REPUBLIC OF INDONESIA

MINISTRY OF COMMUNICATIONS
DIRECTORATE GENERAL OF LAND TRANSPORT
AND INLAND WATERWAYS

TENDER DOCUMENTS
FOR
NEW RAILWAY LINE FOR CENGKARENG AIRPORT
CONSTRUCTION PROJECT

STRUCTURAL CALCULATION SHEETS

PACKAGE I CIVIL AND ARCHITECTURAL WORK

1 of 11

AUGUST 1984

JAPAN INTERNATIONAL COOPERATION AGENCY
(JICA)

SDF
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STRUCTURAL CALCULATION SHEETS

CONTENTS

§§ 1. P.C. GIRDERS

Contents

Prestressed Concrete Girder Structural Calculation Sheets

Bridge Number	Girder Number	Station Beginning	Station Ending	Girder Length (m)	Girder Depth (m)	Track of Straight or Curve	Girder of Right Angle or Skew	Design Drawing: General View	Design Drawing: Main Beam	Design Drawing: Lateral Joint	Design Drawing: Material list	Structural Calculation Sheet	Material Calculation Sheet	Remark
B 01	PC 01	$10^{K}979^{M}$	$10^{K}999^{M}$	20	1.80	Straight	Skew Left 60°	○	○	○	○	○	○	Cengkareng Flood Way
	02	999^{M}	$11^{K}039^{M}$	40	2.40	〃	〃	○	○	○	○	○	○	〃
	03	$11^{K}039^{M}$	059^{M}	20	1.80	〃	〃	—	PC 01	—	—	—	—	〃
B 02	04	$13^{K}655^{M}$	$13^{K}680^{M}$	25	1.40	〃	Right Angle	○	○	○	○	○	○	JL. Kapuk Muara
B 03	05	774^{M}	794^{M}	20	1.80	〃	〃	○	PC 01	—	—	—	○	Kali Muara Angke
	06	794^{M}	824^{M}	30	1.80	〃	〃	○	○	○	○	○	○	〃
	07	824^{M}	844^{M}	20	1.80	Transition Curve	90°00′00″ 90°00′05″	PC 05	PC 01	—	—	—	PC 05	〃
	08	844^{M}	864^{M}	20	1.80	〃	90°05′11″ 90°09′01″	〃	〃	—	—	—	〃	
	09	864^{M}	864^{M}	20	1.80	〃	90°16′39″ 90°20′28″	〃	〃	—	—	—	〃	
	10	884^{M}	909^{M}	25	1.40	〃	90°36′09″ 90°40′52″	—	PC 04	—	—	—	—	JL. 8
	11	909^{M}	929^{M}	20	1.80	Curve R=1,000m	90°34′25″	PC 05	PC 01	—	—	—	PC 05	
B 04	12	$14^{K}041^{M}$	$14^{K}071^{M}$	30	2.15	Transition Curve	90°47′42″ 90°40′18″	PC 13	PC 28	—	—	—	PC 13	JL. 2A
B 05	13	211^{M}	241^{M}	30	2.15	Straight	Right Angle	○	〃	—	—	—	○	〃
	14	241^{M}	271^{M}	30	2.15	〃	〃	PC 13	〃	—	—	—	PC 13	JL. VI
	15	271^{M}	306^{M}	35	2.00	〃	〃	○	○	○	○	○	○	JL. 11
	16	306^{M}	341^{M}	35	2.00	〃	〃	—	PC 15	—	—	—	—	Banjir Kanal
	17	341^{M}	381^{M}	40	2.40	〃	〃	○	PC 02	—	—	—	○	〃
	18	381^{M}	416^{M}	35	2.00	〃	〃	—	PC 15	—	—	—	—	〃
B 06	19	775^{M}	815^{M}	40	2.40	〃	Skew Left 65°	—	PC 02	—	—	—	—	Kali Muara Karang
B 07	20	$15^{K}579^{M}$	$15^{K}609^{M}$	30	1.80	〃	Skew Left 85°	—	PC 06	—	—	—	—	JL. Jembatan Tiga
	21	609^{M}	639^{M}	30	1.80	〃	〃	—	〃	—	—	—	—	〃

Bridge Number	Girder Number	Station Beginning	Station Ending	Girder Length (m)	Girder Depth (m)	Track of Straight or Curve	Girder of Right Angle or Skew	Design Drawing: General View	Design Drawing: Main Beam	Design Drawing: Lateral Joint	Design Drawing: Material list	Structural Calculation Sheet	Material Calculation Sheet	Remark
B 06	PC 22	17K 048M	17K 073M	25	1.40	Straight	Right Angle	——	PC 04	——	——	——	——	JL. Gedong Panjang
	23	073M	098M	25	1.40	〃	〃	——	〃	——	——	——	——	〃
	24	098M	123M	25	2.35	〃	〃	○	PC 29	——	——	——	○	
	25	123M	148M	25	2.35	〃	〃	PC 24	〃	——	——	——	PC 24	Kali Sunter
B 09	26	590M	625M	35	2.00	〃	〃	——	PC 15	——	——	——	——	Kali Krukut
B 10	27	759M	784M	25	1.40	〃	〃	——	PC 04	——	——	——	——	JL. Tongkol
B 11	28	18K 106M	18K 136M	30	2.15	Curve R=500m	91°43′08″	○	○	○	○	◎	○	Kali Ciliwung
B 12	29	720M	745M	25	2.35	〃	91°25′57″	○	○	○	○	◎	○	Gudang Yard
	30	745M	770M	25	2.35	〃	〃	——	PC 29	——	——	——	——	〃
	31	770M	795M	25	2.35	〃	〃	——	〃	——	——	——	——	〃
	32	795M	825M	30	2.15	〃	91°43′08″	——	PC 28	——	——	——	——	〃
	33	825M	850M	25	2.35	〃	Left 69°34′03″	○	PC 29	——	——	——	○	〃
	34	850M	880M	30	2.15	〃	Left 72°43′08″	○	PC 28	——	——	——	○	JL. Raya Kampung
B 13	35	880M	910M	30	2.15	〃	91°43′08″	——	PC 28	——	——	——	——	
	36	910M	940M	30	2.15	〃	〃	——	〃	——	——	——	——	
	37	940M	970M	30	2.15	〃	〃	——	〃	——	——	——	——	
B 14	38	970M	19K 000M	30	2.15	Transition Curve	90°42′48″ 90°39′45″	——	〃	——	——	——	——	
	39	19K 000M	028M	28	2.15	〃	91°08′38″ 60°53′44″	○	PC 28	——	——	——	○	Kota Yard
	40	028M	061M	33	2.15	〃	120°25′19″ 70°03′11″	○	○	○	○	◎	○	〃
	41	061M	091M	30	2.15	Straight	Right 70°	○	PC 40	——	——	——	○	〃
	42	091	117M	26	2.35	〃	Right 70°	○	○	○	○	◎	○	〃

NO. 1 P.C. GIRDERS

SUPER-STRUCTURE

DESIGN CALCULATION

BO - PC01 L = 20^{m}, H = 1.80^{m}

(Skew Left 60°)

CONTENTS

Chapter 1. Design criteria

1. Basis for design and loading conditions

- Kind of bridge: Pre-stressed concrete railroad bridge.
- Type of Bridge/Girders: Bridge superstructure is a simple beam, consisted of 2 main girders aligned in parallel.
  Girder is made of post-tensioned concrete of I type section.
- Length of girder: 19.960 m
- Span of main girder: 18.960 m
- Live load : KS-16
- Impact coefficient : i = 0.376
- Crossing angle: { at younger change: Left 60° 00′ 00″
  at elder change: Left 60° 00′ 00″
- Railroad curve: Straight

2. Strength of materials for design

2-1. Concrete

(1) Concrete used for main girder

- Standard strength for design (28 day value).
  : σ_{CK} = 400 kg/cm^2
- Allowable compressive strength for bending calculation
  : σ_{ca} = 140 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 180 kg/cm^2
- Allowable tensile strength for bending calculation applied for,
  - design loading : σ_{cat} = -10 kg/cm^2
  - dead load : $\sigma_{cat'}$ = 0 kg/cm^2
  - immediate after the pre-stressing: $\sigma_{cat''}$= -15 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_c=3.5×10^5 kg/cm^2

(2) Concrete used for lateral connection

- Standard strength for design (28 day value)
  : σ_{ck} = 300 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 110 kg/cm^2
- Allowable tensile strength for bending calculation : $\sigma_{ca'}$ = -8 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 140 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_c=3.0x10^{5}kg/cm^2

(3) Cantilever part of bridge slab, edge coaming and handrail concrete

- Standard strength for design (28 day value) : σ_{ck} = 240 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 80 kg/cm^2

2-2. Steel materials used for P.C. concrete

(1) P.C. Cable (SWPR-7B) 12T 12.7 mm

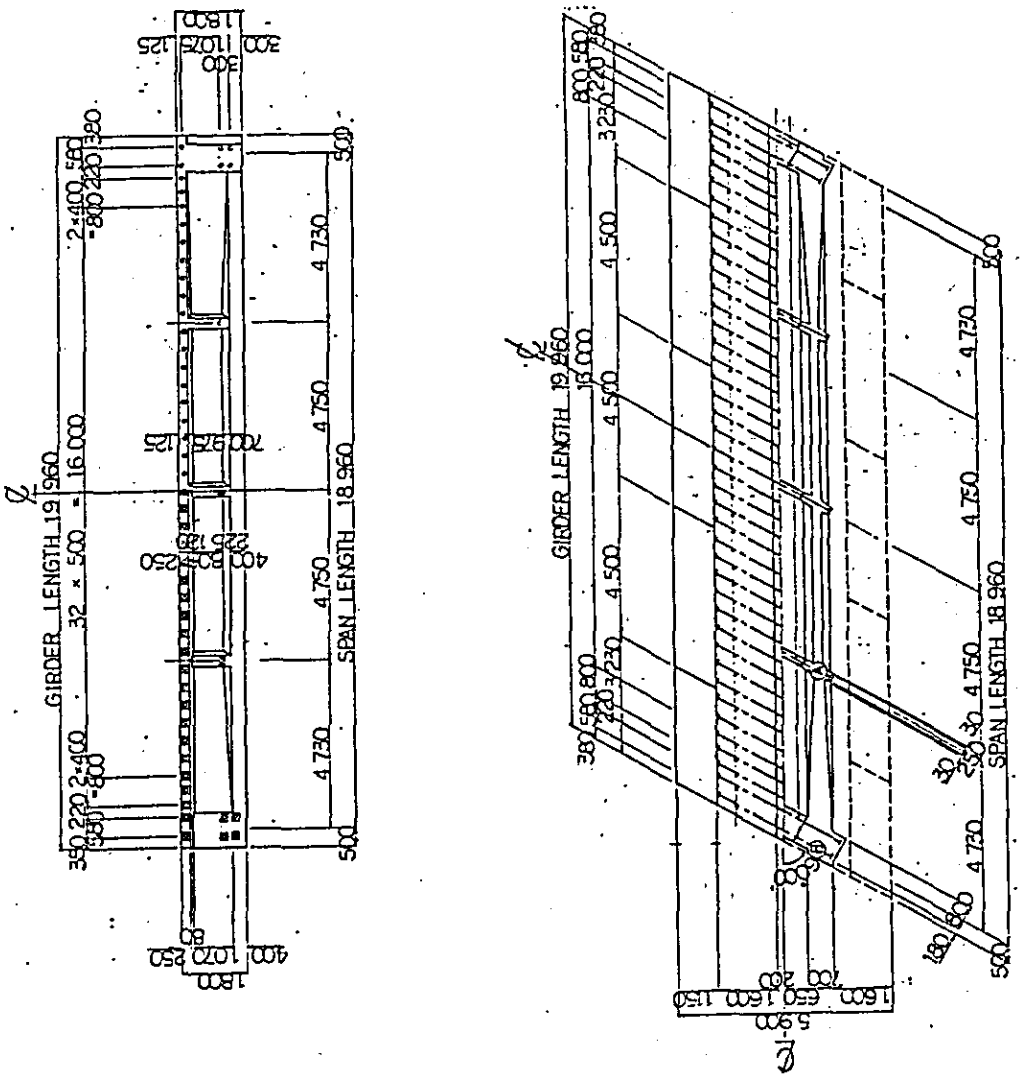
- Tensile strength : σ_{pu} = 190 kg/mm^2
- Yielding point : σ_{py} = 160 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 114 kg/mm^2
  - immediate after the pre-stressing: σ_{pat}= 133 kg/mm^2
  - during pre-stressing : σ_{pai}= 145 kg/mm^2
- Young's modulus of P.C. steel material : E_p=2.0×10^{6}kg/cm^2

(2) P.C. steel bar (SBPR 95/110) ϕ 23 mm

- Tensile strength : σ_{pu} = 110 kg/mm^2
- Yielding point : σ_{py} = 95 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 66 kg/mm^2
  - immediate after the pre-stressing: σ_{pat}= 77 kg/mm^2
  - during pre-stressing : σ_{pai}=85.5 kg/mm^2
- Young's modulus of P.C. steel material : E_p=2.0×10^{6}kg/mm^2

2-3. Reinforcing Bar : SD 30

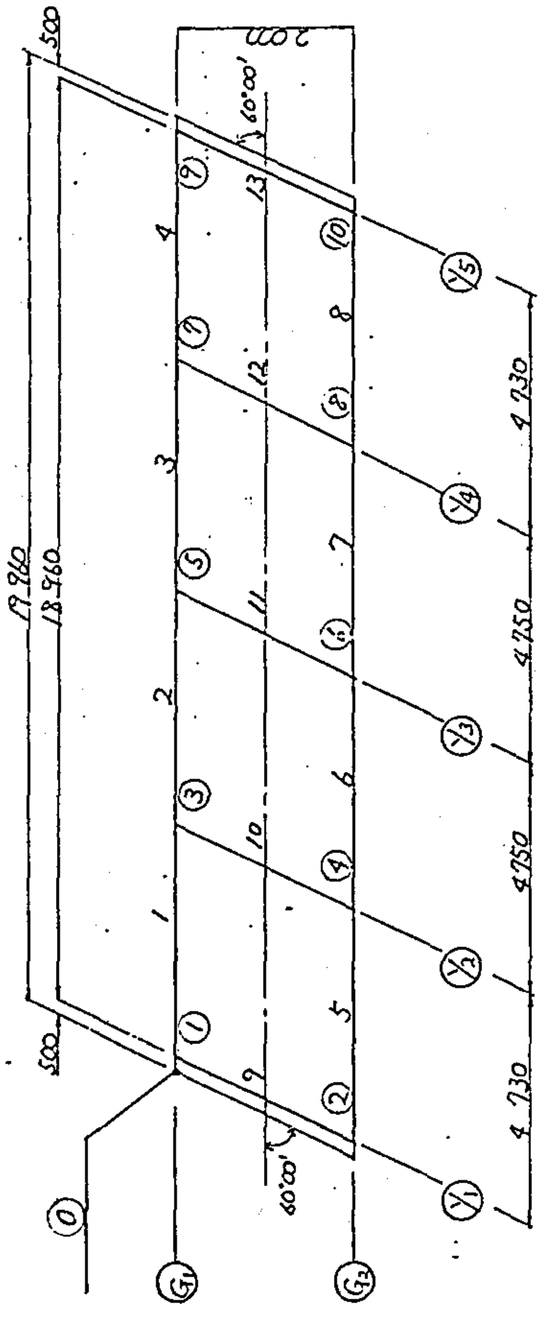
Chapter 2. Configuration and Dimensions of Bridge



Chapter 3. Input for Grid-system calculation

§1. Numbering & Coordinates of Skeleton Point

1. Member numbering & Skeleton point numbering



2. Coordinates calculations of Skeleton points

Assumed the Skeleton point (0) as fundamental point, coordinates of other skeleton points are calculated as listed below.

(Unit: m)

Skeleton point number	Skeleton point coordinates x	Skeleton point coordinates y	Skeleton point number	Skeleton point coordinates x	Skeleton point coordinates y
(1)	0.500	0	( )		
(2)	-0.655	-2.000	( )		
(3)	5.230	0	( )		
(4)	4.075	-2.000	( )		
(5)	9.980	0	( )		
(6)	8.825	-2.000	( )		
(7)	14.730	0	( )		
(8)	13.575	-2.000	( )		
(9)	19.460	0	( )		
(10)	18.305	-2.000	( )		
( )			( )		
( )			( )		
( )			( )		
( )			( )		

§2. Support conditions and Young's modulus of Concrete

1. Support conditions

Skeleton number	Rotation around		Z direction
	Y axis	X axis	
(1)	free	free	restricted
(2)	"	"	"
(9)	"	"	"
(10)	"	"	"
○			
○			
○			
○			

2. Young's modulus of concrete

(1) Young's modulus

Main girder : $E\ell = 3.50 \times 10^5\ kg/cm^2 = 35.0 \times 10^5\ t/m^2$

Cross beam : $Et = 3.00 \times 10^5\ kg/cm^2 = 30.0 \times 10^5\ t/m^2$

(2) Young's modulus corresponding to shearing

$G = 0.43E$

Main girder : $G\ell = 0.43 \times 35.0 \times 10^5 = 15.05 \times 10^5\ t/m^2$

Cross beam : $Gt = 0.43 \times 30.0 \times 10^5 = 12.90 \times 10^5\ t/m^2$

§3. Configuration and Dimensions of Main girder and Cross beam

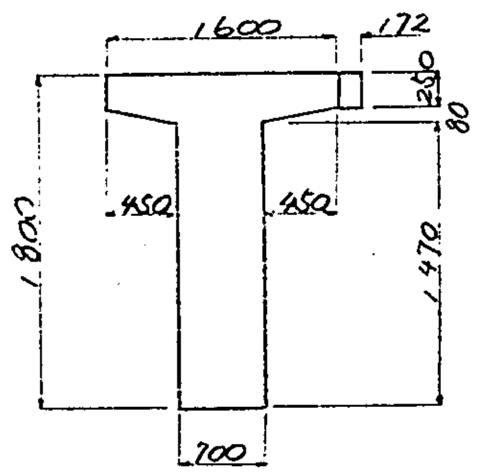
1. Configuration and Dimensions of Main girder

Dimension of concrete between Girders are as shown.

