In the analyses, the allowable stresses are increased by 50 % for such tentative and rare cases as the seismic and flood conditions in accordance with the standard.
As seen in the analyses, the reinforcement bar arrangement of D19 @ 200 which is considered minimum requirement of the reinforcement bars for the structure will withstand the acting forces.

## 4.2 Spillway Bridge

### 4.2.1 General

The spillway structure is located on the left abutment of the damsite. The spillway is a side channel type with an open chuteway.

A bridge is required to cross this open channel at the dam crest level of EL. 196.0 m. The total length of the bridge is 29.8 m. Its span is 29.0 m in terms of the length between two supports. From an economical point of view, the bridge is provided with an effective width of 6.0 m which is the minimum width for traffic to pass each other.

The bridge is designed as the second-order bridge for which the design car load is specified to be 14.0 ton with the following consideration: that is, although the dam design is based on a consideration that the possibility of utilization of dam crest as a traffic road is not ruled out, its road will not be a trunk road but a branch road.

The bridge is designed as a composite girder in which the acting loads are borne by both the girder and floor slab. This section presents the main parts of the design analyses consisting of those on the composite girder. Reference is made to the Data Book with regard to analyses on other detailed parts.

### 4.2.2 Design Condition

The design conditions of the spillway bridge which is based on the Specification for Road Bridge by Japan Society of Road are summarized below:

- Total length ........................................................ 29.8 m
- Span ........................................................ 29.0 m
- Class of bridge ........................................................ Second-order

- Bridge type .............................................................. Composite girder
- Total width .............................................................. 7.2 m
- Effective width .......................................................... 6.0 m
- Pavement thickness ..................................................... 50 mm
- Floor slab thickness ..................................................... 180 mm
- Allowable stress:
  - Compressive strength of concrete ................................ 77.1 $kg/cm^2$(*)
  - Tensile stress of reinforcement steel bar (SS41) ............... 1,400 $kg/cm^2$(**)
  - Tensile and compressive stress of shape steel (SM50Y) ....... 2,100 $kg/cm^2$(**)
  - Shearing stress of reinforcement bar (SS41).................... 800 $kg/cm^2$(**)
  - Shearing stress of shape steel (SM50Y)......................... 1,200 $kg/cm^2$(**)

(*) It is specified that the concrete strength of base slab should not be less than 270 $kg/cm^2$ and that its allowable stress be 1/3.5 times the above concrete strength.

(**) These allowable stresses also follow the Specification for Road Bridge by Japan Society of Road.

- Increase of allowable stress for concrete:
The allowable compressive strength of concrete is allowed to increase by 15% in the case that the temperature difference between base slab and steel girder is taken into consideration.

- Increase of allowable stress for shape steel:
The Specification allows to increase the allowable stress of shape steel as follows:

| | Loading Condition | | Increase of Allowable Stress |
|---|---|---|---|
| (1) | Main loading except the effect due to creep and drying shrinkage | | 0 |
| (2) | Main loading including the effect due to creep and drying shrinkage | Compressive side | 15 |
| | | Tension side | 0 |
| (3) | (2) + Effect due to temperature difference between base slab and steel girder | Compressive side | 30 |
| | | Tension side | 15 |
| (4) | Construction stage | Compressive side | 25 |
| | | Tension side | 25 |

The design allows the above increase of the allowable stress.

- Temperature difference between base slab and steel girder ......... 10°C

- Seismic coefficient .................................................... 0.05
- Wind speed ............................................................ 40 m/sec.

### 4.2.3 Design Calculation

(1) Analysis of composite girder

Fig. 4.1.5 shows the frame plan, section and dimensions of the composite girder. As seen, the composite girder of bridge consists of three (3) main girders (G-1, G-2, G-3) and seven (7) crossing frames.

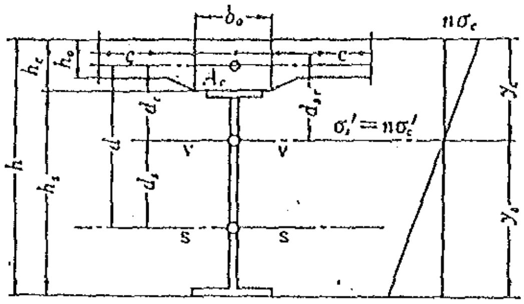
Fig. 4.1.6 and 4.1.7 show the loading conditions. Fig. 4.1.6 shows the loading condition before compounding the base slab and steel girders, and Fig. 4.1.7 shows that after compounding. As mentioned, the bridge is designed as the second-order bridge for which the car load of 14 ton is taken into consideration as the live load. The Specification mentions for this condition that the design should consider the live load and uniform load of 3.5 ton/m and 0.245 ton/$m^2$ respectively with a width of 5 m (A half of the above is imposed on the remaining width). Thus, the loading condition considers the above live load in addition to the dead load as seen in Figures.

The analysis of the composite girder is made in Table 4.1.21 to 4.1.32. Table 4.1.21 to 4.1.23 presents the bending moments and shearing forces to occur in the frames due to the loadings. Table 4.1.24 to 4.1.32 analyze the stresses to arise in the composite girder. Fig. 4.1.8 to 4.1.10 summarize all results of analyses on the composite girder. As seen in Fig. 4.1.8 to 4.1.10, all the stresses to be caused by the loadings are within the allowable stresses, and the composite girder will safely withstand the loadings.

(2) Major formula used for stress analysis

Major formula used for the stress analysis are as follows:

<u>Stress due to the bending moment:</u>



where,

| | | |
|---|---|---|
| v - v | : | Neutral axis of composite girder |
| c - c | : | Center of gravity of concrete section |
| s - s | : | Center of gravity of steel girder |
| Ac | : | Sectional area of concrete section |
| As | : | Sectional area of steel girder section |

n = Es/Ec = Young modulus ratio between steel and concrete (n = 7.0)

The stress are calculated as follows:

$\sigma_c = M \cdot y_c/I_v,$ $\quad\quad \sigma_c' = M \cdot y_c'/I_v$

$\sigma_s = n \cdot M \cdot y_s/I_v,$ $\quad\quad \sigma_s' = n \cdot \sigma_c'$

where,

| | | |
|---|---|---|
| $\sigma_c$ | : | Stress in upper edge of concrete |
| $\sigma_c'$ | : | Stress in lower edge of concrete |
| $\sigma_s$ | : | Stress in lower edge of steel |
| $\sigma_s'$ | : | Stress in upper edge of steel |
| $I_v$ | : | Moment of inertia of area for neutral axis of composite girder (v-v) $I_v = I_s + \frac{1}{n} \cdot I_c + A_s \cdot d_s^2 + \frac{1}{n} \cdot A_c \cdot d_c^2$ |
| $I_s$ | : | Moment of inertia of area for axis of center of gravity of steel girder (s-s) |
| $I_c$ | : | Moment of inertia of area for axis of center of gravity of concrete (c-c) |
| M | : | Bending moment |

Stress due to creep:

The stress due to creep is obtained by the following formula:

$$\sigma_{cu} = \frac{N_c}{A_c} - \frac{M_c}{I_c} \cdot Y_{cu}$$

$$\sigma_{cl} = \frac{N_c}{A_c} - \frac{M_c}{I_c} \cdot Y_{cl}$$

$$\sigma_{su} = \frac{N_s}{A_s} - \frac{M_s}{I_s} \cdot Y_{su}$$

$$\sigma_{sl} = \frac{N_s}{A_s} - \frac{M_s}{I_s} \cdot Y_{sl}$$

$$N_c = -N_s = -N_{co}\,(1 - e^{-F\varphi_1})$$

$$N_{co} = -N_{so} = -\frac{d_c A_c}{nI_v} \cdot M_o$$

$$M_s = d \cdot N_c$$

$$M_c = \frac{H}{1 - F}\,( e^{-F\varphi_1} - e^{-\varphi_1} )$$

where,

$\sigma_{cu}$ : Stress due to creep at upper edge of concrete

$\sigma_{cl}$ : Stress due to creep at lower edge of concrete

$\sigma_{su}$ : Stress due to creep at upper edge of steel girder

$\sigma_{sl}$ : Stress due to creep at lower edge of steel girder

$N_c$ and $N_s$: Incremental axial force due to creep acting to center of gravity of concrete slab and steel girder, respectively

$M_c$ and $M_s$: Incremental bending moment due to creep acting to center of gravity of concrete slab and steel girder, respectively

$N_{co}$ and $N_{so}$: Axial force at time T=0 acting to center of gravity of concrete slab and steel girder, respectively

$M_{co}$ and $M_{so}$: Bending moment at time T=0 acting to center of gravity of concrete slab and steel girder, respectively

$y_{cu}$ : Distance from neutral axis of concrete slab to its upper edge

$y_{cl}$ : Distance from neutral axis of concrete slab to its lower edge

$y_{su}$ : Distance from neutral axis of steel girder to its upper edge

$y_{sl}$ : Distance from neutral axis of steel girder to its lower edge

$\varphi_1$ : Creep coefficient from time T=0 to T=∞ ($\varphi_1 = 2.0$ is specified to be used in the case of the composite girder)

