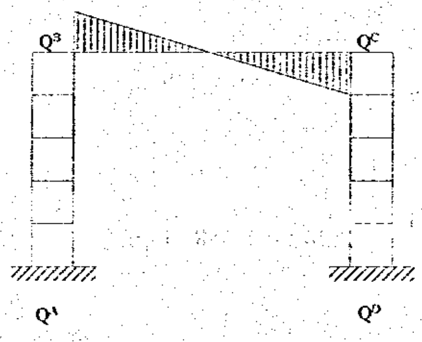
Case B



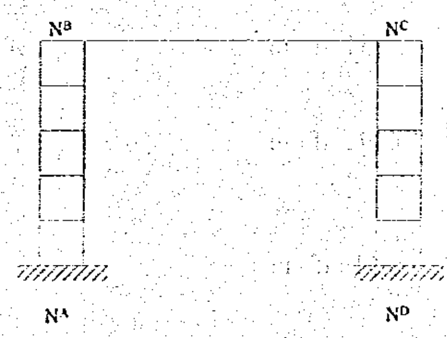
Structural and Loading Condition



Bending Moment Diagram



Shearing Force Diagram



Axial Force Diagram

(ii) Bending Moments

Case A

$M_A = M_D \quad = -\dfrac{K+3}{12 \times (K+2)} \times W \times h^2$

$= -\dfrac{0.2+3}{12 \times (0.2+2)} \times 3.08 \times 0.62^2$

$= -0.144 \quad tf \cdot m$

$M_B = M_C \quad = -\dfrac{K}{12 \times (K+2)} \times W \times h^2$

$= -\dfrac{0.2}{12 \times (0.2+2)} \times 3.08 \times 0.62^2$

$= -0.009 \quad tf \cdot m$

My $(y = \frac{h}{2})$ $= -\dfrac{K+3}{12 \times (K+2)} \times W \times h^2 + \dfrac{2K+5}{4 \times (K+2)} \times W \times h \times \dfrac{h}{2} - \dfrac{W}{2} \times \left(\dfrac{h}{2}\right)^2$

$= -\dfrac{0.2+3}{12 \times (0.2+2)} \times 3.08 \times 0.62^2 + \dfrac{2 \times 0.2 + 5}{4 \times (0.2+2)} \times 3.08 \times \dfrac{0.62^2}{2} - \dfrac{3.08 \times 0.62^2}{8}$

$= 0.072 \quad tf \cdot m$

Case B

$M_A = M_D \quad = \dfrac{W \cdot \ell^2}{12 \times (K+2)} = \dfrac{3.08 \times 3.1^2}{12 \times (0.2+2)} = 1.121 \quad tf \cdot m$

$M_B = M_C \quad = -2\,MA \quad = -2.242 \quad tf \cdot m$

Mx $(x = \frac{\ell}{2})$ $= \dfrac{W \cdot \ell^2}{8} + M_B = \dfrac{3.08 \times 3.1^2}{8} - 2.242 = 1.458 \quad tf \cdot m$

Sum of Bending Moment (case A + case B)

$M_A = M_D \quad = -0.144 + 1.121 \quad = 0.977 \quad tf \cdot m$

$M_B = M_C \quad = -0.009 + (-2.242) \quad = -2.251 \quad tf \cdot m$

Mx $(x = \frac{\ell}{2})$ $= -0.009 + 1.458 \quad = 1.449 \quad tf \cdot m$

My $(y = \frac{h}{2})$ $= 0.072 - 0.586 \quad = -0.514 \, tf \cdot m$

(iii) Shearing Force

Case A

$$H = Q = \frac{2K+5}{4\times(K+2)} \times W \times h = \frac{2\times0.2+5}{4\times(0.2+2)} \times 3.08 \times 0.62 = 1.172 \text{ tf}$$

Case B

$$H = Q = \frac{W\cdot\ell^2}{4\times(K+2)\times h} = \frac{3.08\times3.1^2}{4\times(0.2+2)\times0.62} = 5.425 \text{ tf}$$

Sum of shearing force

$H = 5.425 - 1.172 = 4.253$ tf

(iv) Axial Force

Case A

$N_B = N_C = H = 1.172$ tf

Case B

$$\underset{A\to B}{N} = \underset{D\to C}{N} = \overline{V} = \frac{W\ell}{2} = \frac{3.08\times3.1}{2} = 4.774 \text{ tf}$$

(v) Reaction Force

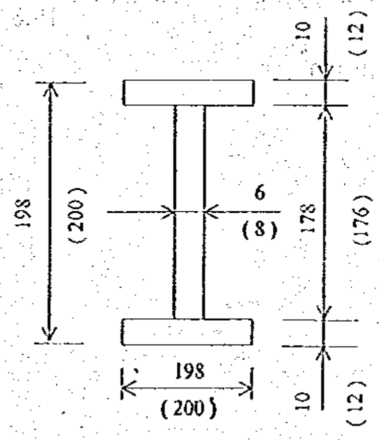
$H = 5.425 - 1.172 = 4.253$ tf

$\overline{V} = 4.774$ tf

(b) Stress of Supporting Frame

(i) Section Properties

H 200 x 200 x 8/12 (steel quality SS400) is adopted.



$I = 3784$ (cm^4)

$Z = 382$ (cm^3)

$A = 50.28$ (cm^2)

$Aw = 10.68$ (cm^2)

Corrosion allowance of 1.0 mm has already been eliminated for these section properties.

(ii) Stress

Stress due to bending moment and axial force shall be superposed. Supporting frame member AB and CD yields larger stress compared with others BC.

At the point B or C

$$\sigma = \pm \frac{MB}{Z} + \frac{NB}{A}$$

$$= \pm \frac{2.251 \times 10^5}{382} + \frac{4.774 \times 10^3}{50.28}$$

$= 684$ kgf/cm^2 (compression side)

-494 kgf/cm^2 (tension side)

$$\tau = \frac{Q}{Aw} = \frac{4.253 \times 10^3}{10.68} = 424 \text{ kgf/cn}^2$$

Allowable stress

Bending stress

Tension $\sigma a = 1.125 \times \sigma y / 2 = 1350$ kgf/cm^2

Compression $\sigma a = 1.125 \times \sigma y / 2 - 12 \times (K \times \frac{\ell}{b} - 9)$

$$\frac{Aw}{Ac} = \frac{10.68}{1.0 \times 19.8} = 0.539 < 2$$

Then,

$K = 2$

$$\sigma a = 1.125 \times 2400 / 2 - 12 \times (2 \times \frac{310}{19.8} - 9)$$

$= 1082$ kgf/cm^2

Shearing stress

$\tau a = 1.125 \times \sigma y / 2\sqrt{3}$

$= 1.125 \times 2400 / 2 / \sqrt{3}$

$= 779$ kgf/cm^2