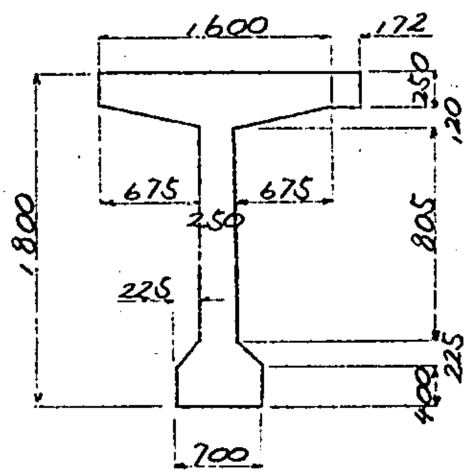
$$Et/E\ell = \frac{30.0 \times 10^5}{35.0 \times 10^5} = 0.857 \fallingdotseq 0.86$$

$$b = 0.400 \times 0.86 \times \frac{1}{2} = 0.172$$

SECTION NUMBER ①: G1, G2 (Y1, Y5)

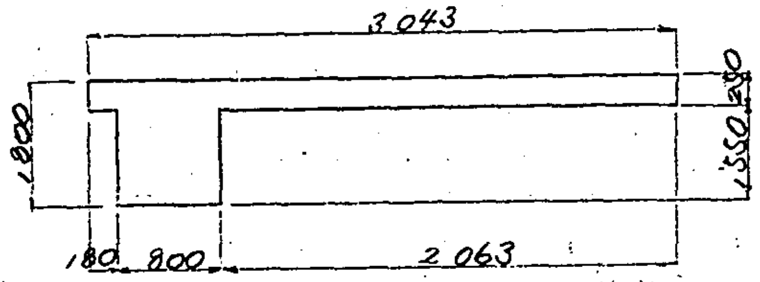


SECTION NUMBER ② G1, G2 (Y2 ~ Y4)

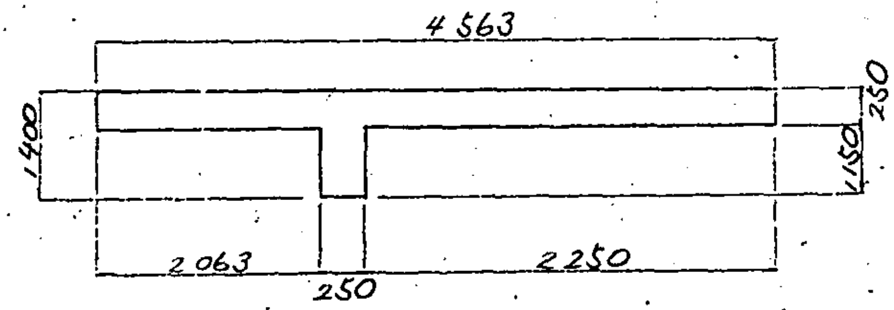


2. Configuration and Dimensions of Cross beam

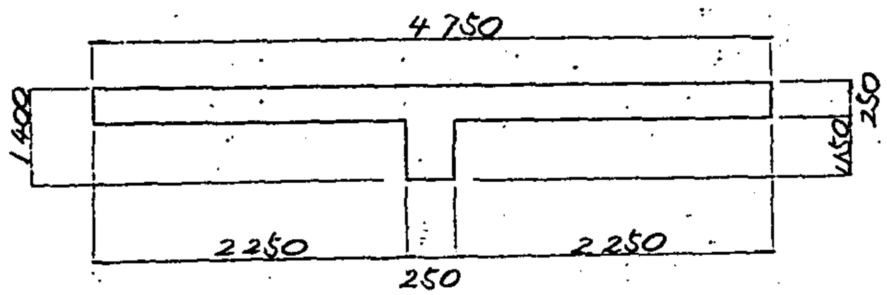
SECTION NUMBER ③ (y_1, y_5)



SECTION NUMBER ④ (y_2 y_4)



SECTION NUMBER ⑤ (y_3)



3. Applicable section number for various Girder, Beam/location

Girders		Location of number	Section number	Notes
Main girder	G_1, G_2	Location of Cross beam : y_1 , y_5	①	
		〃 : $y_2 \sim y_4$	②	
			○	
			○	
Cross beam		y_1 , y_5	③	
		y_2 , y_4	④	
		y_3	⑤	

4. Moment of inertia of the section

(Unit: m^4)

Girders		Members	Moment of inertia (Average)
Main girder	G_1, G_2	1, 4, 5, 8	0.46545
		2, 3, 6, 7	0.44821
Cross beam		9, 13	0.63413
		10, 12	0.15014
		11	0.15129

§4. Loads and Loading conditions

1. Application of loads for calculation

(1) Application of static load

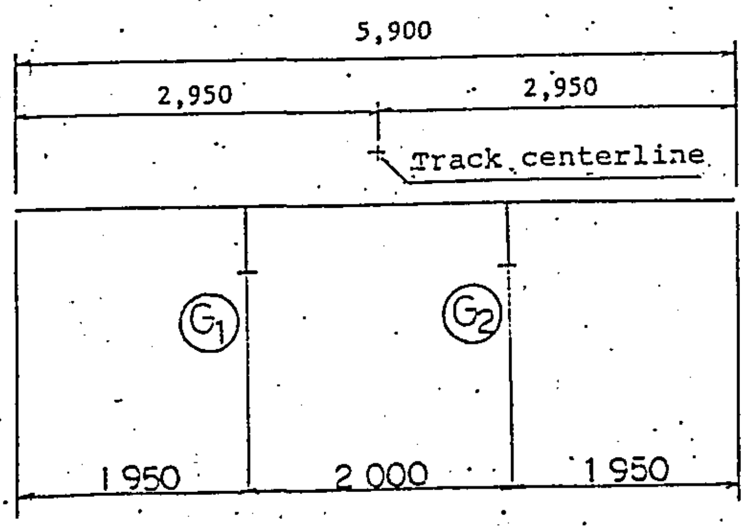
As the grid-system are carried out based on influence lines, the static load loading is applied in dual ways, one is a lined loading and the other is a uniformly distributed loading, to determine the loading length and width.

(2) Application of combined train loading

(a) Train load loading

Train load is assumed to be transmitted through sleepers downwards and distributed to the enlarged width within inclined lines with 53 deg. starting at both end points of sleeper bottom.

Distribution of loads through track is shown in the sketch drawing.



(b) Combined loading of train load

(i) Train load is supposed to distribute entire length of the span.

(ii) Train load is supposed to distribute limited to one side of span with 1/2 ℓ length.

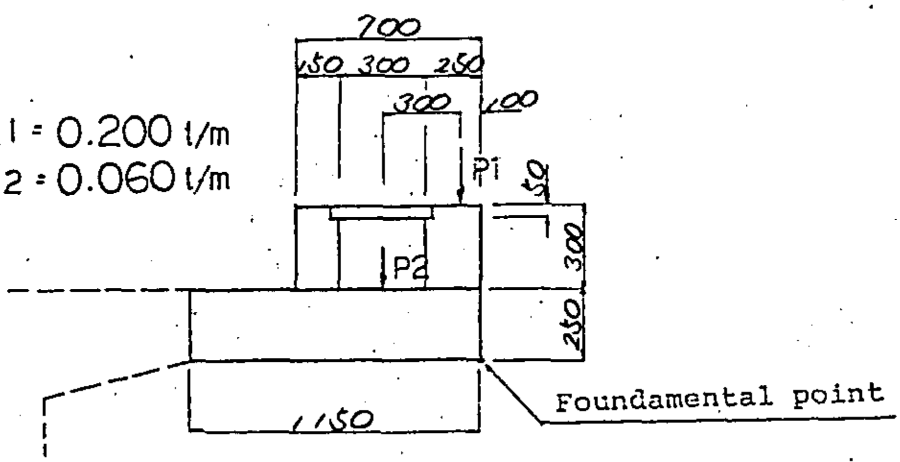
Train load is applied combined the above (i) and (ii) loadings. Thus, further calculations are made for the sectional strength.

2. Dead load calculations of the own weight of structure

(1) Cantilever part of bridge slab, edge coaming and handrail concrete

(a) G2 girder side

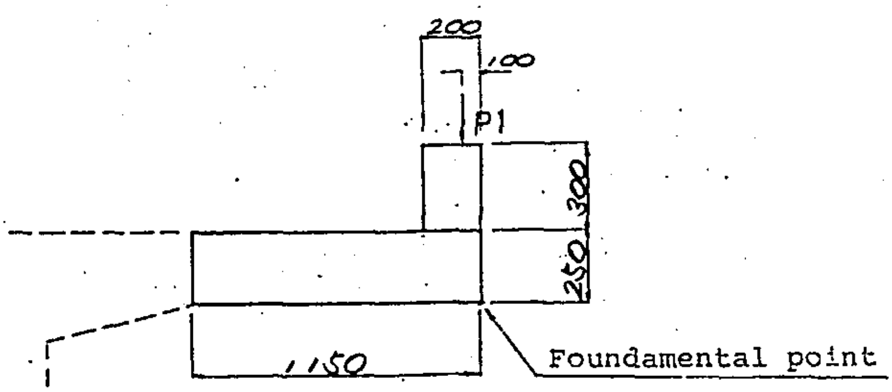
P1 = 0.200 t/m
P2 = 0.060 t/m



Load/Load acting point

Total dead load : ΣW (t/m) = 1.318
Total bending moment : $\Sigma W X$ (t-m/m) = 0.567
Acting point of resultant force : $X = \Sigma W X / \Sigma W$ (m) = 0.430

(b) G1 girder side

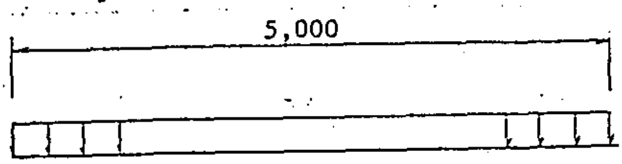


Load/Load acting point

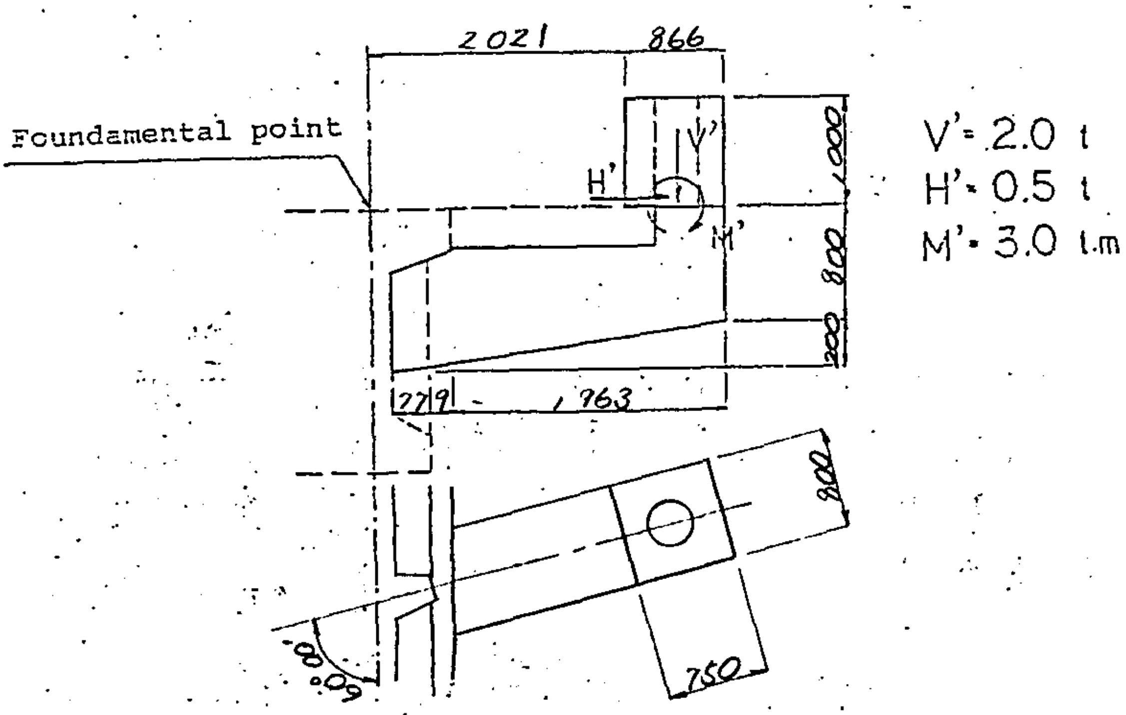
Total dead load : ΣW (t/m) = 1.069
Total bending moment : $\Sigma W X$ (t-m/m) = 0.448
Acting point of resultant force : $X = \Sigma W X / \Sigma W$ (m) = 0.419

(2) Graded Concrete

$Wp = 2.35 \times 0.07 = 0.165\ t/m^2$

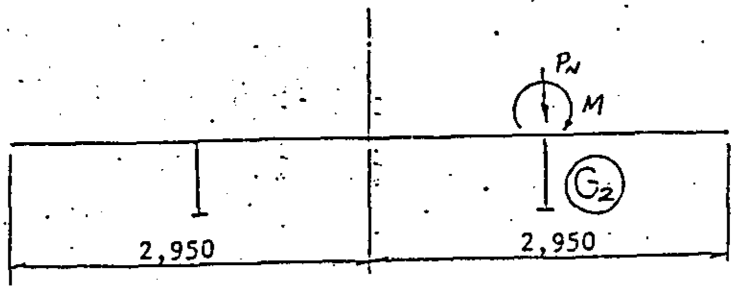


(3) Electric pole and its supporting beam



Load/Load acting point

Total dead load : Σ W(t/m) = 6.738
Total bending moment : Σ W X(t-m/m) = 13.489
$M = M' + \Sigma WX$ = 16.489



3. Dead load calculations of surcharge

(1) Surcharge load of ballast

Calculated as a uniformly distributed load.

$$W_B = 1.9 \text{ t/m}^3 \times (h_B - h_p) = 0.914 \text{ t/m}^2$$

(2) Surcharge load of track assembly

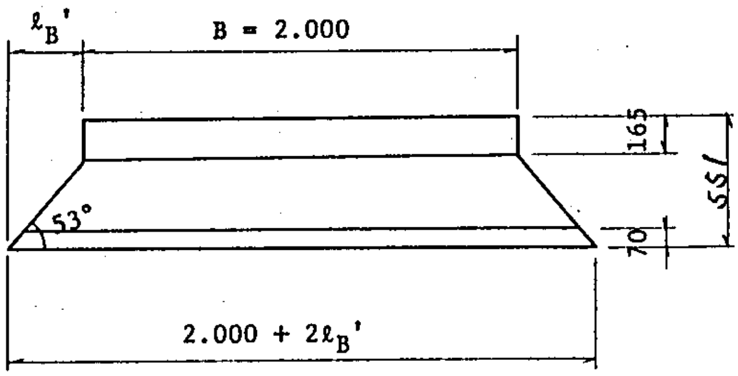
Load of track assembly is assumed to be distributed on the bridge slab with the width between two points on the slab, where lines drawn from the both ends of sleeper bottom with 53 deg. inclination towards outward-downward, crossing the slab surface.

- Load of track assembly : $\Sigma W_R = 0.450$ t/m
- Width of sleeper : $B = 2.000$ m
- Thickness of sleeper : $h_M = 0.165$ m
- Height between the girder top and the sleeper top : $h_B = 0.551$ m
- Average thickness of graded concrete for drainage : $h_p = 0.070$ m

$$2\ell_B' = 2(h_B - h_M) \cdot \cot 53° = 0.582 \text{ m}$$

- Load distribution width:

$$\ell_B = B + 2\ell_B' = 2.582 \text{ m}$$



Uniformly distributed load:

$$W_R = \frac{\Sigma W_R}{\ell_B} = 0.174 \text{ t/m}^2$$

4. Uniformly distributed load, equivalent to the train loading

Bending moment calculation:

For the bending moment calculation, the equivalent uniformly distributed load at the 1/4 span point will be employed and confirmed as calculated below.

$$M\ell = \{M\ell_{min} + \frac{\ell - \ell_{min}}{\ell_{max} - \ell_{min}} \cdot (M\ell_{max} - M\ell_{min})\}\ \gamma \cdot \beta \times \frac{1}{18}$$

where, $\ell = 18.960$, $\ell_{max} = 19.000$, $\ell_{min} = 18.500$

$\gamma = 2$ $\beta = 16$

$M\ell(\ell/4)_{min} = 143.0\ tm$, $M\ell(\ell/4)_{max} = 149.7\ tm$

$M\ell(\ell/2)_{min} = 185.0\ tm$, $M\ell(\ell/2)_{max} = 193.8\ tm$

$$M\ell(\ell/4) = \{143.0 + \frac{0.46}{0.50} \times (149.7 - 143.0)\}\ 2 \times 16 \times \frac{1}{18}$$

$$= 265.180\ tm$$

$$M\ell(\ell/2) = \{185.0 + \frac{0.46}{0.50} \times (193.8 - 185.0)\}\ 2 \times 16 \times \frac{1}{18}$$

$$= 343.282$$

Equivalent uniformly distributed load at $\ell/4$ span point, which is Wm, will be

$$W_m = \frac{32}{3} \times \frac{M\ell(\ell/4)}{\ell^2} = 7.869$$

Employed the above Wm value and applied for the bending moment calculation at $\ell/2$ point.

$$M'_{\ell/2} = W_m \cdot \frac{\ell^2}{8} = 353.595\ tm$$

$$> M\ell_{(\ell/2)} = 343.282\ tm$$

The result is larger than the value of $M_{\ell/2}$.

$Wm = 7.869$ t/m

Train loading for bending moment:

$W\ell = Wm(1 + i) = 10.828$ t/m

Train loading for bending moment: calculation

Train loading is distributed expanded with 53 deg. inclination from the both ends of sleeper bottom.