$M_o$ : Bending moment acting to composite girder

$$F = \frac{1}{1 + \frac{A_c}{nA_s} + \frac{A_c\,d^2}{I_c + nI_s}}$$

$$H = \frac{I_C}{nI_S} d\, F\, N_{CO}$$

<u>Stress due to temperature difference (between concrete slab and steel girder)</u>:

The stress due to temperature difference between concrete slab and steel girder is obtained by the following formula:

$$\pm\sigma_{cu} = \frac{N_C}{A_C} - \frac{M_C}{I_C} \bullet Y_{cu}$$

$$\pm\sigma_{cl} = \frac{N_C}{A_C} + \frac{M_C}{I_C} \bullet Y_{cl}$$

$$\pm\sigma_{su} = \frac{N_S}{A_S} - \frac{M_S}{I_S} \bullet Y_{su}$$

$$\pm\sigma_{sl} = \frac{N_S}{A_S} + \frac{M_S}{I_S} \bullet Y_{sl}$$

$$N_C = -N_S = \frac{\alpha t E_S}{\frac{n}{A_C} + \frac{1}{A_S} + \frac{nd^2}{I_C + nI_S}}$$

$$Mc = N_C d \frac{I_C}{I_C + nI_S}$$

$$M_S \bullet N_C d \frac{nI_C}{I_S + nI_S}$$

where,

| | | |
|---|---|---|
| $\sigma$ | : | Incremental stress due to temperature difference |
| $\alpha$ | : | $(1.2 \times 10^{-5})$ |
| t | : | Temperature difference between concrete slab and steel girder (10°C is specified to be used as standard) |
| $N_C$ | : | Incremental axial force due to temperature difference acting to center of gravity of concrete slab |
| $M_C$ | : | Incremental bending moment due to temperature difference acting to center of gravity of concrete slab |
| $M_S$ | : | Incremental bending moment due to temperature difference acting to center of gravity |

<u>Stress due to shrinkage of concrete slab</u>:

The stress due to shrinkage of concrete slab is obtained by the following equations:

$$\sigma_{su} = \frac{N_s}{A_s} - \frac{M_c}{I_c} \cdot Y_{su}$$

$$\sigma_{sl} = \frac{N_s}{A_s} + \frac{M_s}{I_s} \cdot Y_{sl}$$

$$\sigma_{cu} = \frac{N_c}{A_c} - \frac{M_c}{I_c} \cdot Y_{cu}$$

$$\sigma_{cl} = \frac{N_c}{A_c} + \frac{M_c}{I_c} \cdot Y_{cl}$$

$$N_s = N_c = \frac{\varepsilon_s \cdot E_s}{\frac{n_\varphi}{A_c} + \frac{1}{A_s} + \frac{n_\varphi d^2}{I_c + n_\varphi I_s}}$$

$$Ms = \frac{n_\varphi I_s}{I_c + n_\varphi I_s} N_c d$$

$$Mc = \frac{I_c}{I_c + n_\varphi I_s} N_c d$$

$$n_\varphi = n\left(1 + \frac{\varphi_2}{2}\right) \qquad (\varphi_2 = 4.0)$$

where,

$\sigma$ : Incremental stress due to shrinkage of concrete slab

$\varepsilon_s$ : Final rate of shrinkage ($18 \times 10^{-5}$)

$N_c$ and $M_c$: Incremental axial force and bending moment due to shrinkage acting to center of gravity of concrete slab

$N_s$ and $M_s$: Incremental axial force and bending moment due to shrinkage acting to center of gravity of steel girder

## 4.3. Intake

### 4.3.1 General

Structural calculation of intake structure is made for the following structural components of intake:

(1) stability analysis of each intake tower,
(2) stability analysis of each block against sliding
(3) structural analysis of inclined waterway conduit, and
(4) stability analysis of thrust block.

### 4.3.2 Stability analysis of Each Intake Tower

(1) Stability Analysis of No. 3 Intake

Since the No. 3 intake is placed on the rigid inlet structure of diversion tunnel and the height of No. 3 intake is relatively low, it is evident that the structure is stable, then the stability analysis of No. 3 intake is omitted.

(2) Stability Analysis of No. 2 Intake

The profile and sections of No. 2 intake tower are shown in Fig. 4.3.1 to Fig. 4.3.3.

The center of gravity of the intake tower is calculated in the attached sheet and it is shown in the above figure.

1) Safety for sliding

$$n = \frac{\mu W + \tau A}{H}$$

where, n : safety factor for sliding, more than 1.5 for normal condition and 1.2 for earthquake condition

$\mu$ : friction coefficient, 0.55 for concrete and rock

W : vertical forces (t), weight of block

$\tau$ : shearing strength, 20 t/$m^2$ for concrete and rock

A : area of horizontal base ($m^2$)

H : horizontal force (t), horizontal force due to earthquake

2) Safety for overturning

$$n = \frac{Mv}{Mt}$$

where, n : safety factor for overturning, more than 1.5 for normal condition and 1.2 for earthquake condition

Mv : resisting moment (t-m)

Mt : overturning moment (t-m)

3) Safety for bearing capacity of foundation

Bearing stress of foundation, which is calculated by the following formula, shall be lower than the allowable bearing stress of foundation, 100 t/$m^2$ for rock.

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{W}{B} \left(1 \pm \frac{6e}{B}\right)$$

where, $P_1$ and $P_2$: bearing stress of foundation (t/$m^2$) in case that the forces act within the middle third of basement

W : vertical force (t)

B : area of basement or length of basement per unit width of the structure (m)

e : eccentricity of load (m)

Stability analysis for normal dry condition

Since there is no horizontal load, there is no problem for sliding and overturning of the structure. The bearing stress is analyzed.

Weight of structure $W = 393.171\ m^3 \times 2.35\ t/m^3 = 924.0\ t$

$x = 4.944\ m$

$$e = \frac{11.927}{2} - x = 1.020\ m < \frac{11.927}{6} = 1.988\ m$$

within middle third

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{924.0}{4.60 \times 11.927}\left(1 \pm \frac{6 \times 1.020}{11.927}\right) = \begin{matrix} 25.5\ t/m^2 \\ 8.2\ t/m^2 \end{matrix} < 100\ t/m^2$$

for dry condition + earthquake

| | |
|---|---|
| Weight of structure | $W = 924.0\ t$ |
| Horizontal force due to earthquake | $H = 0.05W = 46.2\ t$ |
| Area of horizontal basement | $A = 6.05\ m \times 4.60\ m = 27.83\ m^2$ |

1) for sliding

$$n = \frac{0.55W + 20A}{H} = \frac{0.55 \times 924.0 + 20 \times 27.83}{46.2} = 23.0 > 1.2$$

2) for overturning

$Mt = H \cdot z = 46.2\ t \times 2.530\ m = 301.7\ t\text{-}m$

$Mv = W \cdot x = 924.0\ t \times 4.944\ m = 4{,}568.2\ t\text{-}m$

$$n = \frac{Mv}{Mt} = 15.1 > 1.2$$

3) Bearing stress

$$x = \frac{Mv - Mt}{W} = \frac{4{,}568.2 - 301.7}{924.0} = 4.617 \text{ m}$$

$$e = \frac{11.927}{2} - x = 1.346 \text{ m} < \frac{11.927}{6} = 1.988 \text{ m}$$

within middle third

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{924.0}{4.60 \times 11.927} \left(1 \pm \frac{6 \times 1.346}{11.927}\right) = \begin{matrix} 28.2 \text{ t/m}^2 \\ 5.4 \text{ t/m}^2 \end{matrix} < 100 \text{ t/m}^2$$

Normal operation condition (Submerged)

As same as for normal dry condition the bearing stress is only analyzed.

$W = 393.171 \text{ m}^3 \times 1.35 \text{ t/m}^3 = 530.8 \text{ t}$

$x = 4.944 \text{ m}$

$$e = \frac{11.927}{2} - x = 1.020 \text{ m} < \frac{11.927}{6} = 1.988 \text{ m}$$

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{530.8}{4.60 \times 11.927} \left(1 \pm \frac{6 \times 1.020}{11.927}\right) = \begin{matrix} 14.6 \text{ t/m}^2 \\ 4.7 \text{ t/m}^2 \end{matrix} < 100 \text{ t/m}^2$$

Submerged condition + earthquake

$W = 530.8 \text{ t}$

$H = 0.05W = 426.5 \text{ t}$

1) for sliding

$$n = \frac{0.55 \times 530.8 + 20 \times 27.83}{26.5} = 32.0 > 1.2$$

2) for overturning

$Mt = H \cdot z = 26.5 \text{ t} \times 6.530 \text{ m} = 173.0 \text{ t-m}$

$Mv = W \cdot x = 530.8 \text{ t} \times 4.944 \text{ m} = 2{,}624.3 \text{ t-m}$

$$n = \frac{Mv}{Mt} = 15.2 > 1.2$$

3) Bearing stress

$$x = \frac{Mv - Mt}{W} = \frac{2,624.3 - 173.0}{530.8} = 4.618 \text{ m}$$

$$e = \frac{11.927}{2} - x = 1.346 \text{ m} < \frac{11.927}{6} = 1.988 \text{ m}$$

within middle third

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{530.8}{4.60 \times 11.927} \left(1 \pm \frac{6 \times 1.346}{11.927}\right) = \begin{matrix} 16.2 \text{ t/m}^2 \\ 3.1 \text{ t/m}^2 \end{matrix} < 100 \text{ t/m}^2$$

Submerged condition and gate closure

$$W = 393.171 \times 1.35 - 21.646 \times 1.0 = 509.1 \text{ t}$$

$$x = \frac{393.17 \times 1.35 \times 4.944 - 21.646 \times 1.0 \times 4.180}{509.13} = 4.976 \text{ m}$$

$$e = \frac{11.927}{2} - x = 0.988 \text{ m} < \frac{11.927}{6} = 1.988 \text{ m}$$

within middle third

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{509.1}{4.6 \times 11.927} \left(1 \pm \frac{6 \times 0.988}{11.927}\right) = \begin{matrix} 13.9 \text{ t/m}^2 \\ 4.7 \text{ t/m}^2 \end{matrix} < 100 \text{ t/m}^2$$

As shown above to structure is quite safe for any condition. The heaviest bearing stress of the foundation rock occurs at earthquake in the dry condition.

Calculation Sheet of Center of Gravity of No. 2 Intake Tower

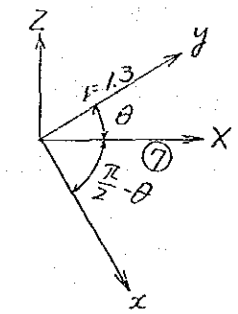
Main body 1 W = 4.6 m

| | A | V | X | Y | Z | XV | YV | ZV |
|---|---|---|---|---|---|---|---|---|
| | $m^2$ | $m^3$ | | | | | | |
| 1 | 5.531 | 25.444 | 1.883 | 0 | 0.763 | 47.911 | 0 | 19.414 |
| 2 | 37.531 | 172.643 | 4.012 | 0 | 4.110 | 692.644 | 0 | 709.563 |
| 3 | 12.287 | 56.522 | 4.390 | 0 | 7.216 | 248.132 | 0 | 407.863 |
| 4 | 7.012 | 32.258 | 4.111 | 0 | 8.500 | 132.613 | 0 | 274.193 |
| 5-1 | 0.960 | 4.416 | -0.400 | 0 | 8.533 | -1.766 | 0 | 37.682 |
| 5-2 | 0.480 | 2.208 | -0.800 | 0 | 8.900 | -1.766 | 0 | 19.651 |
| 5-3 | 0.090 | 0.368 | -1.800 | 0 | 9.100 | -0.662 | 0 | 3.349 |
| 6 | 11.731 | 53.964 | 3.702 | 0 | 10.043 | 199.775 | 0 | 541.960 |
| | $m^2$ | $m^3$ | | | | | | |
| Sub-total | 75.612 | 347.823 | 3.786 | 0 | 5.789 | 1,316.881 | 0 | 2,013.675 |

$X_0 = 6.127$

$Z_0 = 10.189$

$Y_0 = 0$




$$\theta = \tan^{-1}\frac{1}{1.3}$$

Main body 2 W = 4.3 m

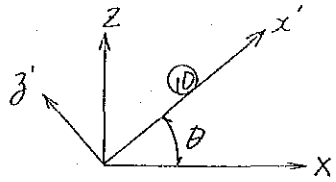
| | A | V | x | y | z | xV | yV | zV |
|---|---|---|---|---|---|---|---|---|
| | $m^2$ | $m^3$ | | | | | | |
| 7 | 14.233 | 61.196 | 1.924 | -0.150 | 1.733 | 117.741 | -9.179 | 106.053 |
| 8 | 4.137 | 17.789 | 1.382 | -0.150 | 4.510 | 24.584 | -2.668 | 80.228 |
| | $m^2$ | $m^3$ | | | | | | |
| Sub-total | 18.370 | 78.985 | 1.802 | -0.150 | 2.358 | 142.325 | -11.847 | 186.281 |

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \sin\theta & 0 & \cos\theta \\ 0 & 1 & 0 \\ -\cos\theta & 0 & \sin\theta \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix}$$

X = 9.095

Y = -0.150

Z = 10.192




$X_0 = 6.127$

$Y_0 = 0$

$Z_0 = 10.189$

Sub body

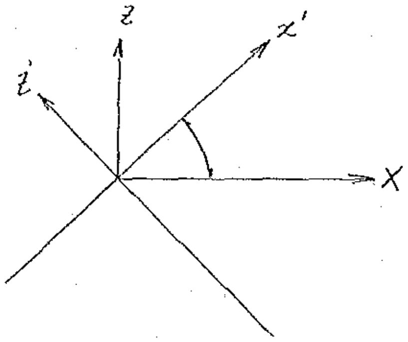
| | A | V | x' | y' | z' | x'V | y'V | z'V |
|---|---|---|---|---|---|---|---|---|
| | $m^2$ | $m^3$ | | | | | | |
| 9 | 0.075 | 0.158 | 0.195 | 0 | 0.089 | 0.031 | 0 | 0.014 |
| 10 | 2.965 | 6.523 | 2.474 | -0.293 | 0.293 | 16.138 | -1.911 | 1.911 |
| 11 | 0.905 | 0.588 | 0.511 | -1.975 | 0.993 | 0.300 | -1.161 | 0.584 |
| | $m^2$ | $m^3$ | | | | | | |
| Sub-total | 3.945 | 7.269 | 2.266 | -0.423 | 0.345 | 16.469 | -3.072 | 2.509 |

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} + \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix}$$

$X = 7.713$

$Y = -0.423$

$Z = 11.844$




$X_0 = 2.948$

$Y_0 = 0$

$Z_0 = 8.500$

## Void

| | A | V | x' | y' | z' | x'V | y'V | z'V |
|---|---|---|---|---|---|---|---|---|
| Above datum | | $m^3$ | | | | | | |
| 12 | - | 7.884 | 0 | 0 | 1.770 | 0 | 0 | 13.955 |
| 13 | - | 4.851 | 0 | 0 | 0.550 | 0 | 0 | 2.668 |
| 14 | - | 6.525 | 2.300 | 0 | 0.350 | 15.008 | 0 | 2.284 |
| | | $m^3$ | | | | | | |
| Sub-total | - | 19.260 | 0.779 | 0 | 0.982 | 15.008 | 0 | 18.907 |
| Below datum | | $m^3$ | | | | | | |
| 15 | - | 16.758 | 0 | 0 | -1.980 | 0 | 0 | -31.840 |
| 15' | - | -0.525 | 0 | 0 | -3.633 | 0 | 0 | 1.907 |
| 15" | - | -0.262 | 0 | -0.883 | -3.633 | 0 | 0.231 | 0.952 |
| 16 | - | 5.675 | 0 | -1.675 | -2.600 | 0 | -9.506 | -14.755 |
| | | $m^3$ | | | | | | |
| Sub-total | - | 21.646 | 0 | -0.428 | -2.020 | 0 | -9.275 | -43.736 |

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} + \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix}$$

| Above datum | Below datum |
|---|---|
| X = 2.967 | X = 4.180 |
| Y = 0 | Y = -0.428 |
| Z = 9.753 | Z = 6.899 |

## Total

| | V | X | Y | Z | XV | YV | ZV |
|---|---|---|---|---|---|---|---|
| | $m^3$ | m | m | m | | | |
| Main body 1 | 347.823 | 3.786 | 0 | 5.789 | 1,316.858 | 0 | 2,013.547 |
| Main body 2 | 78.985 | 9.095 | -0.150 | 10.192 | 718.368 | -11.848 | 805.015 |
| Sub body | 7.269 | 7.713 | -0.423 | 11.844 | 56.066 | -3.075 | 86.094 |
| Void above datum | -19.260 | 2.967 | 0 | 9.753 | -57.144 | 0 | -187.843 |
| Void below datum | -21.646 | 4.180 | -0.428 | 6.899 | -90.480 | 9.264 | -149.336 |
| | $m^3$ | | | | | | |
| Total | 393.171 | 4.944 | -0.014 | 6.530 | 1,943.668 | -5.639 | 2,567.477 |

(3) Stability Analysis of No. 1 Intake

The profile and sections of No. 1 intake tower are shown in Fig. 4.3.4 to Fig. 4.3.6.

The center of gravity of the intake tower is calculated in the attached sheet and it is shown in the above figure.

Formulae and notations for safety of sliding and overturning of the structure and bearing stress of foundation shall be referred to Section 5.2.2 (2).

<u>Stability analysis for normal dry condition</u>

Since there is no horizontal load, there is no problem for sliding and overturning of the structure. Then the bearing stress is analyzed.