Uniformly distributed load: $W\ell$

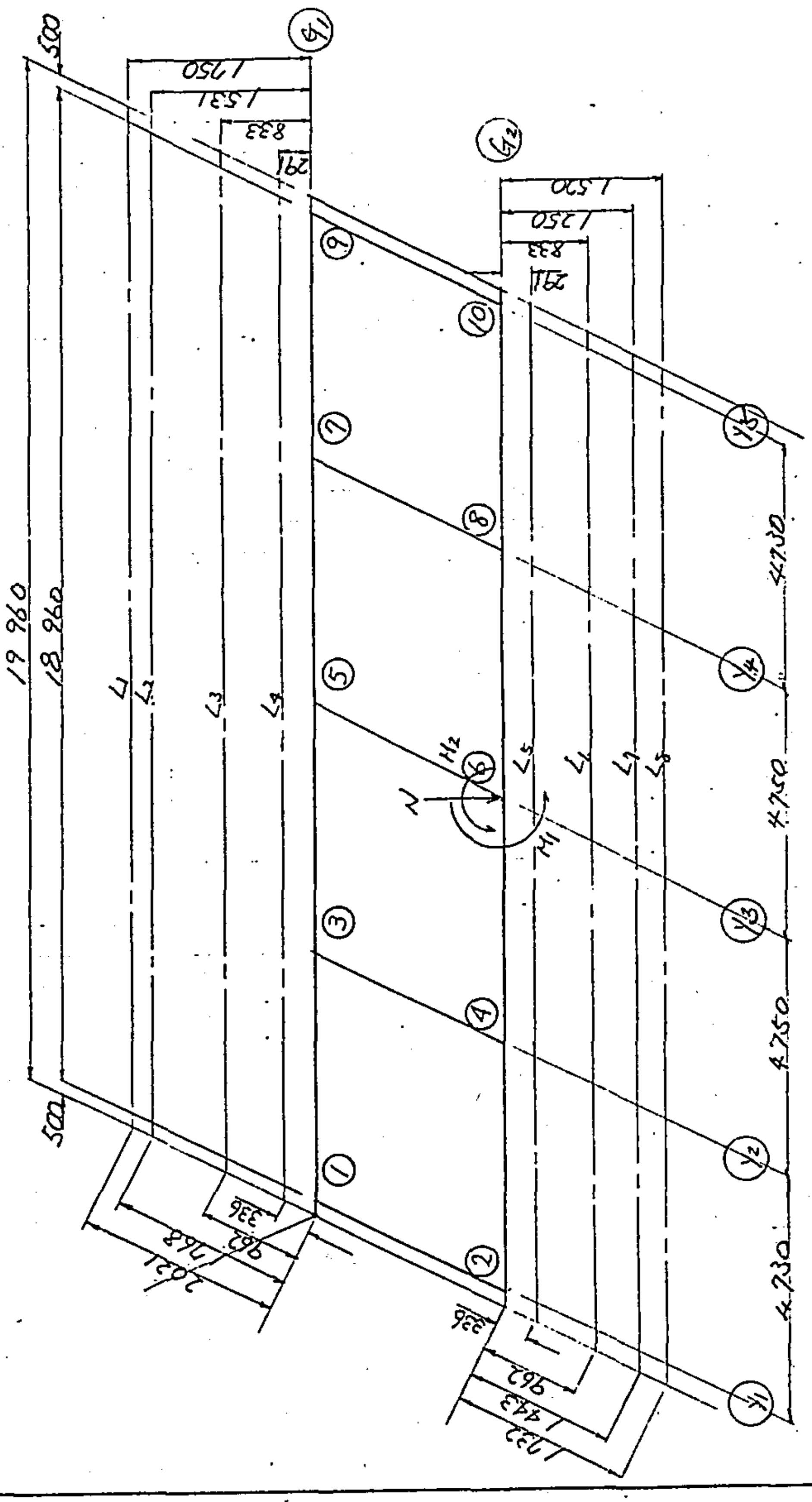
$$W\ell = \frac{Wm\ (1 + i)}{\ell_B} = 4.194 \text{ t/m}^2$$

5. Load/Loading point of various loadings

(1) Summary of loads

Load	Cases	Title	Load distribution area		Intensity of load	Category of load
			Width	Length		
Dead load of surcharge and structure	Case 1	VANJO $-D_1$	L_8	$Y_1 \sim Y_5$	1.318 t/m	Canti. slab, handrail conc., etc.
			L_2	$Y_1 \sim Y_5$	1.069 "	
			$L_1 \sim L_7$	$Y_1 \sim Y_5$	0.165 t/m²	Graded conc.
			$L_3 \sim L_6$	$Y_1 \sim Y_5$	0.914 "	Ballast
			$L_4 \sim L_5$	$Y_1 \sim Y_5$	0.174 "	Track assembly
Electric pole, etc.	Case 2	DENCHU $-D_1$	G_2	Y_3	N = 6.738 t	Electric pole and its supporting beam
					M_1 = 14.280 tm	
					M_2 = 8.245 tm	
Train load	Case 3	L_1	$L_4 \sim L_5$	$Y_1 \sim Y_5$	4.194 t/m²	Live load intensity applied for bending moment calculation
	Case 4	L_2	$L_4 \sim L_5$	$Y_1 \sim Y_3$	4.194 "	
	Case 5	L_3	$L_4 \sim L_5$	$Y_3 \sim Y_5$	4.194 "	

(2) Loading conditions



6. Combined loading

(1) Case 1: Dead load of surcharge

(2) Case 2: Dead load of electric pole

(3) Case 3: Train load, loaded on full span

(4) Case 4: Train load, loaded on half span

(5) Case 5: Train load, loaded on half span

(6) Case 6: Case 1 + Case 2

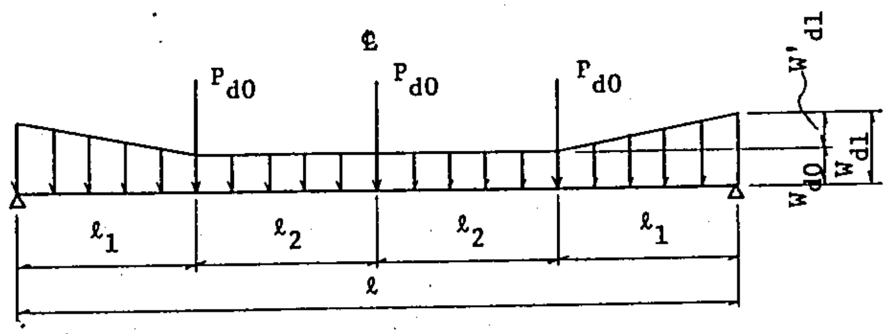
(7) Case 7: Case 6 + Case 3

(8) Case 8: Case 6 + Case 4

(9) Case 9: Case 6 + Case 5

Chapter 4. Design calculations of Main girder cross section

§1. Bending moment caused by own weight of Main girder



Bending moment (at center of span)

$$M_{d0} = \frac{1}{8}\cdot W_{d0}\cdot \ell^2 + \frac{1}{6}\cdot W_{d1}'\cdot \ell_1{}^2 + P_{d0}\cdot\{\frac{n}{2}(\ell_1 + \ell_2) - \ell_2\}$$

W_{d0} : Per meter weight of the section at the center (t/m) = 2.748

W_{d1} : Per meter weight of the section at the point of support (t/m) = 3.803

$W_{d1}' = W_{d1} - W_{d0}$ = 1.055

P_{d0} : Weight of intermediate diaphragm (t) = 0.341

ℓ : Span (m) = 18.960

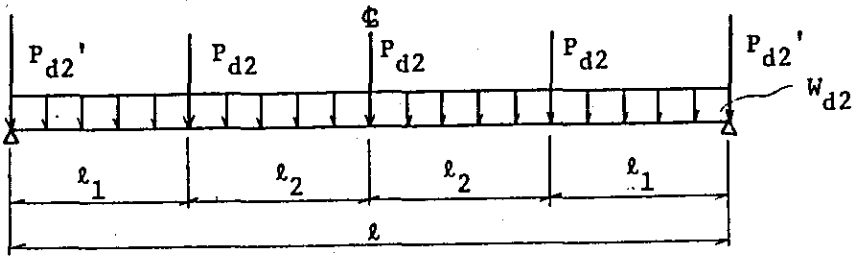
ℓ_1 : Length of the widened part of web (m) = 4.730

ℓ_2 : Location of diaphragm (m) = 4.750

n : Number of intermediate diaphragms

M_{d0} = 130.645 tm

§2. Stress calculations of Cross beam cross section



- Bending moment (at center of span)

$$M_{d0} = \frac{1}{8} \cdot W_{d2} \cdot \ell^2 + P_{d2} \cdot \{ \frac{n}{2} \cdot (\ell_1 + \ell_2) - \ell_2 \}$$

where,

W_{d2} : Own weight of bridge slab between girders (t/m)
= 0.217

P_{d2} : Own weight of intermediate Cross beam (t)
= 1.121

P_{d2}': Own weight of end Cross beam (t)
= 4.488

ℓ : Span (m) = 18.96

ℓ_1, ℓ_2: Location of Cross beam (m) { ℓ_1 = 4.730, ℓ_2 = 4.750

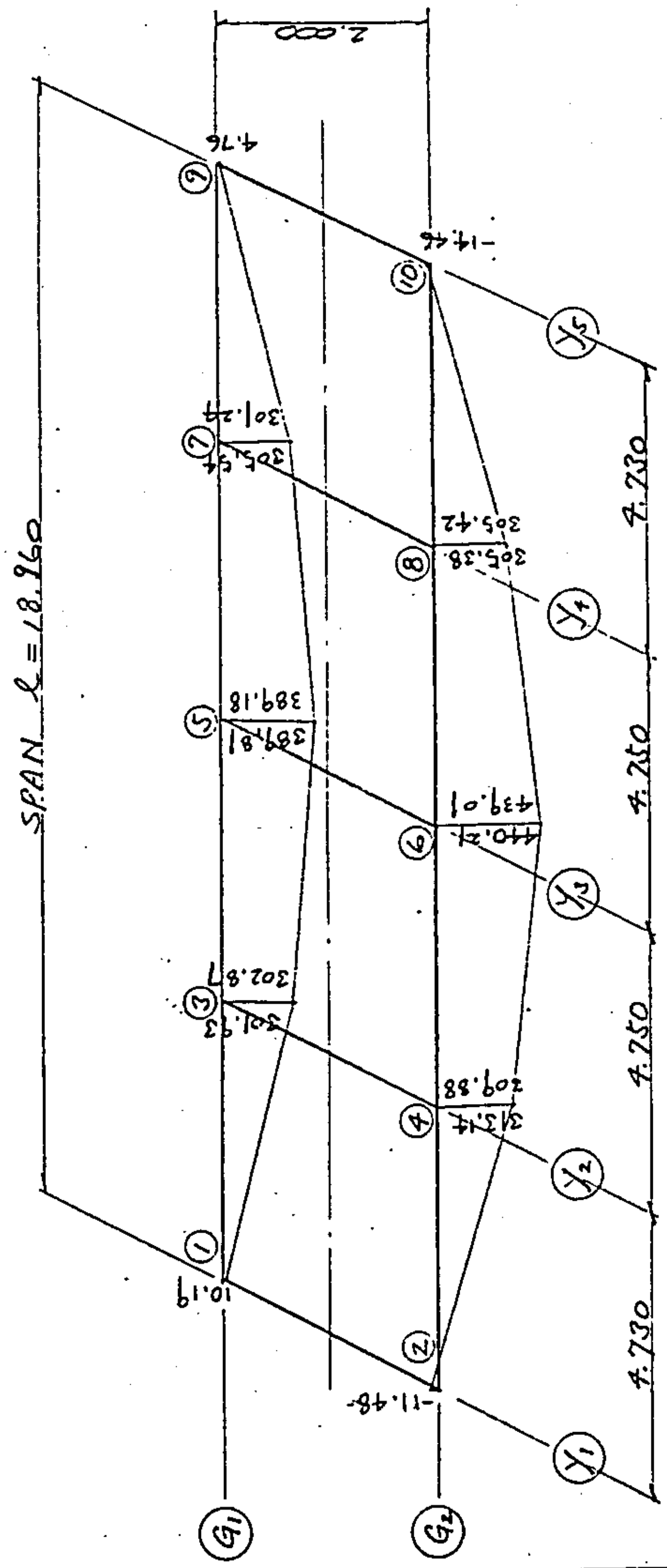
n : Number of intermediate Cross beam = 3

M_{d0} = 11.130

§3. Stress caused by Static and Live load acting at the top of bridge slab

(Computer calculation with grid-system)

Bending moment diagram (Unit: t·m)



§4. Summary of bending moment calculations (at section of mid-span)

(Unit: t m)

Load / Main girder	(1) Own Wt. M.girder	(2) Concrete betw. girders	(3) Ballast Track	(4) Electric pole	(5)=Σ(1)~(4) D. load total	Live load (6) Mℓ	Live load Case	Total ((5) + (6))
G_1	130.645	11.130	153.873	-6.073	289.575	242.010	7	531.585
G_2	〃	〃	159.624	38.656	340.055	241.933	7	581.988

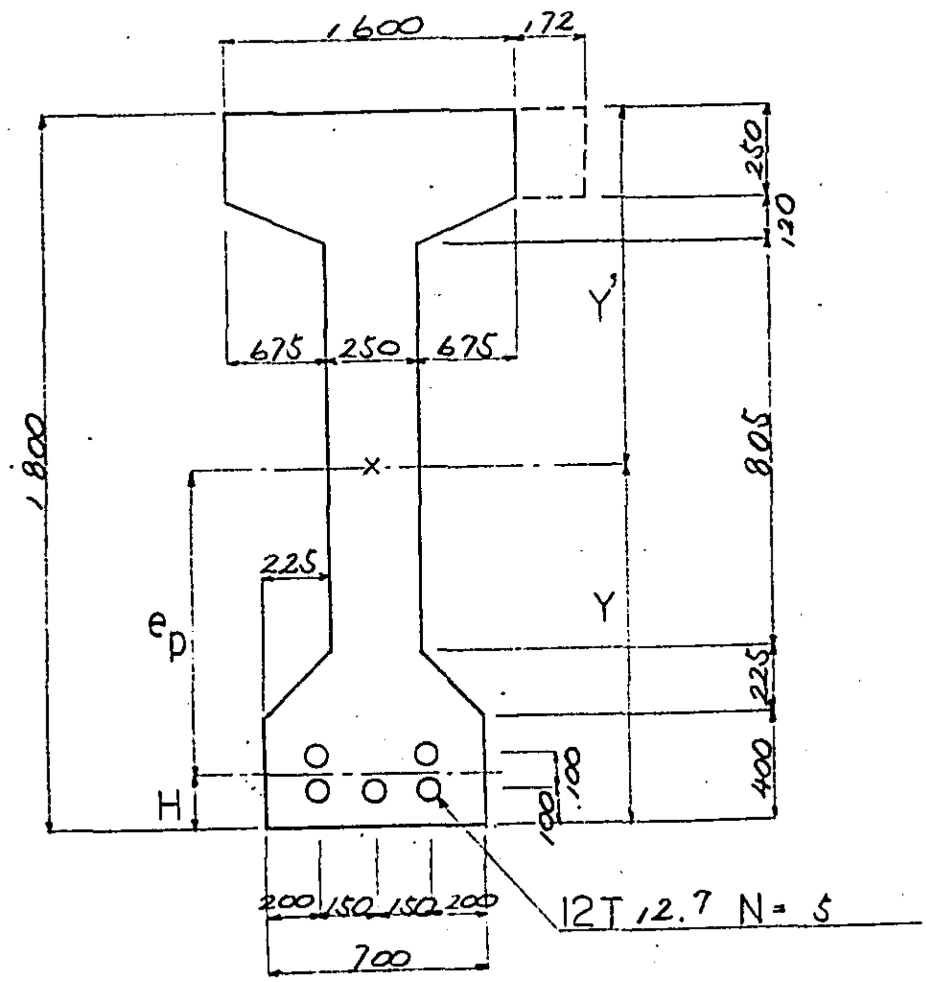
Developed the calculations in the preceding paragraphs, it became known that Maximum bending moment is exerted on Main girder.

Hence, further design calculations for Main girders will be represented by G_2 girder.