Weight of structure $W = 460.115\ m^3 \times 2.35\ t/m^3 = 1{,}081.3\ t$

$x = 8.740$ m

$$e = \frac{16.710}{2} - x = -0.385\ m < \frac{16.710}{6} = 2.785\ m$$

within middle third

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{1{,}081.3}{4.35 \times 16.710}\left(1 \pm \frac{6 \times -0.385}{16.710}\right) = \begin{matrix} 12.82\ t/m^2 \\ 16.93\ t/m^2 \end{matrix} < 100\ t/m^2$$

<u>for dry condition + earthquake</u>

| | |
|---|---|
| Weight of structure | $W = 1{,}081.3$ t |
| Horizontal force due to earthquake | $H = 0.05W = 54.1$ t |
| Area of horizontal basement | $A = 4.850\ m \times 4.35\ m + 3.485\ m \times 4.60\ m$ |
| | $= 37.13\ m^2$ |

1) for sliding

$$n = \frac{0.55W + 20A}{H} = \frac{0.55 \times 1{,}081.3 + 20 \times 37.13}{54.1} = 24.7 > 1.2$$

2) for overturning

$Mt = H \cdot z = 54.1 \text{ t} \times 8.302 \text{ m} = 449.1 \text{ t-m}$

$Mv = W \cdot x = 1{,}081.3 \text{ t} \times 8.740 \text{ m} = 9{,}450.6 \text{ t-m}$

$$n = \frac{Mv}{Mt} = 21.0 > 1.2$$

3) Bearing stress

$$x = \frac{Mv - Mt}{W} = \frac{9{,}450.6 - 449.1}{1{,}081.3} = 8.325 \text{ m}$$

$$e = \frac{16.710}{2} - x = 0.030 \text{ m} < \frac{16.710}{6} = 2.785 \text{ m}$$

within middle third

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{1{,}081.3}{4.35 \times 16.710} \left(1 \pm \frac{6 \times 0.030}{16.710}\right) = \begin{matrix} 15.04 \text{ t/m}^2 \\ 14.72 \text{ t/m}^2 \end{matrix} < 100 \text{ t/m}^2$$

Normal operation condition (Submerged)

As same as for normal dry condition the bearing stress is only analyzed.

$W = 460.115 \text{ m}^3 \times 1.35 \text{ t/m}^3 = 621.2 \text{ t}$

$x = 8.740 \text{ m}$

$$e = \frac{16.710}{2} - x = -0.385 \text{ m} < \frac{16.710}{6} = 2.785 \text{ m}$$

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{621.2}{4.35 \times 16.710} \left(1 \pm \frac{6 \times -0.385}{16.710}\right) = \begin{matrix} 7.36 \text{ t/m}^2 \\ 9.73 \text{ t/m}^2 \end{matrix} < 100 \text{ t/m}^2$$

Submerged condition + earthquake

$W = 621.2 \text{ t}$

$H = 0.05W = 31.1 \text{ t}$

1) for sliding

$$n = \frac{0.55 \times 621.2 + 20 \times 37.13}{31.1} = 34.9 > 1.2$$

2) for overturning

$Mt = H \cdot z = 31.1 \text{ t} \times 8.302 \text{ m} = 258.2 \text{ t-m}$

$Mv = W \cdot x = 621.2 \text{ t} \times 8.740 \text{ m} = 5{,}429.3 \text{ t-m}$

$$n = \frac{Mv}{Mt} = 21.0 > 1.2$$

3) Bearing stress

$$x = \frac{Mv - Mt}{W} = \frac{5{,}429.3 - 258.2}{621.2} = 8.324 \text{ m}$$

$$e = \frac{16.710}{2} - x = 0.031 \text{ m} < \frac{16.710}{6} = 2.785 \text{ m}$$

within middle third

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{621.2}{4.35 \times 16.710} \left(1 \pm \frac{6 \times 0.031}{16.710}\right) = \begin{matrix} 8.64 \text{ t/m}^2 \\ 8.45 \text{ t/m}^2 \end{matrix} < 100 \text{ t/m}^2$$

<u>Submerged condition and gate closure</u>

$W = 460.115 \text{ m}^3 \times 1.35 \text{ t/m}^3 - 73.438 \text{ m}^3 \times 1.0 = 547.7 \text{ t}$

$$x = \frac{460.115 \times 1.35 \times 8.740 - 73.438 \times 1.0 \times 6.602}{547.7} = 9.027 \text{ m}$$

$$e = \frac{16.710}{2} - x = -0.672 \text{ m} < \frac{16.710}{6} = 2.785 \text{ m}$$

within middle third

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{547.7}{4.35 \times 16.710} \left(1 \pm \frac{6 \times -0.672}{16.710}\right) = \begin{matrix} 5.72 \text{ t/m}^2 \\ 9.35 \text{ t/m}^2 \end{matrix} < 100 \text{ t/m}^2$$

## Calculation Sheet of Center of Gravity of No. 1 Intake Tower

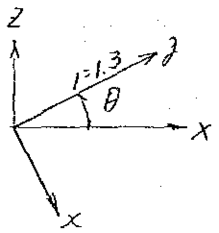
Main body 1 W = 4.35 and 4.6 m

| | A ($m^2$) | V ($m^3$) | X | Y | Z | XV | YV | ZV |
|---|---|---|---|---|---|---|---|---|
| 1 | 19.900 | 86.130 | 2.475 | -0.628 | 2.013 | 213.172 | -54.090 | 173.380 |
| 2 | 2.171 | 9.444 | 4.632 | 0 | 4.788 | 43.745 | 0 | 45.218 |
| 3 | 2.622 | 12.063 | 5.599 | 0 | 1.000 | 67.541 | 0 | 12.063 |
| 4 | 7.420 | 34.131 | 6.536 | 0 | 3.378 | 223.080 | 0 | 115.294 |
| 5 | 57.534 | 172.655 | 9.011 | 0 | 7.100 | 1,555.794 | 0 | 1,225.850 |
| 6 | 12.287 | 56.522 | 9.389 | 0 | 10.206 | 530.685 | 0 | 576.864 |
| 7 | 7.012 | 32.258 | 8.910 | 0 | 11.480 | 287.419 | 0 | 370.322 |
| 8-1 | 0.960 | 4.416 | 4.600 | 0 | 11.523 | 20.314 | 0 | 50.886 |
| 8-2 | 0.490 | 2.208 | 4.200 | 0 | 11.890 | 9.274 | 0 | 26.253 |
| 8-3 | 0.080 | 0.368 | 3.200 | 0 | 12.090 | 1.178 | 0 | 4.449 |
| 9 | 11.731 | 53.964 | 8.702 | 0 | 13.033 | 469.595 | 0 | 703.313 |
| Sub-total | - | 464.159 $m^3$ | 7.372 | -0.116 | 7.118 | 3,421.797 | -54.090 | 3,303.892 |

$X_0 = 11.129$

$Y_0 = 0$

$Z_0 = 13.179$




$$\theta = \tan^{-1}\frac{1}{1.3}$$

Main body 2 W = 4.60 m

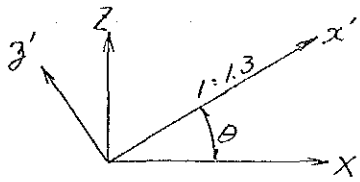
| | A ($m^2$) | V ($m^3$) | x | y | z | xV | yV | zV |
|---|---|---|---|---|---|---|---|---|
| 10 | 16.964 | 77.575 | 1.829 | 0 | 2.127 | 141.885 | 0 | 165.002 |
| 11 | 1.149 | 5.287 | 1.170 | 0 | 5.020 | 6.186 | 0 | 26.541 |
| Sub-total | - | 82.862 $m^3$ | 1.787 | 0 | 2.312 | 148.071 | 0 | 191.543 |

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \sin\theta & 0 & \cos\theta \\ 0 & 1 & 0 \\ -\cos\theta & 0 & \sin\theta \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix}$$

X = 14.049

Y = 0

Z = 13.172




$X_0 = 11.127$

$Y_0 = 0$

$Z_0 = 13.179$

Sub body

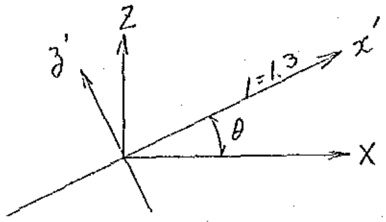
| | A | V | x' | y' | z' | x'V | y'V | z'V |
|---|---|---|---|---|---|---|---|---|
| | $m^2$ | $m^3$ | | | | | | |
| 12 | 0.075 | 0.158 | 0.195 | 0 | 0.089 | 0.031 | 0 | 0.014 |
| 13 | 2.965 | 5.634 | 2.474 | 0 | 0.293 | 13.938 | 0 | 1.651 |
| | | $m^3$ | | | | | | |
| Sub-total | - | 5.792 | 2.412 | 0 | 0.287 | 13.969 | 0 | 1.665 |

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} + \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix}$$

$X = 12.864$

$Y = 0$

$Z = 14.877$




$X_0 = 7.948$

$Y_0 = 0$

$Z_0 = 11.490$

## Void

| | A | V | x' | y' | z' | x'V | y'V | z'V |
|---|---|---|---|---|---|---|---|---|
| Above datum | | $m^3$ | | | | | | |
| 14 | - | 7.884 | 0 | 0 | 1.770 | 0 | 0 | 13.955 |
| 15 | - | 4.851 | 0 | 0 | 0.550 | 0 | 0 | 2.668 |
| 16 | - | 6.525 | 2.300 | 0 | 0.350 | 15.008 | 0 | 2.284 |
| | | $m^3$ | | | | | | |
| Sub-total | - | 19.260 | 0.779 | 0 | 0.982 | 15.008 | 0 | 18.907 |
| Below datum | | $m^3$ | | | | | | |
| 17 | - | 22.284 | 0 | 0 | -2.526 | 0 | 0 | -56.289 |
| 17' | - | -0.375 | 0.883 | 0 | -4.886 | -0.331 | 0 | 1.832 |
| 18 | - | 36.320 | -5.040 | 0 | -4.500 | -183.053 | 0 | -163.440 |
| 19 | - | 8.626 | -10.100 | 0 | -4.100 | -87.123 | 0 | -35.367 |
| 20 | - | 6.583 | -10.400 | -1.775 | -3.850 | -68.463 | -11.685 | -25.344 |
| | | $m^3$ | | | | | | |
| Sub-total | - | 73.438 | -4.616 | -0.159 | -3.794 | -338.970 | -11.685 | -278.608 |

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} + \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix}$$

| Above datum | Below datum |
|---|---|
| X = 8.003 | X = 6.602 |
| Y = 0 | Y = -0.159 |
| Z = 12.743 | Z = 5.668 |

## Total

| | V | X | Y | Z | XV | YV | ZV |
|---|---|---|---|---|---|---|---|
| | $m^3$ | m | m | m | | | |
| Main body 1 | 464.159 | 7.372 | -0.116 | 7.118 | 3,421.780 | -53.842 | 3,303.884 |
| Main body 2 | 82.862 | 14.049 | 0 | 13.172 | 1,164.128 | 0 | 1,091.458 |
| Sub body | 5.792 | 12.864 | 0 | 14.877 | 74.508 | 0 | 86.168 |
| Void above datum | -19.260 | 8.003 | 0 | 12.743 | -154.138 | 0 | -245.430 |
| Void below datum | -73.438 | 6.602 | -0.159 | 5.668 | -484.838 | 11.677 | -416.246 |
| | $m^3$ | | | | | | |
| Total | 460.115 | 8.740 | -0.092 | 8.302 | 4,021.440 | -42.165 | 3,819.834 |

### 4.3.3 Stability Analysis of Each Block against Sliding

As the typical components for the stability analysis against sliding. The following two components are taken up:

(1) inclined conduit, block 2 of No. 3 intake, and
(2) mount block, block 5 of No. 3 intake.

#### 4.3.3.1 Stability Analysis of Inclined Conduit, Block 2

Profile and typical section of the inclined conduit, block 2, are shown in Fig. 4.3.7

The safety factor n against sliding is calculated by the following formula,

$$n = \frac{\mu F + \tau A}{S}$$

where,
- n : safety factor against sliding
- $\mu$ : friction coefficient between concrete and rock = 0.55
- F : right-angled component of block weight to the rock surface (t) = $W \cdot Cos\theta$
- W : weight of block (t)

$Cos\theta = 1.3/\sqrt{1 + 1.3^2} = 0.7926$

- $\tau$ : shearing strength = 20 $t/m^2$ from result of solid test
- A : area of the block contacted to the rock surface ($m^2$)
- S : sliding force or component of block weight parallel to the rock surface (t) = $W \cdot Sin\theta$

$Sin\theta$: $1/\sqrt{1 + 1.3^2} = 0.6097$

The required minimum safety factor n against sliding is 1.5 for normal condition and 1.2 for earthquake.

<u>Dry condition</u> (just after completion or draw down of reservoir water surface)

Weight of the block W and other factors are calculated as shown below:

$$W = \{3.70 \times 4.00 - (2.10 \times 2.40 - 4 \times \frac{1}{2} \times 0.5 \times 0.5) + 0.30 \times 0.90\}$$
$$\times 9.513 \times 2.4 = 240.4 \text{ t}$$

where, the value 2.4 is the unit dead weight of reinforced concrete.

$F = W \cdot Cos\theta = 190.6t$
$S = W \cdot Sin\theta = 146.6t$
$A = 3.70 \times 9.513 = 35.2\ m^2$

$$\therefore\ n = \frac{0.55 \times 190.6 + 20 \times 35.2}{146.6} = 5.5 > 1.5$$

Normal operating condition (submerged)

$$W = \{3.70 \times 4.00 - (2.10 \times 2.40 - 4 \times \frac{1}{2} \times 0.5 \times 0.5) + 0.30 \times 0.90\}$$
$$\times 9.513 \times 1.4 + (2.10 \times 2.40 - 4 \times \frac{1}{2} \times 0.5 \times 0.5) \times 9.513 \times 1.0$$
$$= 240.4\ t$$

where, the value 1.4 in the first term is the unit dead weight of reinforced concrete in submerged condition and the second term is the weight of water in the conduit.

$F = W \cdot Cos\theta = 145.4t$
$S = W \cdot Sin\theta = 111.8t$
$A = 3.70 \times 9.513 = 35.2\ m^2$

$$\therefore\ n = \frac{0.55 \times 145.4 + 20 \times 35.2}{111.8} = 7.0 > 1.5$$

Submerged and non-operating condition

In this case the conduit is empty, then

$$W = \{3.70 \times 4.00 - (2.10 \times 2.40 - 4 \times \frac{1}{2} \times 0.5 \times 0.5) + 0.30 \times 0.90\}$$
$$\times 9.513 \times 1.4 = 140.2\ t$$

$F = W \cdot Cos\theta = 111.2t$
$S = W \cdot Sin\theta = 85.5t$
$A = 3.70 \times 9.513 = 35.2\ m^2$

$$\therefore\ n = \frac{0.55 \times 111.2 + 20 \times 35.2}{85.5} = 8.9 > 1.5$$

Dry condition + Earthquake

$$W = 240.4 \text{ t}$$

$$F = W(\cos\theta - 0.05 \cdot \sin\theta) = 183.2\text{t}$$
$$S = W(\sin\theta + 0.05 \cdot \cos\theta) = 156.1\text{t}$$

where, the value 0.05 is the horizontal earthquake coefficient.

$$\therefore n = \frac{0.55 \times 183.2 + 20 \times 35.2}{156.1} = 5.2 > 1.2$$

As shown above, the inclined conduit placed on the 1:1.3 slope is stable against sliding for any and every conditions. However, against the residual water pressure between structure and rock surface in the case of rapid draw-down of the reservoir, which could not be evaluated, the anchor bar, D29, will be provided at 2.0 m intervals.

#### 4.3.3.2 Stability Analysis of Mount Block, Block 5

Profile and typical section of the mount block, block 5, are shown in Fig. 4.3.8:

As shown above there is a beam at the middle point of the slope on which the mount is placed. The beam will resist against the block sliding, however, the safety factor of the block against sliding is analyzed for the averaged slope of the rock surface.

The formula of safety factor n is the same as in the stability analysis of inclined conduit.

Dry condition (just after completion or draw down of reservoir)

$$W = 3.30 \times 2.465 \times 13.250 \times 2.3 = 247.9\text{t}$$

where, the value 2.3 is the unit dead weight of plain concrete.

$$F = W \cdot \cos\theta = 193.0\text{t}$$
$$S = W \cdot \sin\theta = 155.6\text{t}$$

where, $\cos\theta = 1.24/\sqrt{1 + 1.24^2} = 0.7784$

$$\mathrm{Sin}\theta = 1/\sqrt{1 + 1.24^2} = 0.6278$$

$$A = 3.30 \times 13.250 = 43.7 \ m^2$$

$$\therefore \ n = \frac{0.55 \times 133.0 + 20 \times 43.7}{155.6} = 6.3 > 1.5$$

Submerged condition

$$W = 3.30 \times 2.465 \times 13.25 \times 1.3 = 140.1t$$

$$F = W \cdot \mathrm{Cos}\theta = 109.0t$$
$$S = W \cdot \mathrm{Sin}\theta = 88.0t$$

$$\therefore \ n = \frac{0.55 \times 109.0 + 20 \times 43.7}{88.0} = 10.6 > 1.5$$

Dry condition + Earthquake

$$F = W\ (\mathrm{Cos}\theta - 0.05 \cdot \mathrm{Sin}\theta) = 185.2t$$
$$S = W\ (\mathrm{Sin}\theta + 0.05 \cdot \mathrm{Cos}\theta) = 165.3t$$

where, the value 0.05 is the horizontal earthquake coefficient.

$$\therefore \ n = \frac{0.55 \times 185.2 + 20 \times 43.7}{165.3} = 5.9 > 1.2$$

### 4.3.4 Structural analysis of Inclined Waterway Conduit

Under the normal operation, there is no load on the conduit, because the internal and external water pressure are balanced. However, during the initial reservoir impoundment or periodical inspection of the structure, the conduit is exposed to the heavy external water pressure. The content is analyzed as a box Rahmen (rigid frame) of reinforced concrete.

In high water level (HWL) of the reservoir is configured at HWL 189.00 m at the first stage development, however, it is raised to HWL 209.00 m in the future. Then the water pressure corresponding to the future HWL is taken as the design load.