Chapter 5. Main girder design

§1. Basis for the design calculations

1. Configuration and Dimensions of the girder section of mid span



A : Cross sectional area (cm^2)

I : Moment of inertia (cm^4)

Z : Section modulus (cm^3)

r : Radius of gyration (cm)

ep: Location of cables (cm)

N : Number of cables

6pt: Tensile stress immediate after the practice of pre-stressing (kg/mm^2)

Pt: total tensile stressimmediate after the practice of pre-stressing

n : Ratio of Young's modulus between Modulus of P.C. cables and that of concrete

ψ : Coefficient of creep

ε_s: Drying contraction rate of conerete

η : Effective factor

2. Summary of sectional values (mid span)

(1) Gross cross section

- A_c = 10 991.3 cm^2
- I_c = 43.174 x 10^6 cm^4
- Y_c = 104.8 cm
- Y_c' = 75.2 cm
- $Z_c = I_c/Y_c$ = 4.118 x 10^5 cm^3
- $Z_c' = I_c/Y_c'$ = 5.744 x 10^5 cm^3
- $\gamma_c^2 = I_c/A_c$ = 3.928 x 10^3 cm^2
- $e_{pc} = Y_c - H$ = 90.8 cm

(2) Net cross section

- A_0 = 10 825.4 cm^2
- I_0 = 41.781 x 10^6 cm^4
- Y_0 = 106.2 cm
- Y_0' = 73.8 cm
- $Z_0 = I_0/Y_0$ = 3.934 x 10^5 cm^3
- $Z_0' = I_0/Y_0'$ = 5.661 x 10^5 cm^3
- $\gamma_0^2 = I_0/A_0$ = 3.860 x 10^3 cm^2
- $e_{p0} = Y_0 - H$ = 92.2 cm
- $Z_{0g} = I_0/e_{p0}$ = 4.532 x 10^5 cm^3

(3) Equivalent cross section

- $n = E_p/E_c = \frac{2.0 \times 10^6}{3.5 \times 10^5} = 5.71$
- $n \cdot A_{p1} = 5.71 \times 11.85 = 67.664\ cm^2$
- $A_{c1} = 11163.7\ cm^2$
- $I_{\ell 1} = 44.578 \times 10^6\ cm^4$
- $Y_{\ell 1} = \Sigma A_{e1} \cdot Y / \Sigma A_{e1} = 103.4\ cm$
- $Y_{e1}' = h - Y_{e1} = 76.6\ cm$
- $Z_{e1} = I_{e1}/Y_{e1} = 4.311 \times 10^5\ cm^3$
- $Z_{e1}' = I_{e1}/Y_{e1}' = 5.820 \times 10^5\ cm^3$
- $\gamma_{e1}^2 = I_{e1}/A_{e1} = 3.993 \times 10^3\ cm^2$
- $e_{pe1} = Y_{e1} - H = 89.4\ cm$
- $Z_{e1g} = I_{e1}/e_{pe1} = 4.986 \times 10^5\ cm^3$

(4) Equivalent cross section (including concrete between Girders)

- $A_{ez} = 11593.7\ cm^2$
- $I_{e2} = 46.302 \times 10^6\ cm^4$
- $Y_{e2} = \Sigma A_{e2} \cdot Y / \Sigma A_{e2} = 105.8\ cm$
- $Y_{e2}' = h - Y_{e2} = 74.2\ cm$
- $Z_{e2} = I_{e2}/Y_{e2} = 4.377 \times 10^5\ cm^3$
- $Z_{e2}' = I_{e2}/Y_{e2}' = 6.238 \times 10^5\ cm^3$
- $\gamma_{e2}^2 = I_{e2}/A_{e2} = 3.994 \times 10^3\ cm^2$
- $e_{pe2} = Y_{e2} - H = 91.8\ cm$
- $Z_{e2g} = I_{e2}/e_{pe2} = 5.045 \times 10^5\ cm^3$

§2. Summary of Bending stress calculations at mid span

Loads	Bending moment (x 10^5 kg·cm)	Section modulus (x 10^5 cm^3)		Bending stress (kg/cm^2)		
				At top fibre	At bottom fibre	At the gravity center of cables
Own weight of Main girder	M_{d0} = 130.645	Z_0'	5.661	23.1	——	——
		Z_0	3.934	——	- 33.2	——
		Z_{0g}	4.532	——	——	- 28.8
Concrete between girders	M_{d1} = 11.130	Z_{e1}'	5.820	1.9	——	——
		Z_{e1}	4.311	——	- 2.6	——
		Z_{e1g}	4.986	——	——	- 2.2
Static load (Ballast track Electric pole)	M_{d2} = 198.280	Z_{e2}'	6.238	31.8	——	——
		Z_{e2}	4.377	——	- 45.3	——
		Z_{e2g}	5.045	——	——	- 39.3
Dead load Total	ΣM_d = 340.055	—	————	56.8	- 81.1	- 70.3
Live load	$M\ell$ = 241.933	Z_{e2}'	6.238	38.8	——	——
		Z_{e2}	4.377	——	- 55.3	——
		Z_{e2g}	5.045	——	——	- 48.0
Total	ΣM = 581.988	—	————	95.6	- 136.4	- 118.3

§3. Summary of stress calculations caused by pre-stressing at mid span

States	Items			Unit	Values
Immediate after the practice of pre-stressing	σ_{pt}			kg/mm^2	88
	A_p			mm^2	1185
	N				5
	A_0			$x10^3\ cm^2$	10.825
	e_{p0}			m	-0.922
	Section modulus	Z_0'		$x10^5\ cm^3$	5.661
		Z_0		"	-3.934
		Z_{0g}		"	-4.532
	P_t			$x10^3$ kg	521.40
	Stress	Top fibre	σ_{ct}'	kg/cm^2	-36.7
		Bottom fibre	σ_{ct}	"	170.4
		Grav.Center of cables	σ_{0pt}	"	154.3
Effective pre-stress	n				5.71
	ψ				2.6
	γ				0.05
	$\Sigma\sigma_{dg}$			kg/cm^2	-70.3
	E_p			$x10^5 kg/cm^2$	20.0
	ε_s			$x10^{-5}$	20.00
	$\Delta\sigma_{p\gamma}$			kg/mm^2	-4.60
	$\Delta\sigma_{p\psi}$			"	-12.40
	σ_{pe}			"	75.00
	η				0.815
	Stress	Top fibre	σ_{ce}'	kg/cm^2	-29.7
		Bottom fibre	σ_{ce}	"	137.7
		Grav.Center of cables	σ_{cpe}	"	124.7

§4. Summary of combined Bending stress at mid span

Loads		Stresses (kg/cm^2) Top fibre	Stresses (kg/cm^2) Bottom fibre
(1) Own weight of Main girder		23.1	-33.2
(2) Concrete between girders		1.9	-2.6
(3) Static load		31.8	-45.3
(4) Dead load total ((1) + (2) + (3))		56.8	-81.1
(5) Live load		38.8	-55.3
(6) Total load ((4) + (5))		95.6	-136.4
(7) Immediate after the pre-stressing		-36.7	170.4
(8) Effective pre-stress		-29.7	137.7
Combined stress Immediate after the pre-stressing	(1) + (7)	-13.6	137.2
	Allowable value	> - 15.0	< 180.0
Total Dead loading	(4) + (8)	27.1	56.6
Design loading	(6) + (8)	65.9	1.3
	Allowable value	< 140.0	> -10.0

NO. 2 P.C. GIRDERS

SUPER-STRUCTURE

DESIGN CALCULATION

B01 - PC02 L = 40^{m}, H = 2.40^{m}

(Skew Left 60°)

CONTENTS

Chapter 1. Design criteria

1. Basis for design and loading conditions

- Kind of bridge: Pre-stressed concrete railroad bridge.
- Type of Bridge/Girders: Bridge superstructure is a simple beam, consisted of 4 main girders aligned in parallel.
  Girder is made of post-tensioned concrete of I type section.
- Length of girder: 39.960 m
- Span of main girder: 38.960 m
- Live load : KS-16
- Impact coefficient : i =0.322
- Crossing angle: { at younger change: 60°00'00" LEFT
  at elder change: 60°00'00" LEFT
- Railroad curve: STRAIGHT

2. Strength of materials for design

2-1. Concrete

(1) Concrete used for main girder

- Standard strength for design (28 day value) : σ_{CK} = 400 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 140 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 180 kg/cm^2
- Allowable tensile strength for bending calculation applied for,
  - design loading : σ_{cat} = -10 kg/cm^2
  - dead load : $\sigma_{cat'}$ = 0 kg/cm^2
  - immediate after the pre-stressing : $\sigma_{cat''}$ = -15 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_c=3.5×10^5 kg/cm^2

(2) Concrete used for lateral connection

- Standard strength for design (28 day value) : σ_{ck} = 300 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 110 kg/cm^2
- Allowable tensile strength for bending calculation : $\sigma_{ca'}$ = -8 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 140 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_c=3.0x10^{5}kg/cm^2

(3) Cantilever part of bridge slab, edge coaming and handrail concrete

- Standard strength for design (28 day value)
  : $\sigma_{ck} = 240$ kg/cm^2
- Allowable compressive strength for bending calculation : $\sigma_{ca} = 80$ kg/cm^2

2-2. Steel materials used for P.C. concrete

(1) P.C. Cable (SWPR-7A) 12T 15.2 mm

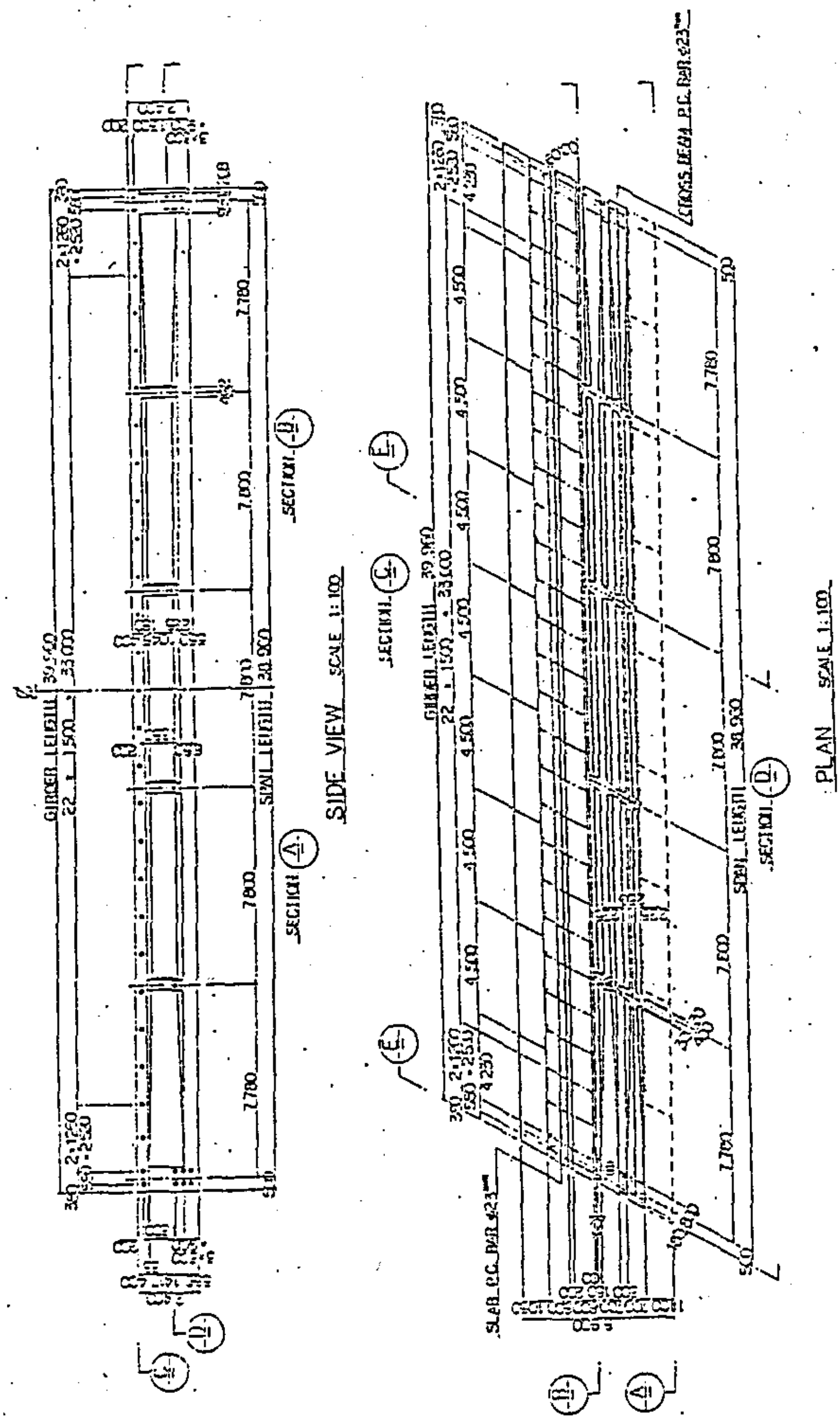
- Tensile strength : $\sigma_{pu} = 165$ kg/mm^2
- Yielding point : $\sigma_{py} = 140$ kg/mm^2
- Allowable tensile strength applied for,
  - design loading : $\sigma_{pa} = 99$ kg/mm^2
  - immediate after the pre-stressing: $\sigma_{pat} = 116$ kg/mm^2
  - during pre-stressing : $\sigma_{pai} = 126$ kg/mm^2
- Young's modulus of P.C. steel material
  : $E_p = 2.0 \times 10^6$ kg/cm^2

(2) P.C. steel bar (SBPR 95/110) ϕ 23 mm

- Tensile strength : $\sigma_{pu} = 110$ kg/mm^2
- Yielding point : $\sigma_{py} = 95$ kg/mm^2
- Allowable tensile strength applied for,
  - design loading : $\sigma_{pa} = 66$ kg/mm^2
  - immediate after the pre-stressing: $\sigma_{pat} = 77$ kg/mm^2
  - during pre-stressing : $\sigma_{pai} = 85.5$ kg/mm^2
- Young's modulus of P.C. steel material
  : $E_p = 2.0 \times 10^6$ kg/mm^2

2-3. Reinforcing Bar : SD 30

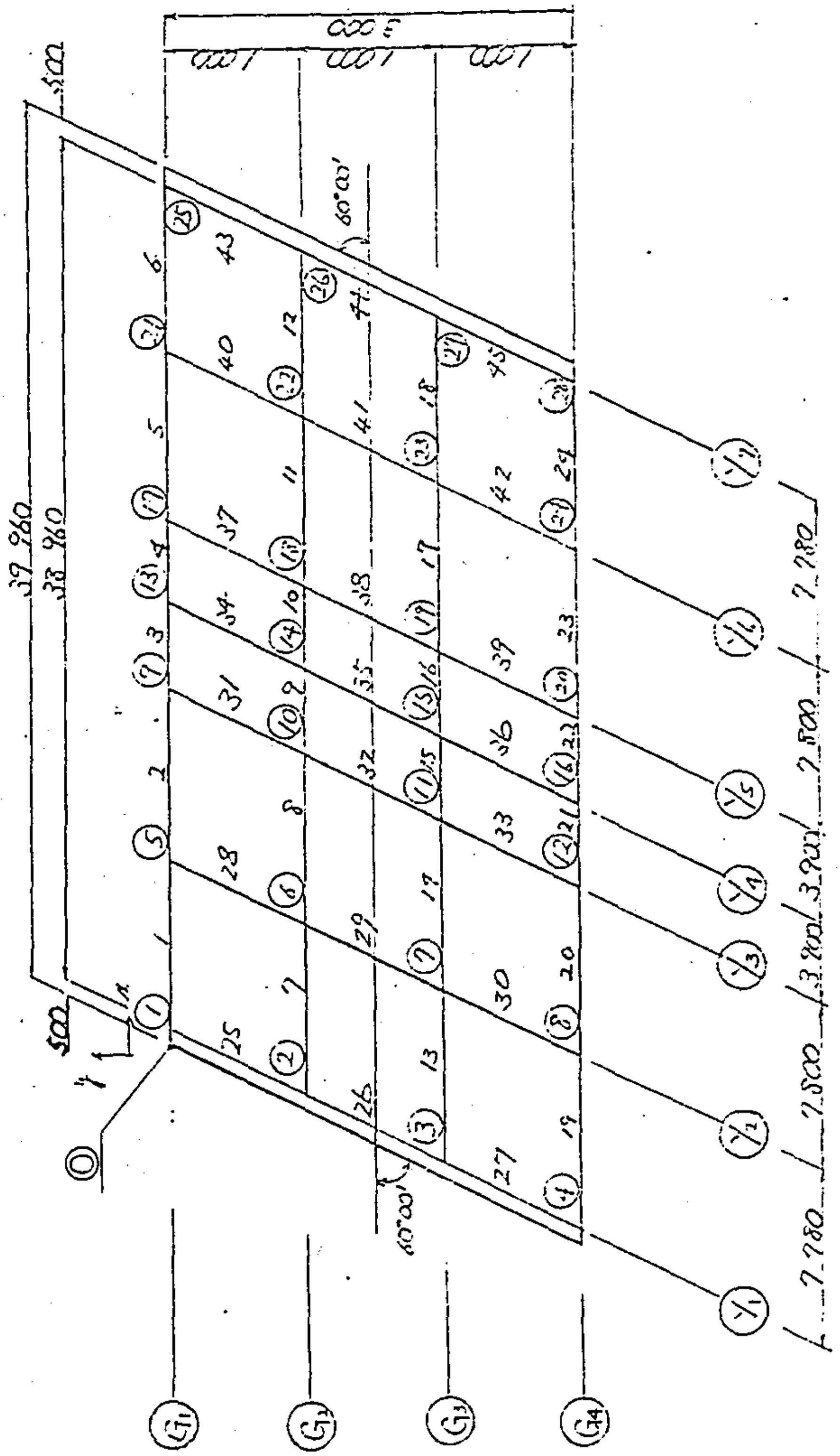
Chapter 2. Configuration and Dimensions of Bridge



Chapter 3. Input for Grid-system calculation

§1. Numbering & Coordinates of Skeleton Point

1. Member numbering & Skeleton point numbering



2. Coordinates calculations of Skeleton points

Assumed the Skeleton point (0) as fundamental point, coordinates of other skeleton points are calculated as listed below.