Applied allowable stresses for the member of Rahmen are as follows:

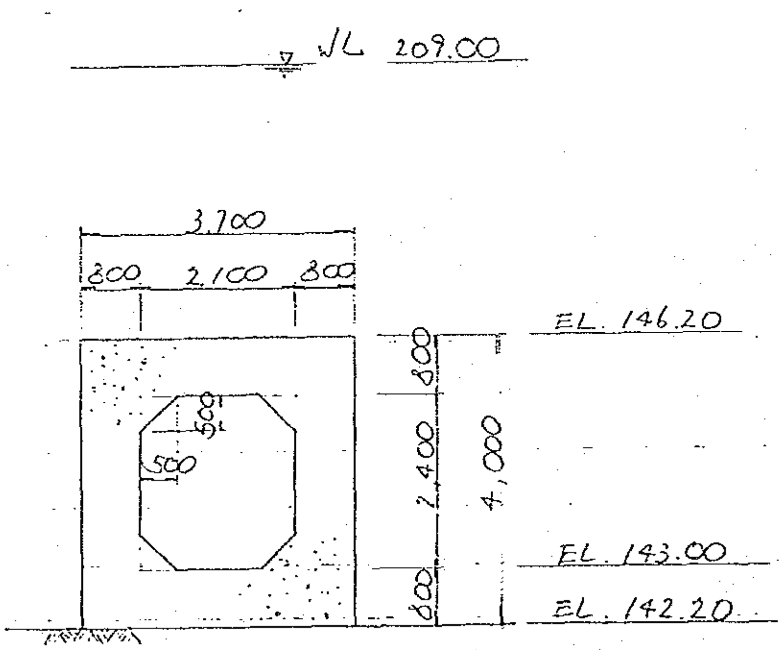
$\sigma_{sa}$ = 1,800 kg/cm$^2$
$\sigma_{ca}$ = 60 kg/cm$^2$
$\tau_a$ = 8 kg/cm$^2$

However, the design condition is a rare and tentative one, then the allowable stresses are increased by 30%. Then,

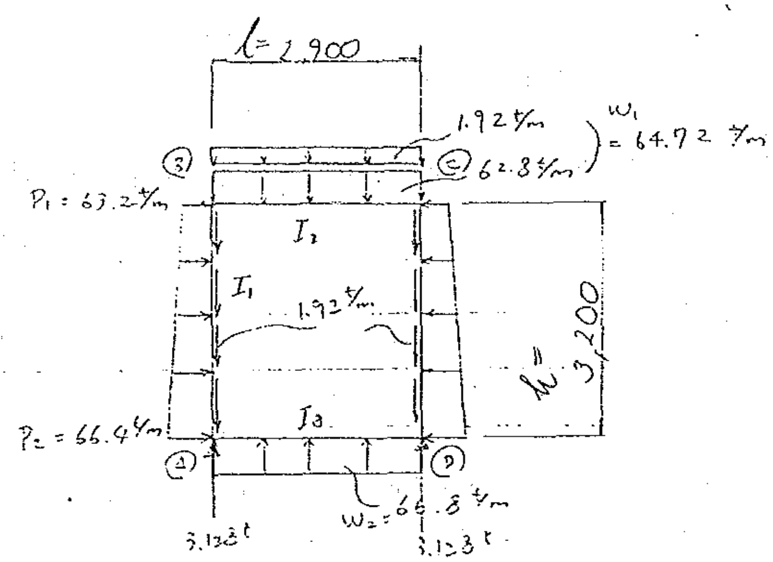
$\sigma_{sa}$ = 1,800 x 1.3 = 2,340 kg/cm$^2$
$\sigma_{ca}$ = 60 x 1.3 = 78 kg/cm$^2$
$\tau_a$ = 8 x 1.3 = 10.4 kg/cm$^2$

where, $\sigma_{sa}$ : allowable tensile stress of reinforcing bar
$\sigma_{ca}$ : allowable compressive stress of concrete
$\tau_a$ : allowable shearing stress of concrete

The typical section of the conduit is shown below:



The Rahmen, physical properties of the member and loading are as shown below:




Physical property of member per unit length along the flow.

Sectional area $A = 0.80\ m^2$

Moment of inertia $I = \dfrac{bh^3}{12} = \dfrac{1.0 \times 0.80^3}{12} = 0.0427\ m^4$

Rahmen calculation is shown below.

$$\alpha = \frac{I_2}{I_1} \cdot \frac{h}{l} = 1.0 \times \frac{3.2}{2.9} = 1.103$$

$$\beta = \frac{I_3}{I_1} \cdot \frac{h}{l} = 1.0 \times \frac{3.2}{2.9} = 1.103$$

$$N_1 = 2 + \alpha = 2 + 1.103 = 3.103$$

$$N_2 = 2 + \beta = 2 + 1.103 = 3.103$$

$$C_{AD} = \frac{W_2 l^2}{12} = \frac{66.8 \times 2.9^2}{12} = 46.816\ t\cdot m$$

$$C_{BC} = \frac{W_1 l^2}{12} = \frac{64.72 \times 2.9^2}{12} = 45.358\ t\cdot m$$

$$C_{AB} = \frac{h^2}{60}(3P_2 + 2P_1) = \frac{3.2^2}{60} \times (3 \times 66.4 + 2 \times 63.2) = 55.569 \text{ t·m}$$

$$C_{BA} = \frac{h^2}{60}(2P_2 + 3P_1) = \frac{3.2^2}{60} \times (2 \times 66.4 + 3 \times 63.2) = 55.023 \text{ t·m}$$

$$Q_A = \frac{N_1 (C_{AB} - C_{AD}) - (C_{BC} - C_{BA})}{N_1 N_2 - 1}$$

$$= \frac{3.103\ (55.569 - 46.816) - (45.358 - 55.023)}{3.103 \times 3.103 - 1} = 4.268 \text{ t·m}$$

$$Q_B = \frac{N_2 (C_{BC} - C_{BA}) - (C_{AB} - C_{AD})}{N_1 N_2 - 1}$$

$$= \frac{3.103\ (45.358 - 55.023) - (55.569 - 46.816)}{3.103 \times 3.103 - 1} = -4.490 \text{ t·m}$$

Corner moment

$M_{AB} = 2Q_A + Q_B - C_{AB} = 2 \times 4.263 + (-4.490) - 55.569 = -51.523$

$M_{AD} = \beta Q_A + C_{AD} = 1.130 \times 4.268 + 46.816 = 51.524$

$M_{BA} = 2Q_B + Q_A + C_{BA} = 2 \times (-4.490) + 4.268 + 55.023 = 50.311$

$M_{BC} = \alpha Q_B - C_{BC} = 1.130 \times (-4.490) - 45.358 = -50.310$

Top slab

$$S_B = S_C = \pm \frac{W_1 \cdot l}{2} = \pm \frac{64.72 \times 2.90}{2} = \pm 93.844 \text{ t}$$

$$M_C = \frac{W_1 \cdot l^2}{8} - M_B = \frac{64.72 \times 2.9^2}{8} - 50.311 = 17.726 \text{ t·m}$$

Bottom slab

$$S_A = S_D = \pm \frac{W_2 \cdot l}{2} = \pm \frac{66.8 \times 2.90}{2} = \pm 96.860 \text{ t}$$

$$M_C = \frac{W \cdot l^2}{8} - M_A = \frac{66.8 \times 2.9^2}{8} - 51.523 = 18.701 \text{ t·m}$$

Side wall

$$S_A = \frac{P_1 h}{2} + \frac{(P_2 - P_1)\ h}{3} - \frac{M_{AB} + M_{BA}}{h}$$

$$= \frac{63.2 \times 3.2}{2} + \frac{3.2 \times 3.2}{3} - \frac{-51.523 + 50.311}{3.2}$$

$= 104.912$ t

$$S_B = \frac{P_1 h}{2} - \frac{(P_2 - P_1)\ h}{6} - \frac{M_{AB} + M_{BA}}{h}$$

$$= \frac{63.2 \times 3.2}{2} - \frac{3.2 \times 3.2}{6} - \frac{-51.523 + 50.311}{3.2}$$

$= -102.448$ t

$M_{Cmax}$

$$A = \frac{\Delta P}{h} = \frac{P_2 - P_1}{h} = \frac{3.2}{3.2} = 1.0$$

$$\therefore \chi = \frac{P_2 - \sqrt{P_2^2 - 2A \cdot R_A}}{A} = \frac{66.4 - \sqrt{66.4^2 - 2 \times 1.0 \times 104.912}}{1.0}$$

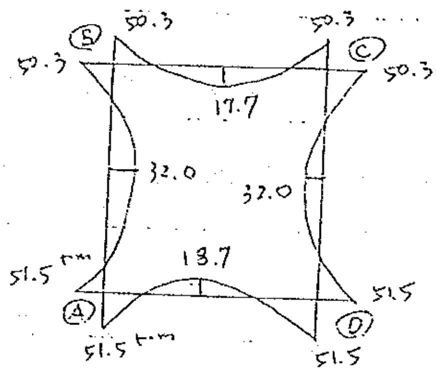
$= 1.599$ m

$$\therefore M_{max} = R_A\ \chi + \frac{P_3 - P_1}{6h} \chi^3 - \frac{P_2}{2} \chi^2 + M_{AB}$$

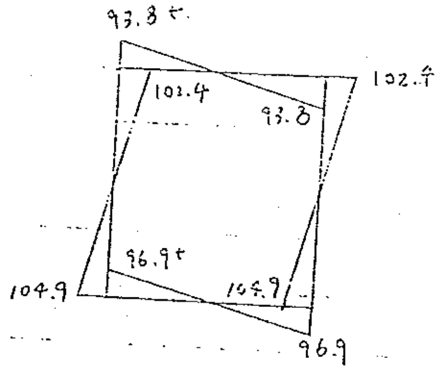
$$= 104.912 \mathrm{x} 1.599 + \frac{3.2}{6 \times 3.2} \mathrm{x} 1.599^3 - \frac{66.4}{2} \times 1.599^2 + (-51.523)$$

$= 32.027$ t·m

The moment and shearing force diadrams are as shown below :



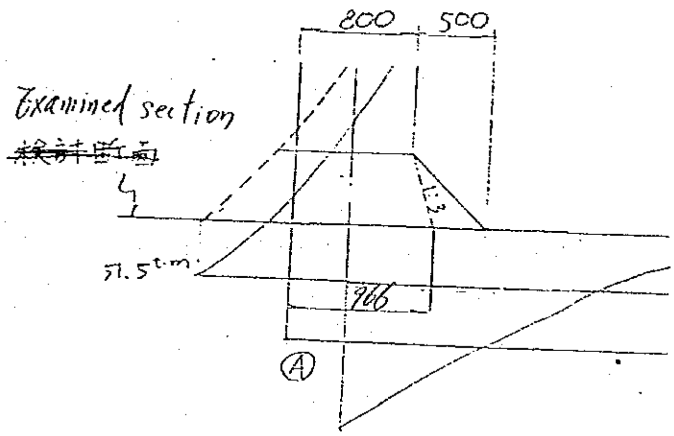

Moment diagram




Shearing force diagram

As shown above, the maximum bending moment and shearing force occur at the point A and D, the bottom edge of the side wall.

Stress analysis at the point A of side wall is as shown below :




Bending moment $M = 51.5$ t·m

Axial force $N = \dfrac{66.8 \times 2.9}{2} = 96.9$ t

$b = 100$ cm

$h = 76.6$ cm

$d = 86.6$ cm

d' = 10.0 cm

As = D22 @200 = 3,871 cm$^2$ x 5 = 19.355 cm$^2$
As' = D22 @200 = 3,871 cm$^2$ x 5 = 19.355 cm$^2$

From these data the tensile stress of the reinforcing bar and compressive stress of concrete are obtained as shown below:

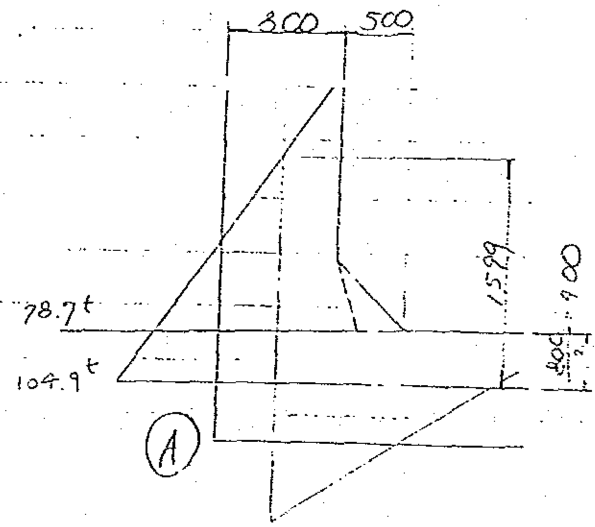
$\sigma_s$ = 1,144 kg/cm$^2$ < $\sigma_{sa}$
$\sigma_c$ = 57 kg/cm$^2$ < $\sigma_{ca}$

Shearing stress at the point A of side wall is as shown below :

$$\tau = \frac{S}{b\,j\,d}$$

$$= \frac{78.7 \times 10^3}{100 \times 0.875 \times 86.6}$$

$$= 10.4 \text{ kg/cm}^2 \fallingdotseq \tau_a = 10.4 \text{ kg/cm}^2$$




as shown above, the shearing stress at the point A of sode wall is just equal to the allowable shearing stress of concrete, however, to sccure the stirrups are provided.

The required stirrups

$$Aw = \frac{Vs \times S}{\sigma sa \times j \times d}$$

where, Aw : sectional area of stirrups in the space of stirrups S
S : space of stirrups in the direction of axis of member = 30 cm
Vs : shearing force bone by stirrups = V - Vc
V : shearing force = 78.7 t
Vc : shearing force bone by concrete

$$= \frac{1}{2}\tau_a\, j\, b\, d = \frac{1}{2} \times 10.4 \times 0.875 \times 100 \times 86.6 = 39.4 \text{ t}$$

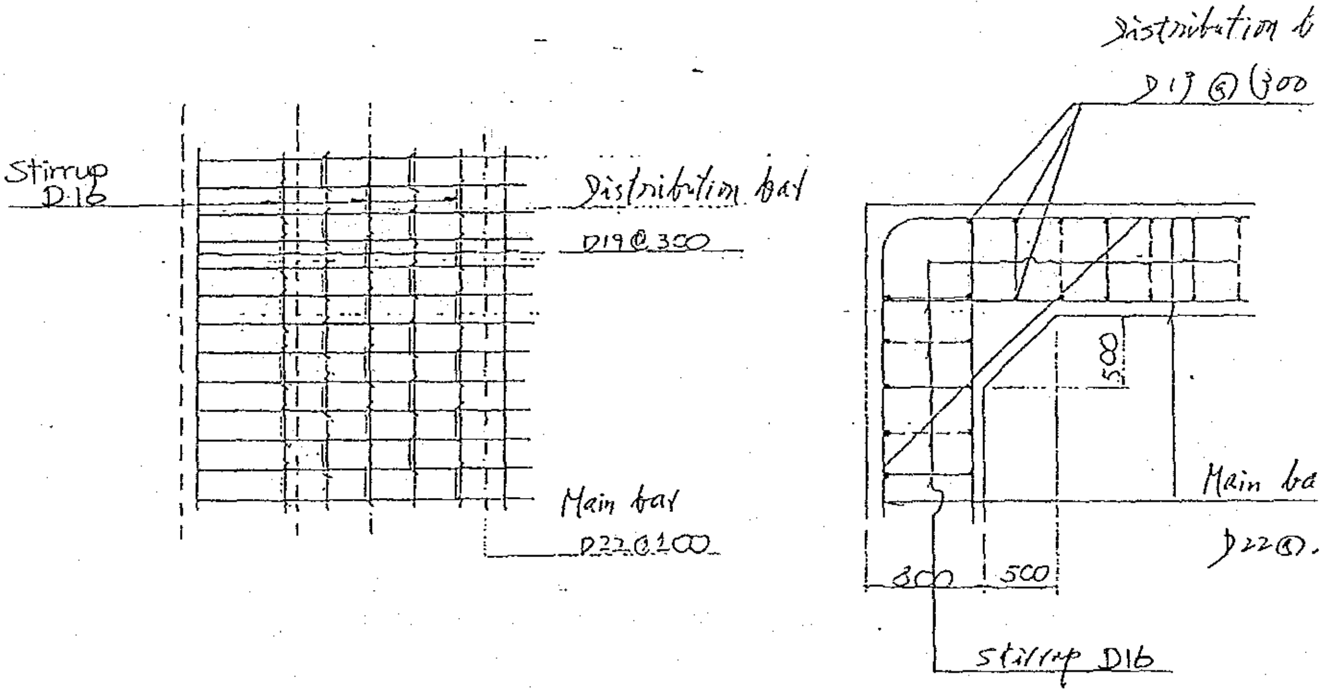
$\therefore$ Vs = V - Vc = 39.3 t

$$\therefore \text{Aw} = \frac{39{,}300 \times 30}{2{,}340 \times 0.876 \times 36.6} = 6.65 \text{ cm}^2$$

D16 x 5 Nos in S=30 cm and unit length of structure along the flow

= 1.986 $\text{cm}^2$ x 5 = 9.93 $\text{cm}^2$

Therefore, the reinforcement bar arrangement is as shown below.




## 4.3.5 Stability Analysis of Thrust Block

Plan, profile and section of the thrust block which is provided at the top of intake structure at EL 196.00 m are shown in Fig. 4.3.9 to Fig. 4.3.10.

Load acts on the thrust block, when the intake gates are operated, whose magnitudes are as follows:

| | Load on Thrust Block | |
|---|---|---|
| | At Gate Opening | Gate Closure |
| No. 1 Intake | 8 t | -2.0 t |
| No. 2 Intake | 9 t | -2.0 t |
| No. 3 Intake | 11 t | -2.1 t |

Owing to the excavated configuration in Lot I, the shape of thrust block is relatively large. Effective width of thrust block resisting the thrust force is assumed to be 1.30 m, taking the width of thrust block projected above ground elevation EL 196.000.