(Unit: m)

Skeleton point number	Skeleton point coordinates		Skeleton point number	Skeleton point coordinates	
	x	y		x	y
(1)	0.500	0	(15)	18.825	- 2.000
(2)	- 0.077	- 1.000	(16)	18.248	- 3.000
(3)	- 0.655	- 2.000	(17)	23.880	0
(4)	- 1.232	- 3.000	(18)	23.303	- 1.000
(5)	8.280	0	(19)	22.725	- 2.000
(6)	7.703	- 1.000	(20)	22.148	- 3.000
(7)	7.125	- 2.000	(21)	31.680	0
(8)	6.548	- 3.000	(22)	31.103	- 1.000
(9)	16.080	0	(23)	30.525	- 2.000
(10)	15.503	- 1.000	(24)	29.948	- 3.000
(11)	14.925	- 2.000	(25)	39.460	0
(12)	14.348	- 3.000	(26)	38.883	- 1.000
(13)	19.980	0	(27)	38.305	- 2.000
(14)	19.403	- 1.000	(28)	37.728	- 3.000

§2. Support conditions and Young's modulus of Concrete

1. Support conditions

Skeleton number	Rotation around		Z direction
	Y axis	X axis	
①	free	free	restricted
②	"	"	"
③	"	"	"
④	"	"	"
㉕	"	"	"
㉖	"	"	"
㉗	"	"	"
㉘	"	"	"

2. Young's modulus of concrete

(1) Young's modulus

Main girder : $E\ell = 3.50 \times 10^5$ kg/cm^2 = 35.0×10^5 t/m^2

Cross beam : $Et = 3.00 \times 10^5$ kg/cm^2 = 30.0×10^5 t/m^2

(2) Young's modulus corresponding to shearing

$G = 0.43E$

Main girder : $G\ell = 0.43 \times 35.0 \times 10^5 = 15.05 \times 10^5$ t/m^2

Cross beam : $Gt = 0.43 \times 30.0 \times 10^5 = 12.90 \times 10^5$ t/m^2

§3. Configuration and Dimensions of Main girder and Cross beam

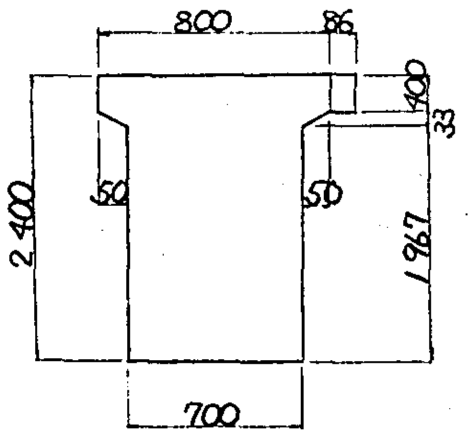
1. Configuration and Dimensions of Main girder

Dimension of concrete between Girders are as shown.

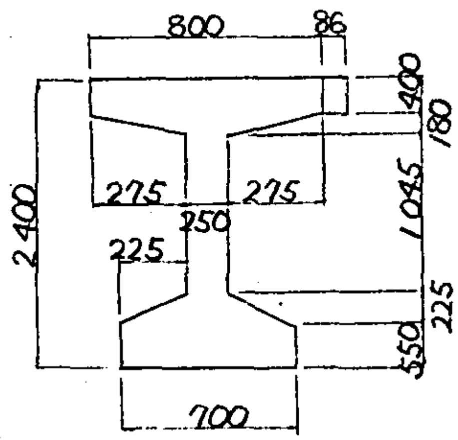
$$Et/E\ell = \frac{30.0 \times 10^5}{35.0 \times 10^5} = 0.857 \fallingdotseq 0.86$$

$$b = 0.200 \times 0.86 \times \frac{1}{2} = 0.086$$

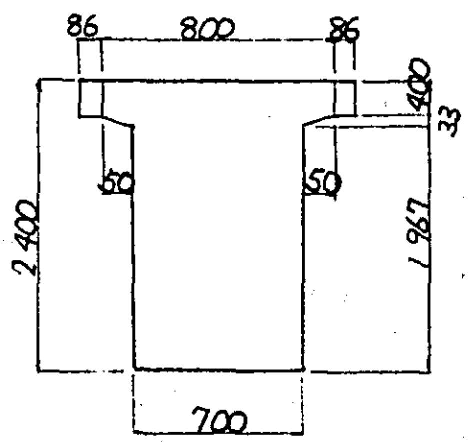
SECTION NUMBER ①: G1, G4 (Y1, Y7)



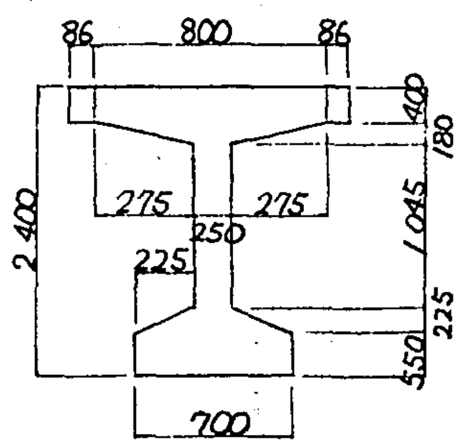
SECTION NUMBER ②: G1, G4 (Y2 ~ Y6)



SECTION NUMBER ③: G2 G3 (Y1, Y7)

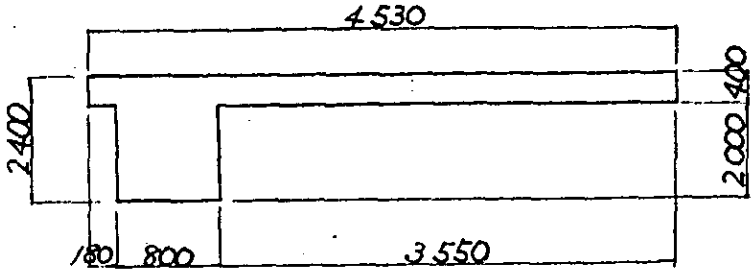


SECTION NUMBER ④: G2 G3 (Y2 ~ Y6)

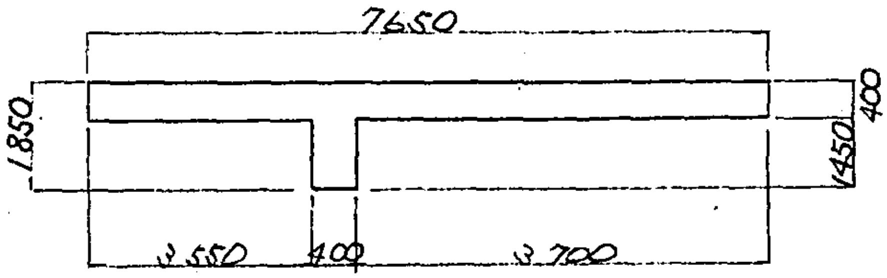


2. Configuration and Dimensions of Cross beam

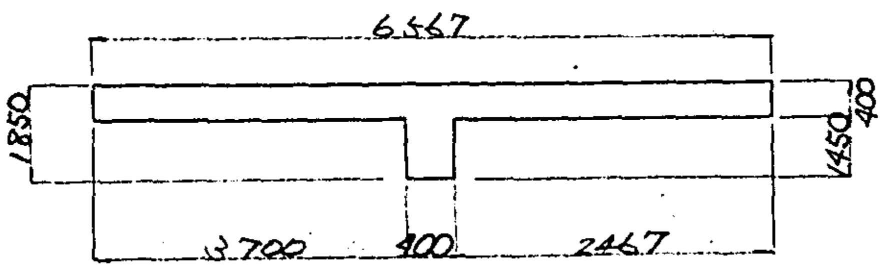
SECTION NUMBER ⑤ (y_1, y_7)



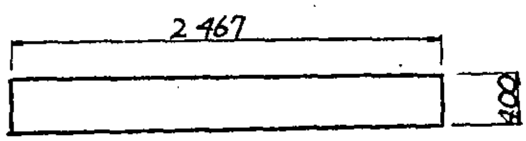
SECTION NUMBER ⑥ (y_2 y_6)



SECTION NUMBER ⑦ (y_3 y_5)



SECTION NUMBER ⑧ (y_4)



3. Applicable section number for various Girder, Beam/location

Girders		Location of number	Section number	Notes
Main girder	G_1, G_4	Location of Cross beam : y_1 , y_7	①	
		〃 : $y_2 \sim y_6$	②	
	G_2, G_3	〃 : y_1 , y_7	③	
		〃 : $y_2 \sim y_6$	④	
Cross beam		y_1 , y_7	⑤	
		y_2, y_6	⑥	
		y_3, y_5	⑦	
		y_4	⑧	

4. Moment of inertia of the section

(Unit: m^4)

Girders		Members	Moment of inertia (Average)
Main girder	G_1 G_4	1, 6, 19, 24	0.84328
		2, 3, 4, 5, 20, 21, 22, 23,	0.80693
	G_2 G_3	7, 12, 13, 18	0.87497
		8, 9, 10, 11, 14, 15, 16, 17	0.83903
Cross beam		25, 26, 27, 43, 44, 45	1.78107
		28, 29, 30, 40, 41, 42	0.55961
		31, 32, 33, 37, 38, 39	0.54315
		34, 35, 36	0.01316

§4. Loads and Loading conditions

1. Application of loads for calculation

(1) Application of static load

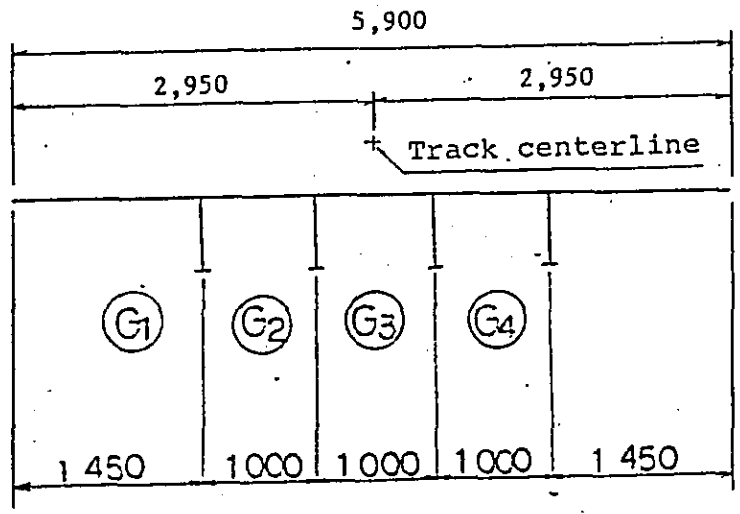
As the grid-system are carried out based on influence lines, the static load loading is applied in dual ways, one is a lined loading and the other is a uniformly distributed loading, to determine the loading length and width.

(2) Application of combined train loading

(a) Train load loading

Train load is assumed to be transmitted through sleepers downwards and distributed to the enlarged width within inclined lines with 53 deg. starting at both end points of sleeper bottom.

Distribution of loads through track is shown in the sketch drawing.



(b) Combined loading of train load

(i) Train load is supposed to distribute entire length of the span.

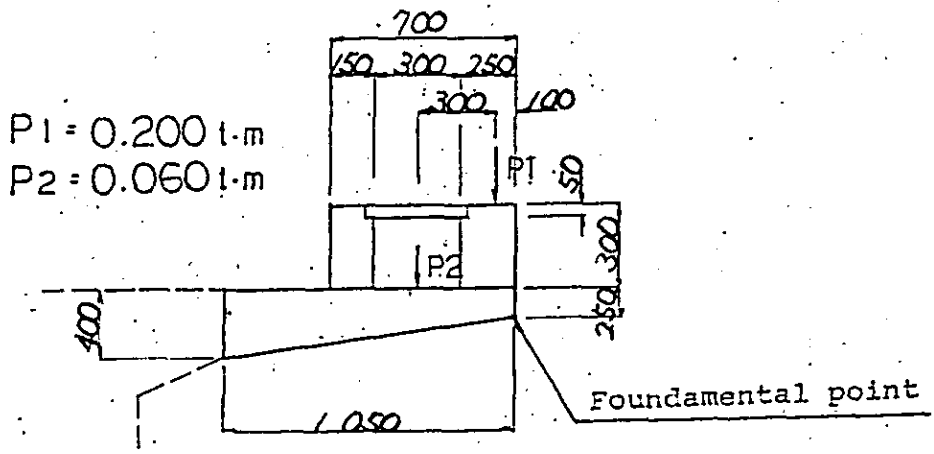
(ii) Train load is supposed to distribute limited to one side of span with 1/2 ℓ length.

Train load is applied combined the above (i) and (ii) loadings. Thus, further calculations are made for the sectional strength.

2. Dead load calculations of the own weight of structure

(1) Cantilever part of bridge slab, edge coaming and handrail concrete

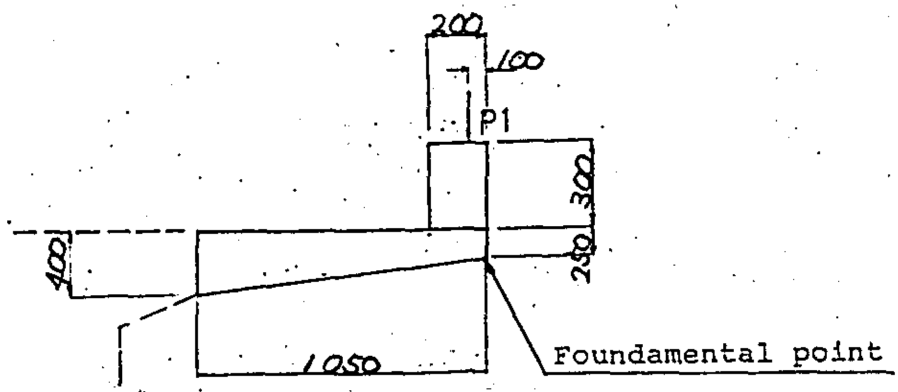
(a) G4 girder side



Load/Load acting point

Total dead load : ΣW (t/m) = 1.452
Total bending moment : $\Sigma W X$ (t-m/m) = 0.636
Acting point of resultant force : $X = \Sigma W X / \Sigma W$ (m) = 0.438

(b) G1 girder side

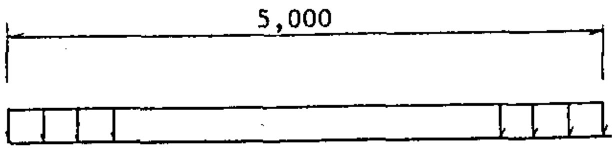


Load/Load acting point

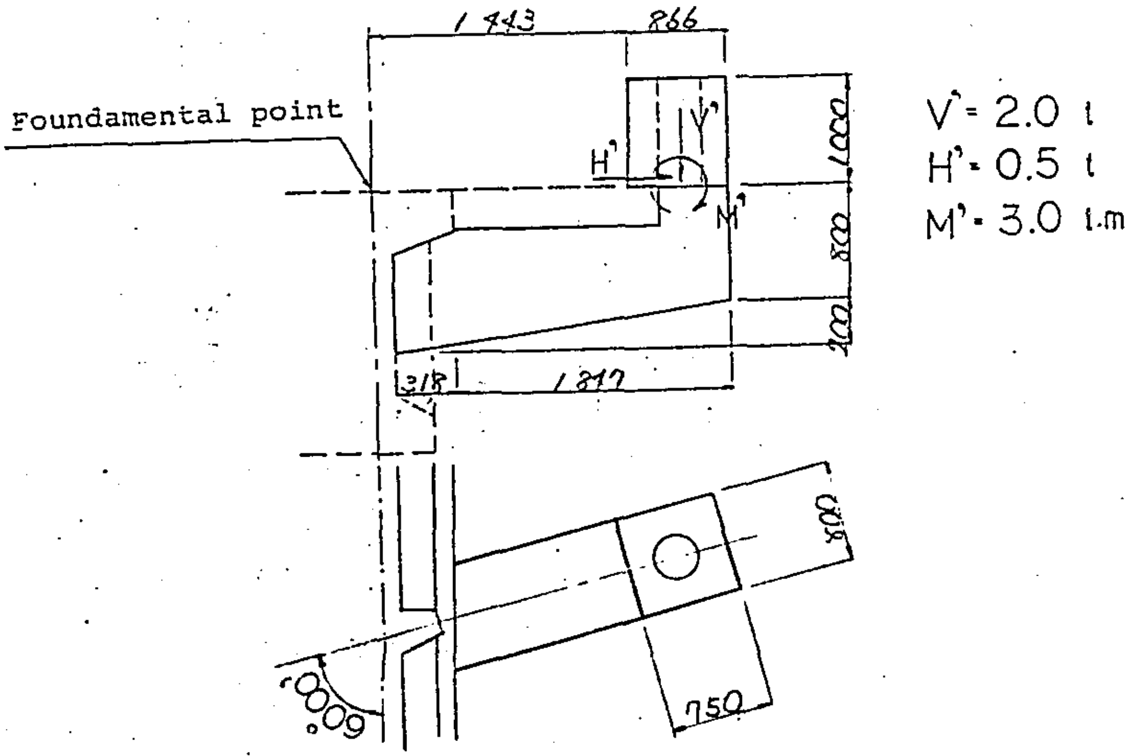
Total dead load : ΣW (t/m) = 1.203
Total bending moment : $\Sigma W X$ (t-m/m) = 0.517
Acting point of resultant force : $X = \Sigma W X / \Sigma W$ (m) = 0.430

(2) Graded Concrete

$Wp = 2.35 \times 0.07 = 0.165\ t/m^2$

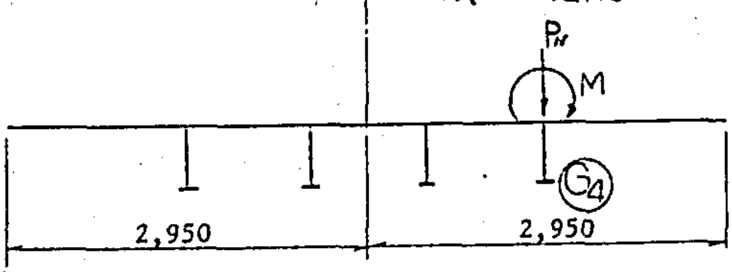


(3) Electric pole and its supporting beam



Load/Load acting point

Total dead load : ΣW (t/m) = 5.685 = P_H
Total bending moment : $\Sigma W X$ (t-m/m) = 9.480
$M = M' + \Sigma WX$ = 12.480



3. Dead load calculations of surcharge

(1) Surcharge load of ballast

Calculated as a uniformly distributed load.

$$W_B = 1.9\ t/m^3 \times (h_B - h_p) = 0.914\ t/m^2$$

(2) Surcharge load of track assembly

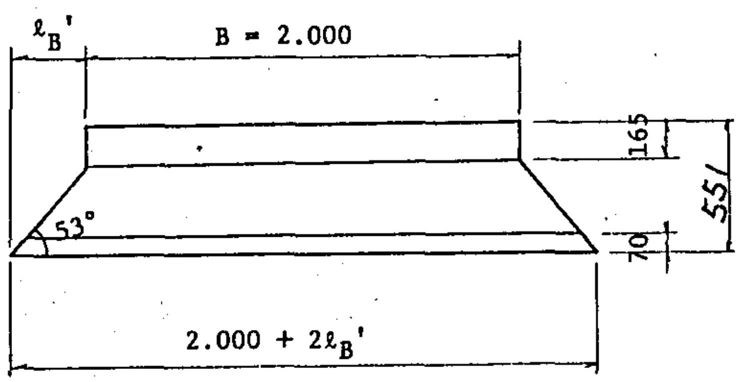
Load of track assembly is assumed to be distributed on the bridge slab with the width between two points on the slab, where lines drawn from the both ends of sleeper bottom with 53 deg. inclination towards outward-downward, crossing the slab surface.

- Load of track assembly : $\Sigma W_R = 0.450$ t/m
- Width of sleeper : $B = 2.000$ m
- Thickness of sleeper : $h_M = 0.165$ m
- Height between the girder top and the sleeper top : $h_B = 0.551$ m
- Average thickness of graded concrete for drainage : $h_p = 0.070$ m

$$2\ell_B' = 2(h_B - h_M) \cdot \text{Cot } 53° = 0.582\ m$$

- Load distribution width:

$$\ell_B = B + 2\ell_B' = 2.582\ m$$



Uniformly distributed load:

$$W_R = \frac{\Sigma W_R}{\ell_B} = 0.174\ t/m^2$$

4. Uniformly distributed load, equivalent to the train loading

Bending moment calculation:

For the bending moment calculation, the equivalent uniformly distributed load at the 1/4 span point will be employed and confirmed as calculated below.

$$M\ell = \{M\ell_{min} + \frac{\ell - \ell_{min}}{\ell_{max} - \ell_{min}} \cdot (M\ell_{max} - M\ell_{min})\}\ \gamma \cdot \beta \times \frac{1}{18}$$

where, $\ell = 38.960$, $\ell_{max} = 39.000$, $\ell_{min} = 38.000$

$\gamma = 2$ $\quad\beta = 16$

$M\ell(\ell/4)_{min} = 533.7\,tm$, $M\ell(\ell/4)_{max} = 559.7\,tm$

$M\ell(\ell/2)_{min} = 696.0\,tm$, $M\ell(\ell/2)_{max} = 732.2\,tm$

$$M\ell(\ell/4) = \{533.7 + \frac{0.96}{1.00} \times (559.7 - 533.7)\}\ 2 \times 16 \times \frac{1}{18}$$
$$= 993.173$$

$$M\ell(\ell/2) = \{696.0 + \frac{0.96}{1.00} \times (732.2 - 696.0)\}\ 2 \times 16 \times \frac{1}{18}$$
$$= 1299.115$$

Equivalent uniformly distributed load at $\ell/4$ span point, which is Wm, will be

$$W_m = \frac{32}{3} \times \frac{M\ell(\ell/4)}{\ell^2} = 6.979$$

Employed the above Wm value and applied for the bending moment calculation at $\ell/2$ point.

$$M'_{\ell/2} = W_m \cdot \frac{\ell^2}{8} = 1324.162$$
$$> M\ell_{(\ell/2)} = 1299.115$$

The result is larger than the value of $M_{\ell/2}$.

$Wm = 6.979$ t/m

Train loading for bending moment:

$W\ell = Wm(1 + i) = 9.226$ t/m

Train loading for bending moment: calculation

Train loading is distributed expanded with 53 deg. inclination from the both ends of sleeper bottom.

Uniformly distributed load: $W\ell$

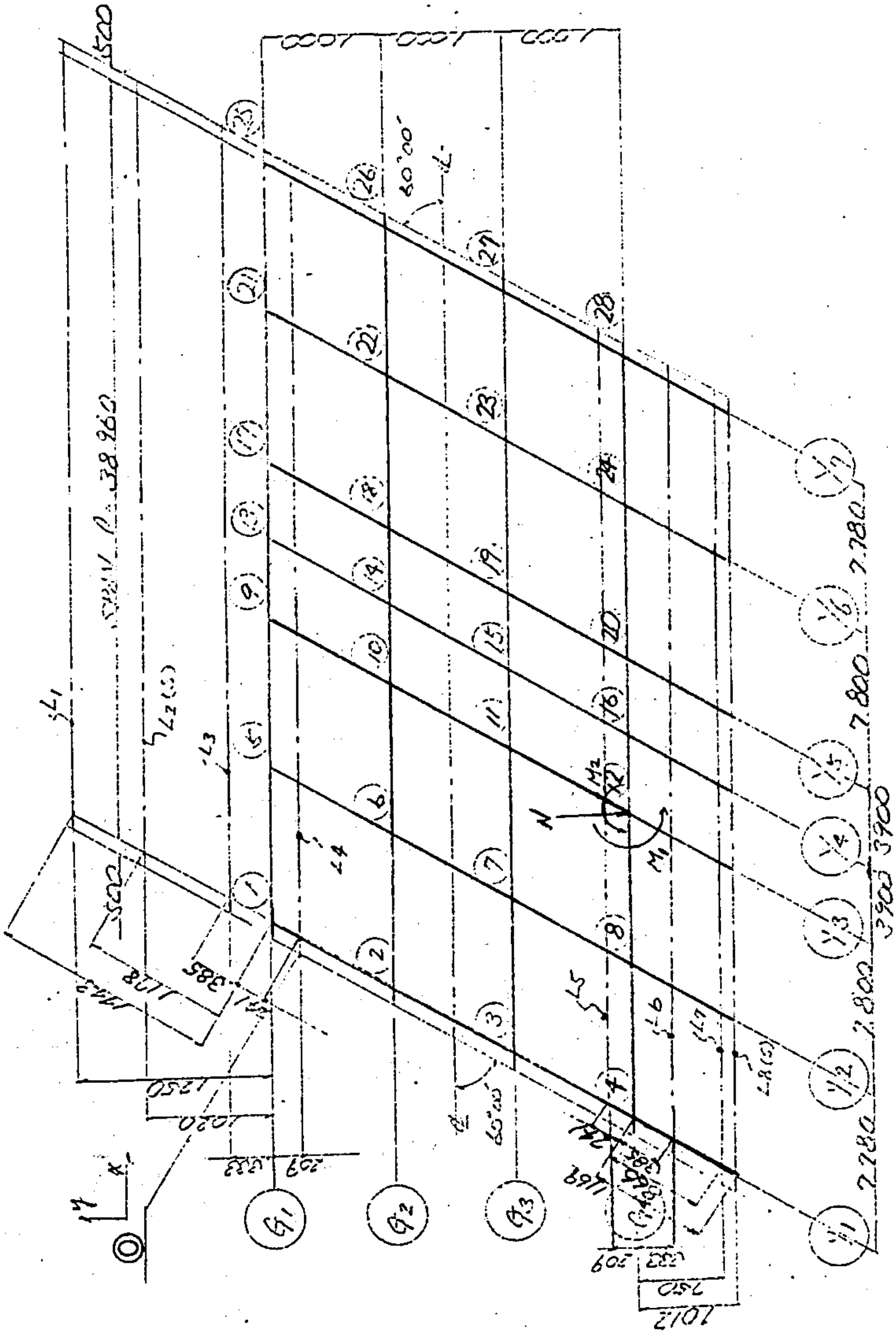
$$W\ell = \frac{Wm\ (1 + i)}{\ell_B} = 3.573\ t/m^2$$

5. Load/Loading point of various loadings

(1) Summary of loads

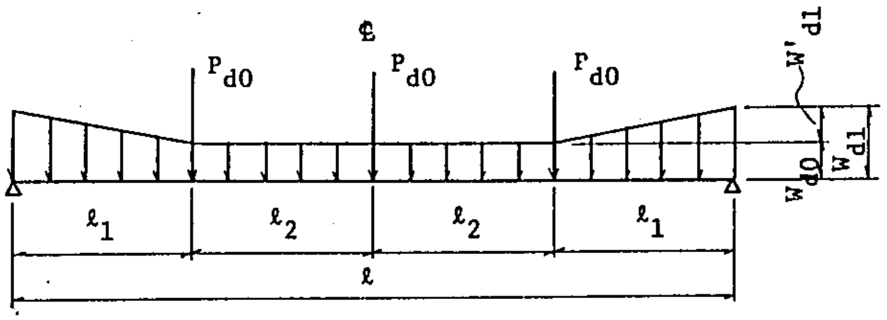
Load	Cases	Title	Load distribution area: Width	Load distribution area: Length	Intensity of load	Category of load
Dead load of surcharge and structure	Case 1	VANJO $-D_1$	L_8	$y_1 \sim y_7$	1.452 t/m	Canti. slab, handrail conc., etc.
			L_2	$y_1 \sim y_7$	1.203 t/m	
			$L_1 \sim L_7$	$y_1 \sim y_7$	0.165 t/m²	Graded conc.
			$L_3 \sim L_6$	$y_1 \sim y_7$	0.914 t/m²	Ballast
			$L_4 \sim L_5$	$y_1 \sim y_7$	0.174 t/m²	Track assembly
Electric pole, etc.	Case 2	DENCHU $-D_1$	G_4	y_3	N = 5.685 t	Electric pole and its supporting beam
					M_1 = 10.808 tm	
					M_2 = 6.240 tm	
Train load	Case 3	L_1	$L_4 \sim L_5$	$y_1 \sim y_7$	3.573 t/m²	Live load intensity applied for bending moment calculation
	Case 4	L_2	$L_4 \sim L_5$	$y_1 \sim y_4$	3.573 t/m²	
	Case 5	L_3	$L_4 \sim L_5$	$y_4 \sim y_7$	3.573 t/m²	

(2) Loading conditions



Chapter 4. Design calculations of Main girder cross section

§1. Bending moment caused by own weight of Main girder



Bending moment (at center of span)

$$M_{d0} = \frac{1}{8}\cdot W_{d0}\cdot \ell^2 + \frac{1}{6}\cdot W_{d1}'\cdot \ell_1{}^2 + P_{d0}\cdot\{\frac{n}{2}(\ell_1 + \ell_2) - \ell_2\}$$

W_{d0} : Per meter weight of the section at the center (t/m) = 2.919

W_{d1} : Per meter weight of the section at the point of support (t/m) = 4.304

$W_{d1}' = W_{d1} - W_{d0}$ = 1.385

P_{d0} : Weight of intermediate diaphragm (t) = 0.688

ℓ : Span (m) = 38.960

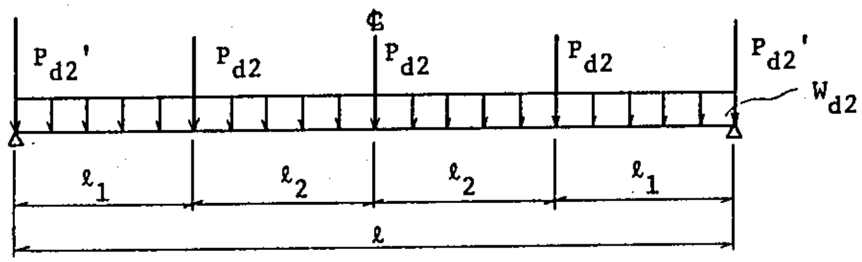
ℓ_1 : Length of the widened part of web (m) = 7.780

ℓ_2 : Location of diaphragm (m) = 7.800

n : Number of intermediate diaphragms

M_{d0} = 586.566 tm

§2. Stress calculations of Cross beam cross section



- Bending moment (at center of span)

$$M_{d0} = \frac{1}{8} \cdot W_{d2} \cdot \ell^2 + P_{d2} \cdot \{ \frac{n}{2} \cdot (\ell_1 + \ell_2) - \ell_2 \}$$

where,

W_{d2} : Own weight of bridge slab between girders (t/m) = 0.173

P_{d2} : Own weight of intermediate Cross beam (t) = 0.375

P_{d2}': Own weight of end Cross beam (t) = 1.035

ℓ : Span (m) = 38.960

ℓ_1, ℓ_2: Location of Cross beam (m) { ℓ_1 = 7.780, ℓ_2 = 7.800

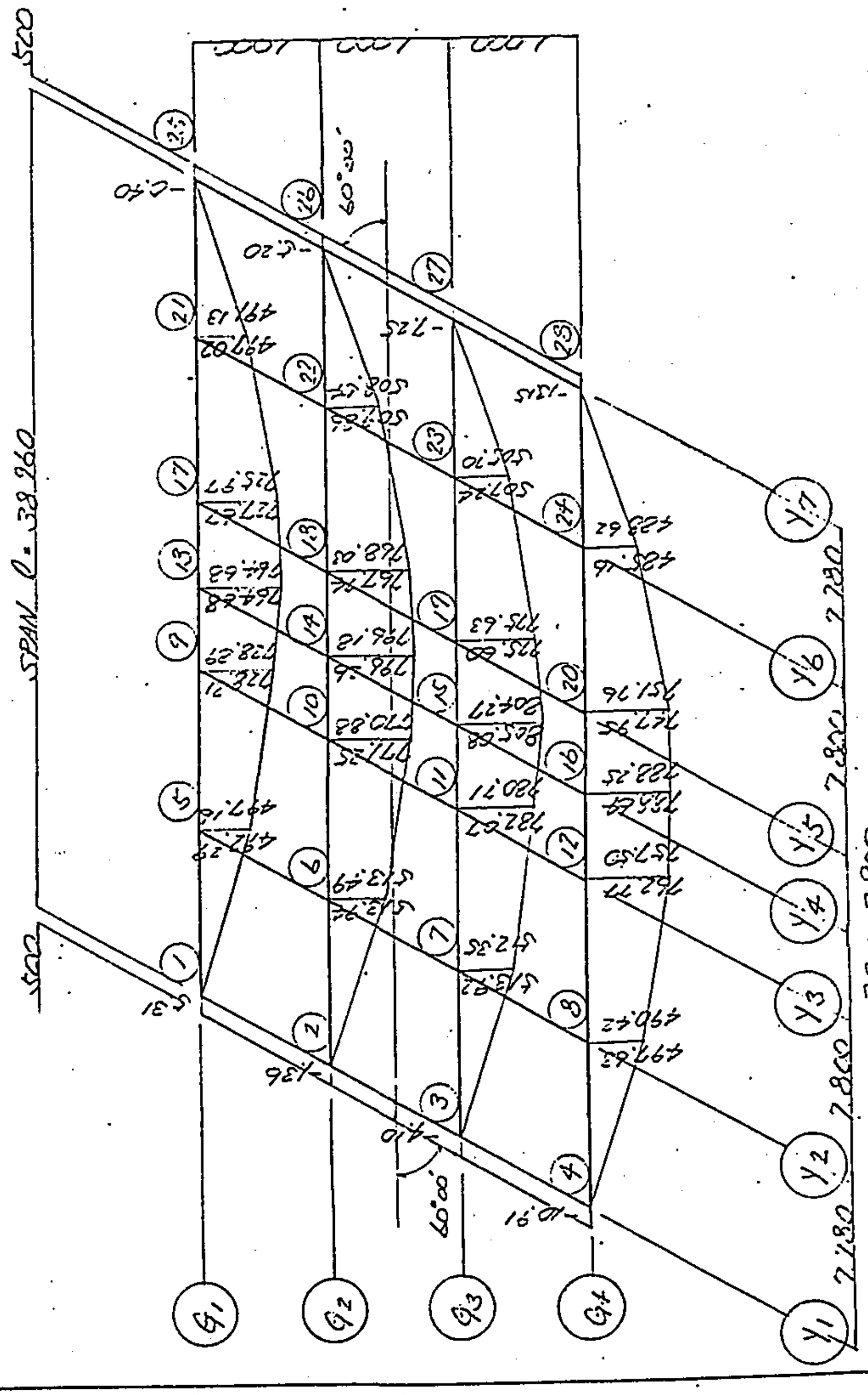
n : Number of intermediate Cross beam = 3

M_{d0} = 41.583 tm

§3. Stress caused by Static and Live load acting at the top of bridge slab

(Computer calculation with grid-system)

Bending moment diagram (Unit: t·m)



§4. Summary of bending moment calculations (at section of mid-span)

(Unit: t m)

Load / Main girder	(1) Own Wt. M.girder	(2) Concrete betw. girders	(3) Ballast Track	(4) Electric pole	(5)=Σ(1)~(4) D. load total	Live load (6) Mℓ	Live load Case	Total ((5) + (6))
G_1	586.566	41.583	340.245	2.543	970.937	421.892	7	1392.829
G_2	〃	〃	340.718	7.940	976.807	447.604	7	1424.411
G_3	〃	〃	343.817	14.065	986.031	447.201	7	1433.232
G_4	〃	〃	348.104	18.638	994.891	421.892	7	1416.783

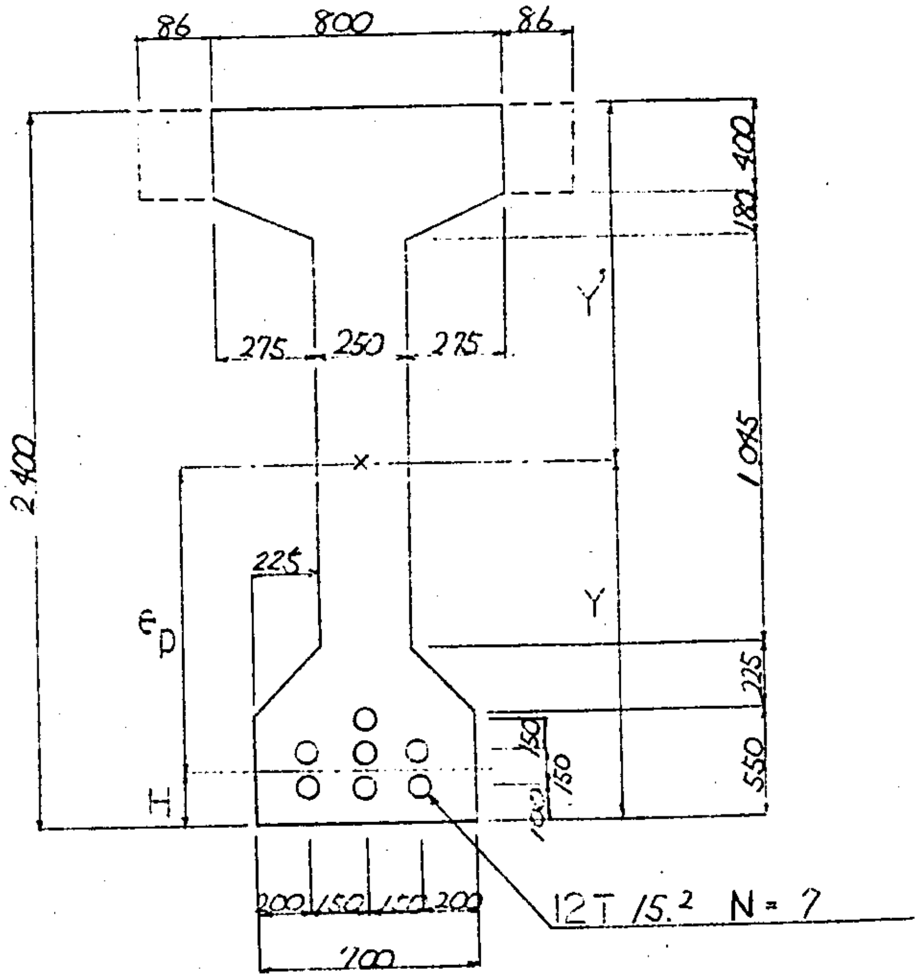
Developed the calculations in the preceding paragraphs, it became known that Maximum bending moment is exerted on Main girder.