The center of gravity of the block is calculated as shown below:

| | Area | x | z | Ax | Az |
|---|---|---|---|---|---|
| Base, below EL 196.0 | | m | m | $m^2$-m | $m^2$-m |
| ① | $\frac{1}{2}0.8 \times 4.0 = 1.60\ m^2$ | 0.533 | 1.333 | 0.853 | 2.133 |
| ② | $1.8 \times 4.0 = 7.20$ | 1.700 | 2.000 | 12.240 | 14.400 |
| ③ | $\frac{1}{2}1.2 \times 4.0 = 2.40$ | 3.000 | 2.667 | 7.200 | 6.400 |
| | Sub-total 11.20 $m^2$ | | | 20.293 | 22.933 |

x = 1.812 m

z = 2.048 m

| | Area | x | z | Ax | Az |
|---|---|---|---|---|---|
| Mount, above EL 196.0 | | | | | |
| ④ | $\frac{1}{2}0.30 \times 1.50 = 0.225\ m^2$ | 0.200 | 0.500 | 0.045 | 0.112 |
| ⑤ | $1.00 \times 1.50 = 1.550$ | 0.800 | 0.750 | 1.240 | 1.162 |
| ⑥ | $\frac{1}{2}1.154 \times 1.50 = 0.866$ | 1.685 | 0.500 | 1.459 | 0.433 |
| | Sub-total 2.641 $m^2$ | | | 2.744 | 1.707 |

x = 1.039 m

z = 0.646 m

Integrated center of gravity

$$x = \frac{11.20 \times 1.812 + 2.641 \times (0.80 + 1.039)}{11.20 + 2.641} = 1.817\ m$$

$$z = \frac{11.20 \times 2.048 + 2.641 \times (4.00 + 0.646)}{11.20 + 2.641} = 2.544\ m$$

Thrust block should resist the thrusting force as an integrated block of basement and mount, and also mount only. As usual the sliding, overturning and bearing stress are checked.

1) Safety for sliding

$$n = \frac{\mu V + \tau A}{H}$$

where,
- $n$ : safety factor for sliding, more than 1.5 for normal condition and 1.2 for earthquake condition
- $\mu$ : friction coefficient, 0.55 for concrete and rock and 0.65 for concrete and concrete
- $V$ : vertical forces (t), sum of weight of block and vertical component of thrust force
- $\tau$ : shearing strength, 20 $t/m^2$ for concrete and rock and 40 $t/m^2$ for concrete and concrete

2) Safety for overturning

$$n = \frac{Mv}{Mt}$$

where,
- $n$ : safety factor for overturning, more than 1.5 for normal condition and 1.2 for earthquake condition
- $Mv$ : resisting moment (t-m)
- $Mt$ : overturning moment (t-m)

3) Safety for bearing capacity of foundation

Bearing stress of foundation, which is calculated by the following formula, shall be lower than the allowable bearing stress of foundation, 100 $t/m^2$ for rock and 600 $t/m^2$ for concrete.

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{V}{B} \left(1 \pm \frac{6e}{B}\right)$$

where,
- $P_1$ and $P_2$: bearing stress of foundation ($t/m^2$) in case that the forces act within the middle third of basement
- $V$ : vertical force (t)

B : area of basement or length of basement per unit width of the structure (m)

e : eccentricity of load (m)

Stability analysis as a whole integrated block for normal operation

1) for sliding

Weight of block $W = (11.20 + 2.641\ m^2) \times 1.3\ m \times 2.3\ t/m^2 = 41.4\ t$

Vertical component of thrust force $V' = 11t \cdot \sin\theta = 6.7\ t$

$\sin\theta = 1/\sqrt{1 + 1.3^2} = 0.6097$

Horizontal component of thrust force $H = 11t \cdot \cos\theta = 8.7\ t$

$\cos\theta = 1.3/\sqrt{1 + 1.3^2} = 0.0.7976$

$A = 1.30\ m \times 2.60\ m = 3.38\ m^2$

$V = W + V' = 48.1\ t$

$$\therefore\ n = \frac{0.55 \times 48.1 + 20 \times 3.38}{8.7} = 10.8 > 1.5$$

2) for overturning

$Mt = H \cdot z = 8.7\ t \times 5.014\ m = 43.6\ t\text{-}m$

$Mv = W \cdot x + V' \cdot z' = 41.4\ t \times 1.817\ m + 6.7\ t \times 2.474\ m = 91.8\ t\text{-}m$

$$\therefore\ n = \frac{91.8}{43.6} = 2.1 > 1.5$$

3) Bearing stress

$$x = \frac{Mv - Mt}{V} = \frac{91.8 - 43.6}{48.1} = 1.002\ m$$

$$e = \frac{2.60}{2} - x = 0.298\ m < \frac{B}{6} = 0.433\ m$$

$\therefore$ within middle third

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{48.1}{2.60 \times 1.30}\left(1 \pm \frac{6 \times 0.298}{2.60}\right) = \begin{matrix} 24.0\ t/m^2 \\ 4.4\ t/m^2 < 100\ t/m^2 \end{matrix}$$

for gate operation + earthquake

1) for sliding

Horizontal force due to earthquake $H' = 0.05 \cdot W = 2.1$ t

$$\therefore\ n = \frac{0.55 \times 48.1 + 20 \times 3.38}{8.7 + 2.1} = 8.7 > 1.2$$

2) for overturning

$Mt = H \cdot z + H'z' = 43.6 + 2.1 \times 2.544 = 48.9$ t

$Mv = 91.8$ t-m

$$\therefore\ n = \frac{91.8}{48.9} = 1.8 > 1.2$$

3) Bearing stress

$$x = \frac{Mv - Mt}{V} = \frac{91.8 - 48.9}{48.1} = 0.892 \text{ m}$$

$$e = \frac{2.60}{2} - x = 0.408 \text{ m} < \frac{B}{6} = 0.433 \text{ m}$$

$\therefore$ within middle third

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{48.1}{2.60 \times 1.3}\left(1 \pm \frac{6 \times 0.408}{2.60}\right) = \begin{matrix} 27.6 \text{ t/m}^2 \\ 0.8 \text{ t/m}^2 \end{matrix} < 100 \text{ t/m}^2$$

Stability analysis of projected mount
for normal operation

1) for sliding

Weight of block $W = 2.641 \text{ m}^2 \times 1.3 \text{ m} \times 2.3 \text{ t/m}^2 = 7.9$ t

Vertical component of thrust force $V' = 6.7$ t

Horizontal component of thrust force $H = 8.7$ t

$\therefore\ V = W + V' = 14.6$ t

$A = 2.454 \text{ m} \times 1.3 \text{ m} = 3.19 \text{ m}^2$

$$\therefore\ n = \frac{0.65 \times 14.6 + 40 \times 3.19}{8.7} = 15.8 > 1.5$$

2) for overturning

Mt = H·z = 8.7 t x 1.014 m = 8.8 t-m

Mv = W·x + V'·x' = 7.9 t x 1.039 m + 6.7 t x 1.674 m = 19.4 t-m

$$\therefore\ n = \frac{19.4}{8.8} = 2.2 > 1.5$$

3) Bearing stress

$$x = \frac{Mv - Mt}{V} = \frac{19.4 - 5.6}{14.6} = 0.945 \text{ m}$$

$$e = \frac{2.454}{2} - x = 0.281 \text{ m} < \frac{B}{6} = 0.409 \text{ m}$$

∴ within middle third

$$\left.\begin{matrix} P_1 \\ P_2 \end{matrix}\right\} = \frac{1.46}{2.454 \times 1.3} \left(1 \pm \frac{6 \times 0.281}{2.454}\right) = \begin{matrix} 7.7 \text{ t/m}^2 \\ 1.4 \text{ t/m}^2 \end{matrix} < 600 \text{ t/m}^2$$

for gate operation + earthquake

1) for sliding

Horizontal force due to earthquake H' = 0.05 · W = 0.4 t

$$\therefore\ n = \frac{0.65 \times 14.6 + 40 \times 3.19}{8.7 + 0.4} = 15.0 > 1.2$$

2) for overturning

Mt = H·z + H'·z' = 8.8 t-m + 0.4 t x 0.646 m = 9.0 t-m

Mv = 19.4 t-m

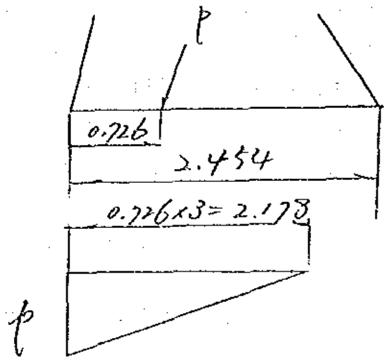
$$\therefore\ n = \frac{19.4}{9.0} = 2.1 > 1.2$$

3) Bearing stress

$$x = \frac{Mv - Mt}{V} = \frac{19.4 - 8.8}{14.6} = 0.726 \text{ m}$$

$$e = \frac{2.454}{2} - x = 0.501 \text{ m} > \frac{B}{6} = 0.409 \text{ m}$$

$\therefore$ outside middle third




$$P = 2 \times \frac{V}{1.30 \times 2.178} = 2 \times \frac{14.6}{1.30 \times 2.178} = 10.3 \text{ t/m}^2 < 600 \text{ t/m}^2$$