Hence, further design calculations for Main girders will be represented by G_3 girder.

Chapter 5. Main girder design

§1. Basis for the design calculations

1. Configuration and Dimensions of the girder section of mid span



A : Cross sectional area (cm^2)

I : Moment of inertia (cm^4)

Z : Section modulus (cm^3)

r : Radius of gyration (cm)

ep: Location of cables (cm)

N : Number of cables

6pt: Tensile stress immediate after the practice of pre-stressing (kg/mm^2)

Pt: total tensile stressimmediate after the practice of pre-stressing

n : Ratio of Young's modulus between Modulus of P.C. cables and that of concrete

ψ : Coefficient of creep

ε_s: Drying contraction rate of conerete

η : Effective factor

2. Summary of sectional values (mid span)

(1) Gross cross section

- $A_c = 11676.30$ cm^2
- $I_c = 77.294 \times 10^6$ cm^4
- $Y_c = 119.80$ cm
- $Y_c' = 120.20$ cm
- $Z_c = I_c/Y_c = 6.450 \times 10^5$ cm^3
- $Z_c' = I_c/Y_c' = 6.432 \times 10^5$ cm^3
- $\gamma_c^2 = I_c/A_c = 6.620 \times 10^3$ cm^2
- $e_{pc} = Y_c - H = 94.8$ cm

(2) Net cross section

- $A_0 = 11367.04$ cm^2
- $I_0 = 74.141 \times 10^6$ cm^4
- $Y_0 = 122.50$ cm
- $Y_0' = 117.50$ cm
- $Z_0 = I_0/Y_0 = 6.052 \times 10^5$ cm^3
- $Z_0' = I_0/Y_0' = 6.310 \times 10^5$ cm^3
- $\gamma_0^2 = I_0/A_0 = 6.523 \times 10^3$ cm^2
- $e_{p0} = Y_0 - H = 101.8$ cm
- $Z_{0g} = I_0/e_{p0} = 7.283 \times 10^5$ cm^3

(3) Equivalent cross section

- $n = E_p/E_c = \frac{2.0 \times 10^6}{3.5 \times 10^5} = 5.71$
- $n \cdot A_{pl} = 5.71 \times 16.64 = 95.01$ cm²
- $A_{el} = 12\,032.13$ cm²
- $I_{\ell 1} = 80.724 \times 10^6$ cm⁴
- $Y_{\ell 1} = \Sigma A_{el} \cdot Y / \Sigma A_{el} = 116.9$ cm
- $Y_{el}' = h - Y_{el} = 123.1$ cm
- $Z_{el} = I_{el}/Y_{el} = 6.905 \times 10^5$ cm³
- $Z_{el}' = I_{el}/Y_{el}' = 6.558 \times 10^5$ cm³
- $\gamma_{el}^2 = I_{el}/A_{el} = 6.709 \times 10^3$ cm²
- $e_{pel} = Y_{el} - H = 96.2$ cm
- $Z_{elg} = I_{el}/e_{pel} = 8.391 \times 10^5$ cm³

(4) Equivalent cross section (including concrete between Girders)

- $A_{ez} = 12\,720.13$ cm²
- $I_{e2} = 87.734 \times 10^6$ cm⁴
- $Y_{e2} = \Sigma A_{e2} \cdot Y / \Sigma A_{e2} = 122.5$ cm
- $Y_{e2}' = h - Y_{e2} = 117.5$ cm
- $Z_{e2} = I_{e2}/Y_{e2} = 7.162 \times 10^5$ cm³
- $Z_{e2}' = I_{e2}/Y_{e2}' = 7.467 \times 10^5$ cm³
- $\gamma_{e2}^2 = I_{e2}/A_{e2} = 6.897 \times 10^3$ cm²
- $e_{pe2} = Y_{e2} - H = 101.8$ cm
- $Z_{e2g} = I_{e2}/e_{pe2} = 8.618 \times 10^5$ cm³

§2. Summary of Bending stress calculations at mid span

Loads	Bending moment (x 10^5 kg·cm)	Section modulus (x 10^5 cm^3)		Bending stress (kg/cm^2) At top fibre	At bottom fibre	At the gravity center of cables
Own weight of Main girder	M_{d0} = 586.57	Z_0'	6.310	93.0	—	—
		Z_0	- 6.052	—	- 96.9	—
		Z_{0g}	- 7.283	—	—	- 80.5
Concrete between girders	M_{d1} = 41.58	Z_{e1}'	6.558	6.3	—	—
		Z_{e1}	- 6.905	—	- 6.0	—
		Z_{e1g}	- 8.391	—	—	- 5.0
Static load (Ballast track Electric pole)	M_{d2} = 357.88	Z_{e2}'	7.467	47.9	—	—
		Z_{e2}	- 7.162	—	- 50.0	—
		Z_{e2g}	- 8.618	—	—	- 41.5
Dead load Total	ΣM_d = 986.03	—	—	147.2	-152.9	- 127.0
Live load	M_ℓ = 447.20	Z_{e2}'	7.467	59.9	—	—
		Z_{e2}	- 7.162	—	- 62.4	—
		Z_{e2g}	- 8.618	—	—	- 51.9
Total	ΣM = 1433.23	—	—	207.1	- 215.3	- 178.9

§3. Summary of stress calculations caused by pre-stressing at mid span

States	Items			Unit	Values
Immediate after the practice of pre-stressing	σ_{pt}			kg/mm^2	90
	A_p			mm^2	1664
	N				7
	A_0			$x10^3\ cm^2$	11.367
	e_{p0}			m	- 1.018
	Section modulus	Z_0'		$x10^5\ cm^3$	6.310
		Z_0		"	- 6.052
		Z_{0g}		"	- 7.283
	P_t			$x10^3$ kg	1048.320
	Stress	Top fibre	σ_{ct}'	kg/cm^2	- 76.9
		Bottom fibre	σ_{ct}	"	268.6
		Grav. Center of cables	σ_{0pt}	"	238.8
Effective pre-stress	n				5.71
	ψ				2.6
	γ				0.05
	$\Sigma\sigma dg$			kg/cm^2	- 127.0
	E_p			$x10^5 kg/cm^2$	20
	ε_s			$x10^{-5}$	20
	$\Delta\sigma_{p\gamma}$			kg/mm^2	4.50
	$\Delta\sigma_{p\psi}$			"	13.96
	σ_{Pe}			"	71.54
	η				0.795
	Stress	Top fibre	σ_{ce}'	kg/cm^2	- 61.1
		Bottom fibre	σ_{ce}	"	213.5
		Grav. Center of cables	σ_{cpe}	"	189.8

§4. Summary of combined Bending stress at mid span

Loads		Stresses (kg/cm^2) Top fibre	Bottom fibre
(1) Own weight of Main girder		93.0	- 96.9
(2) Concrete between girders		6.3	- 6.0
(3) Static load		47.9	- 50.0
(4) Dead load total ((1) + (2) + (3))		147.2	- 152.9
(5) Live load		59.9	- 62.4
(6) Total load ((4) + (5))		207.1	- 215.3
(7) Immediate after the pre-stressing		- 76.9	268.6
(8) Effective pre-stress		- 61.1	213.5
Combined stress Immediate after the pre-stressing	(1) + (7)	16.1	171.7
	Allowable value	> - 15.0	< 180.0
Total Dead loading	(4) + (8)	86.1	60.6
Design loading	(6) + (8)	146.0	- 1.8
	Allowable value	≒. 140.0	> -10.0

NO. 3 P.C. GIRDERS

SUPER-STRUCTURE

DESIGN CALCULATION

B02 - PC04 $L = 25^m, H = 1.40^m$

(Right Angle)

CONTENTS

Chapter 1. Design criteria

1. Basis for design and loading conditions

- Kind of bridge: Pre-stressed concrete railroad bridge.
- Type of Bridge/Girders: Bridge superstructure is a simple beam, consisted of 4 main girders aligned in parallel.
  Girder is made of post-tensioned concrete of I type section.
- Length of girder: 24.960 m
- Span of main girder: 24 200 m
- Live load : KS-16
- Impact coefficient : i = 0.357
- Crossing angle: { at younger change: 90°00′00″
  at elder change: 90°00′00″
- Railroad curve: STRAIGHT

2. Strength of materials for design

2-1. Concrete

(1) Concrete used for main girder

- Standard strength for design (28 day value)
  : σ_{CK} = 400 kg/cm^2
- Allowable compressive strength for bending calculation
  : σ_{ca} = 140 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 180 kg/cm^2
- Allowable tensile strength for bending calculation applied for,
  - design loading : σ_{cat} = -10 kg/cm^2
  - dead load : $\sigma_{cat'}$ = 0 kg/cm^2
  - immediate after the pre-stressing: $\sigma_{cat''}$= -15 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_c=3.5×10^5 kg/cm^2

(2) Concrete used for lateral connection

- Standard strength for design (28 day value)
  : σ_{ck} = 300 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 110 kg/cm^2
- Allowable tensile strength for bending calculation : $\sigma_{ca'}$ = -8 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 140 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_c=3.0x10^{5}kg/cm^2

(3) Cantilever part of bridge slab, edge coaming and handrail concrete

- Standard strength for design (28 day value) : σ_{ck} = 240 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 80 kg/cm^2

2-2. Steel materials used for P.C. concrete

(1) P.C. Cable (SWPR-7B) 12T 12.7 mm

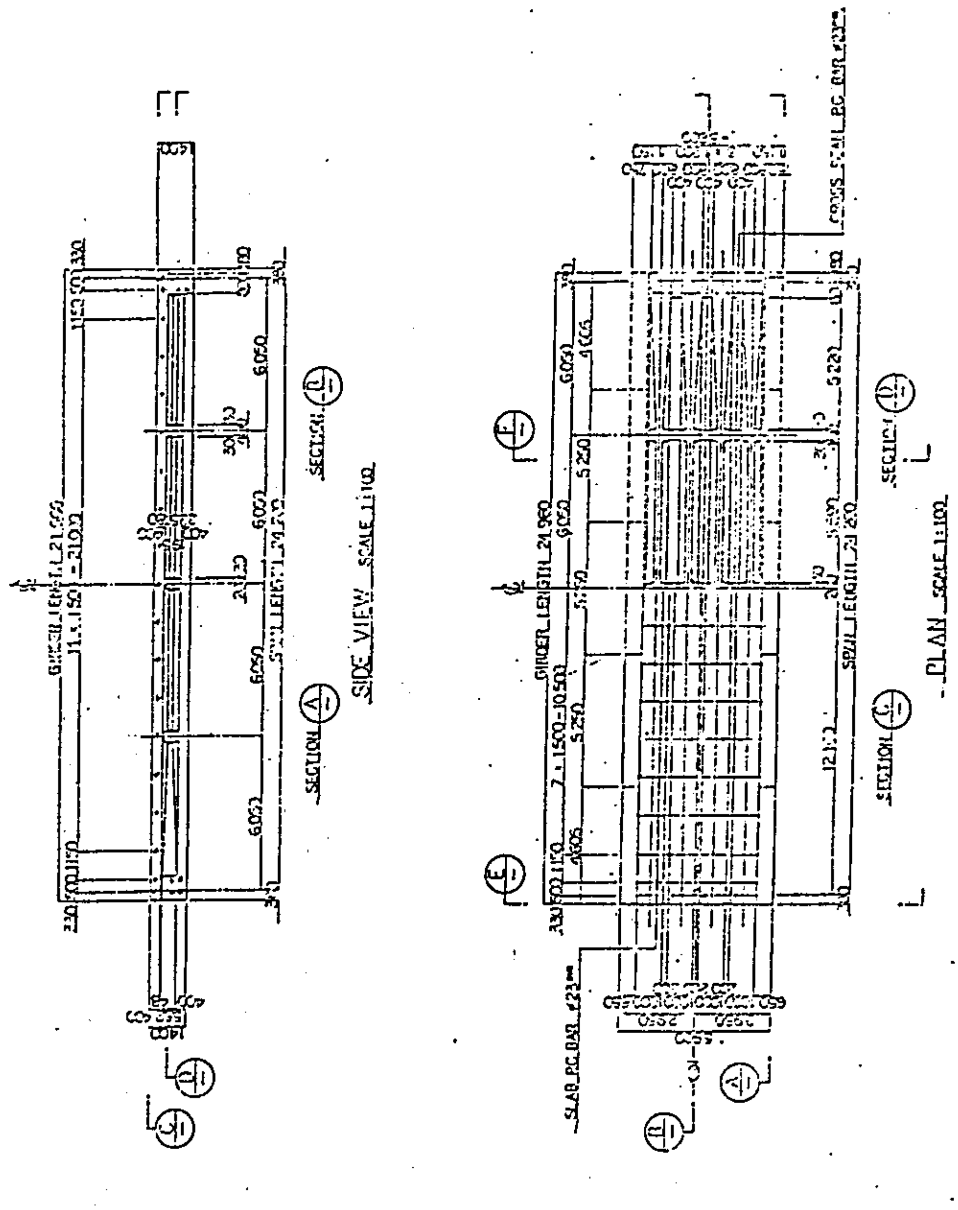
- Tensile strength : σ_{pu} = 190 kg/mm^2
- Yielding point : σ_{py} = 160 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 114 kg/mm^2
  - immediate after the pre-stressing: σ_{pat}= 133 kg/mm^2
  - during pre-stressing : σ_{pai}= 145 kg/mm^2
- Young's modulus of P.C. steel material : E_p=2.0×10^{6}kg/cm^2

(2) P.C. steel bar (SBPR 95/110) ϕ 23 mm

- Tensile strength : σ_{pu} = 110 kg/mm^2
- Yielding point : σ_{py} = 95 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 66 kg/mm^2
  - immediate after the pre-stressing: σ_{pat}= 77 kg/mm^2
  - during pre-stressing : σ_{pai}=85.5 kg/mm^2
- Young's modulus of P.C. steel material : E_p=2.0×10^{6}kg/mm^2

2-3. Reinforcing Bar : SD 30

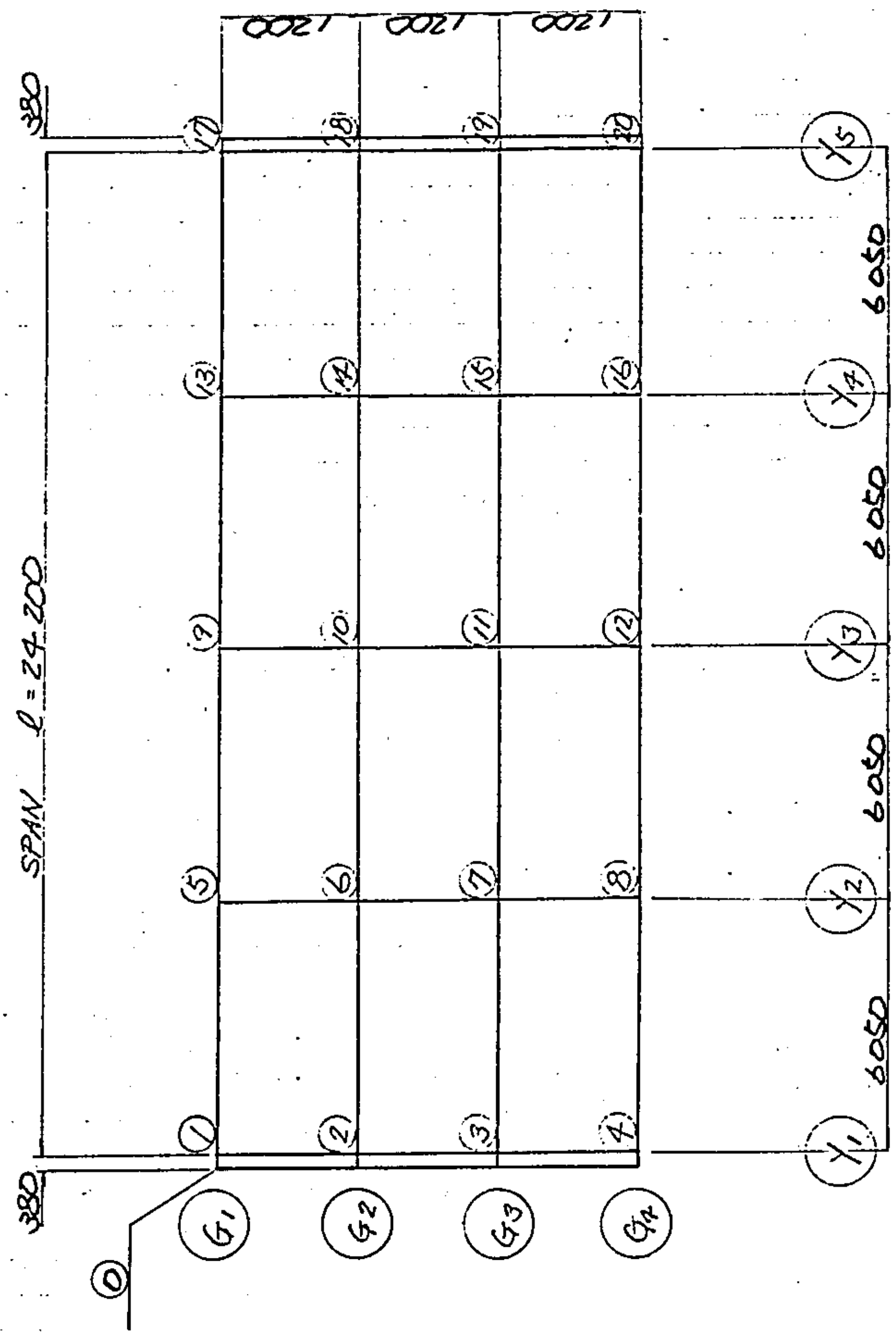
Chapter 2. Configuration and Dimensions of Bridge



Chapter 3. Input for Grid-system calculation

§1. Numbering & Coordinates of Skeleton Point

1. Member numbering & Skeleton point numbering



2. Coordinates calculations of Skeleton points

Assumed the Skeleton point (0) as fundamental point, coordinates of other skeleton points are calculated as listed below.

(Unit: m)

Skeleton point number	Skeleton point coordinates		Skeleton point number	Skeleton point coordinates	
	x	y		x	y
(1)	0.380	0	(15)	18.530	-2.400
(2)	"	-1.200	(16)	"	-3.600
(3)	"	-2.400	(17)	24.580	0
(4)	"	-3.600	(18)	"	-1.200
(5)	6.430	0	(19)	"	-2.400
(6)	"	-1.200	(20)	"	-3.600
(7)	"	-2.400	( )		
(8)	"	-3.600	( )		
(9)	12.480	0	( )		
(10)	"	-1.200	( )		
(11)	"	-2.400	( )		
(12)	"	-3.600	( )		
(13)	18.530	0	( )		
(14)	"	-1.200	( )		

§2. Support conditions and Young's modulus of Concrete

1. Support conditions

Skeleton number	Rotation around		Z direction
	Y axis	X axis	
①	free	free	restricted
②	"	"	"
③	"	"	"
④	"	"	"
⑰	"	"	"
⑱	"	"	"
⑲	"	"	"
⑳	"	"	"

2. Young's modulus of concrete

(1) Young's modulus

Main girder : $E\ell = 3.50 \times 10^5\ kg/cm^2 = 35.0 \times 10^5\ t/m^2$

Cross beam : $Et = 3.00 \times 10^5\ kg/cm^2 = 30.0 \times 10^5\ t/m^2$

(2) Young's modulus corresponding to shearing

$G = 0.43E$

Main girder : $G\ell = 0.43 \times 35.0 \times 10^5 = 15.05 \times 10^5\ t/m^2$

Cross beam : $Gt = 0.43 \times 30.0 \times 10^5 = 12.90 \times 10^5\ t/m^2$

§3. Configuration and Dimensions of Main girder and Cross beam

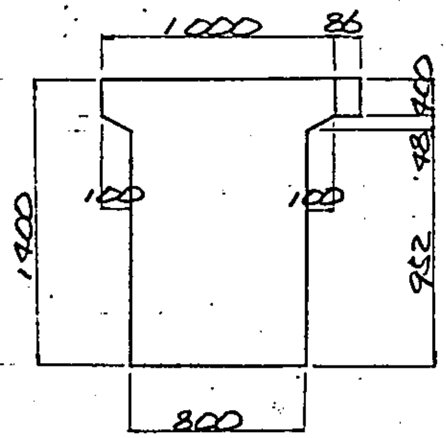
1. Configuration and Dimensions of Main girder

Dimension of concrete between Girders are as shown.

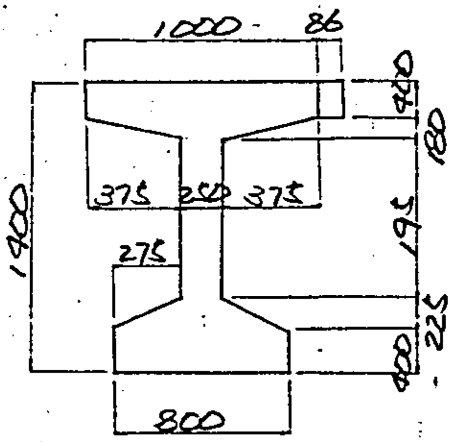
$$Et/E\ell = \frac{30.0 \times 10^5}{35.0 \times 10^5} = 0.857 \fallingdotseq 0.86$$

$$b = 0.200 \times 0.86 \times \frac{1}{2} = 0.086$$

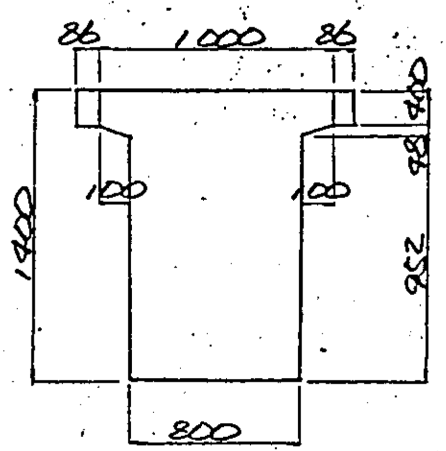
SECTION NUMBER ①: G1, G4 (Y1, Y5)



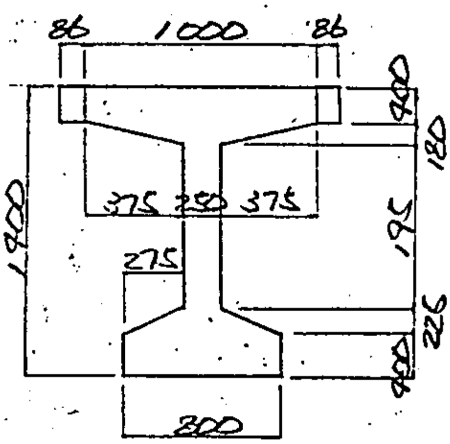
SECTION NUMBER ②: G1, G4 (Y2 ~ Y4)



SECTION NUMBER ③: G2 G3 (Y1, Y5)

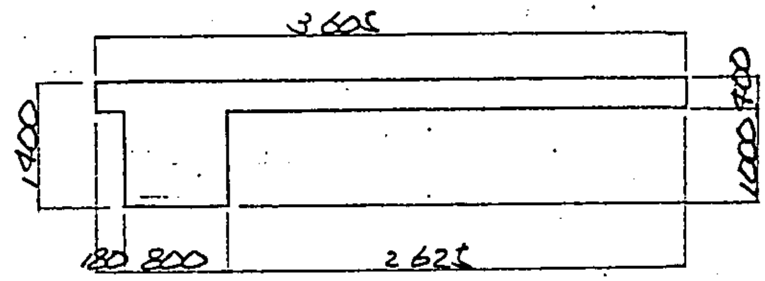


SECTION NUMBER ④: G2 G3 (Y2 ~ Y4)

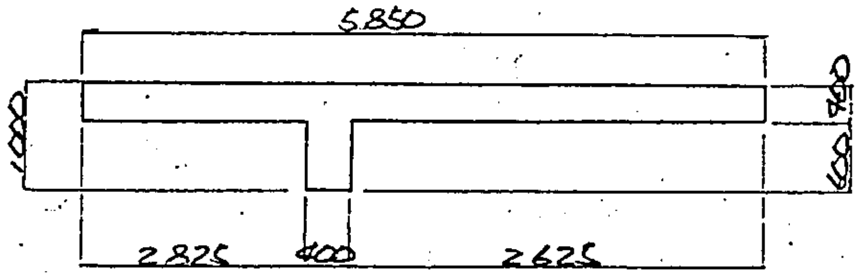


2. Configuration and Dimensions of Cross beam

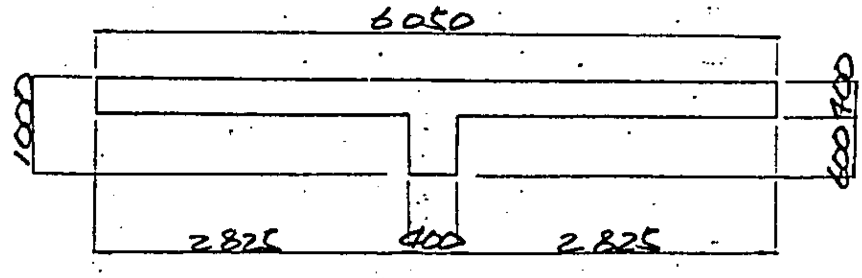
SECTION NUMBER ⑤ (Y1, Y5)



SECTION NUMBER ⑥ (Y2, Y4)



SECTION NUMBER ⑦ (Y3)



3. Applicable section number for various Girder, Beam/location

Girders		Location of number	Section number	Notes
Main girder	G_1, G_4	Location of Cross beam : y_1 , y_5	①	
		〃 : $y_2 \sim y_4$	②	
	G_2, G_3	〃 : y_1 , y_5	③	
		〃 : $y_2 \sim y_4$	④	
Cross beam		y_1 , y_4	⑤	
		y_2 , y_5	⑥	
		y_3	⑦	

4. Moment of inertia of the section

(Unit: m^4)

Girders		Members	Moment of inertia (Average)
Main girder	G_1, G_4	1, 4, 13, 16	0.20887
		2, 3, 14, 15	0.20706
	G_2, G_3	5, 8, 9, 12	0.21602
		6, 7, 10, 11	0.21403
Cross beam		17, 18, 19, 29, 30, 31	0.33801
		20, 21, 22, 26, 27, 28	0.09282
		23, 24, 25	0.09406

§4. Loads and Loading conditions

1. Application of loads for calculation

(1) Application of static load

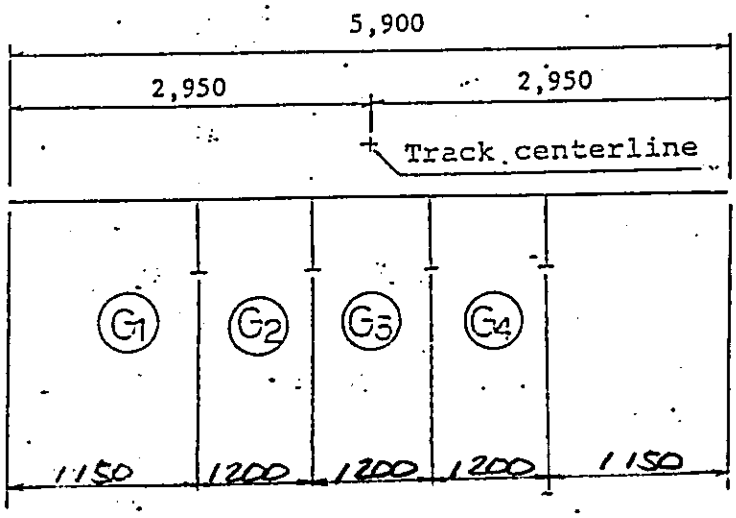
As the grid-system are carried out based on influence lines, the static load loading is applied in dual ways, one is a lined loading and the other is a uniformly distributed loading, to determine the loading length and width.

(2) Application of combined train loading

(a). Train load loading

Train load is assumed to be transmitted through sleepers downwards and distributed to the enlarged width within inclined lines with 53 deg. starting at both end points of sleeper bottom.

Distribution of loads through track is shown in the sketch drawing.



(b) Combined loading of train load

(i) Train load is supposed to distribute entire length of the span.

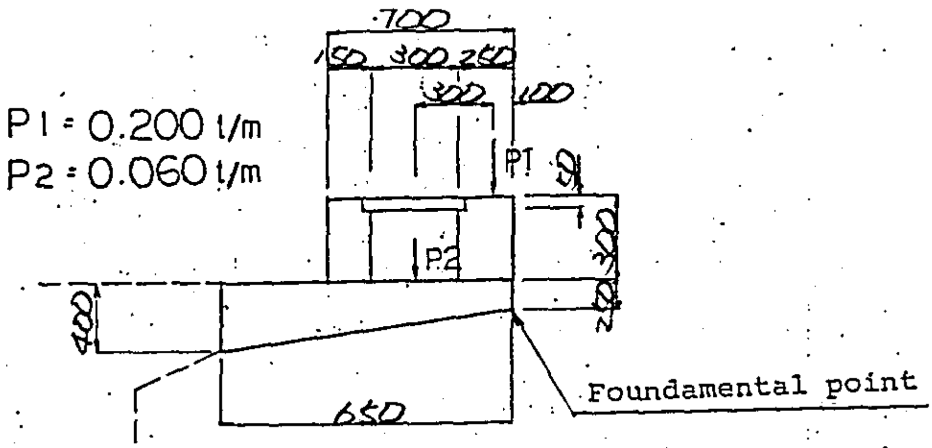
(ii) Train load is supposed to distribute limited to one side of span with 1/2 ℓ length.

Train load is applied combined the above (i) and (ii) loadings. Thus, further calculations are made for the sectional strength.

2. Dead load calculations of the own weight of structure

(1) Cantilever part of bridge slab, edge coaming and handrail concrete

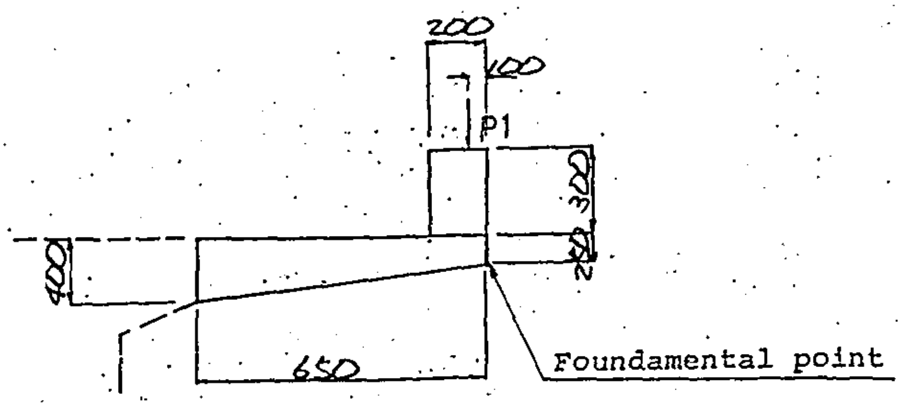
(a) G4 girder side



Load/Load acting point

Total dead load : ΣW (t/m) = 1.127
Total bending moment : $\Sigma W X$ (t-m/m) = 0.339
Acting point of resultant force : $X = \Sigma W X / \Sigma W$ (m) = 0.301

(b) G1 girder side

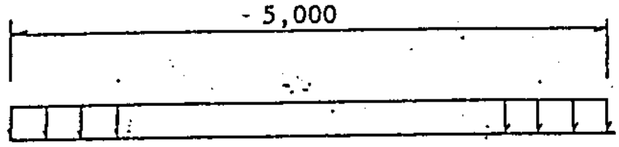


Load/Load acting point

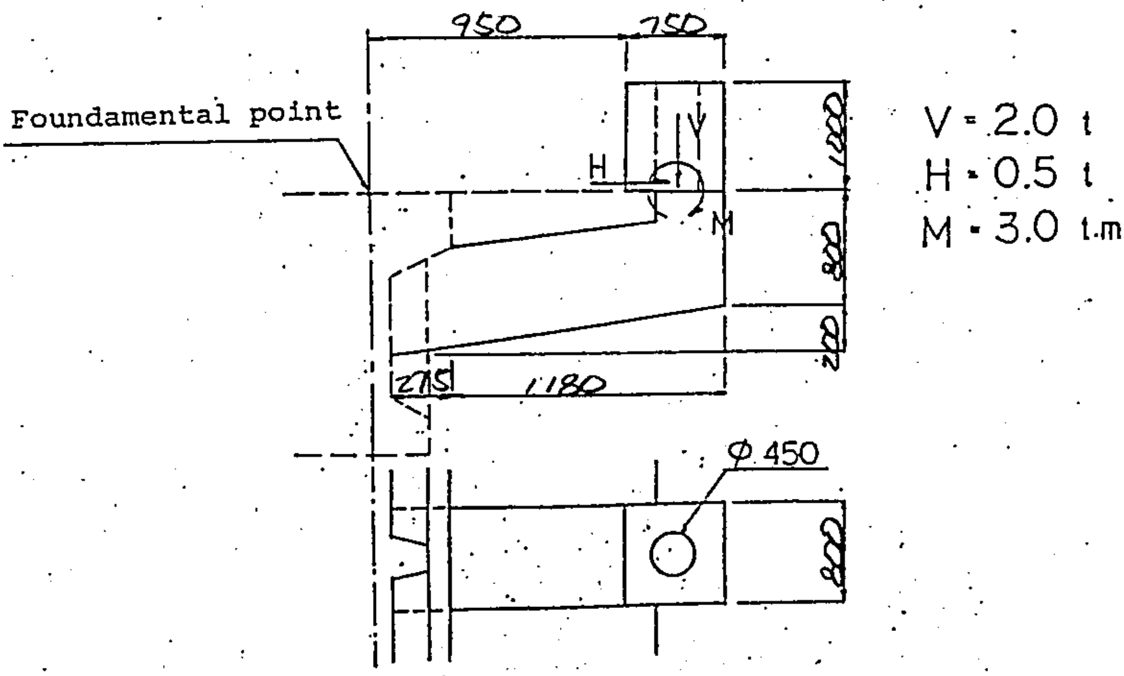
Total dead load : ΣW (t/m) = 0.878
Total bending moment : $\Sigma W X$ (t-m/m) = 0.220
Acting point of resultant force : $X = \Sigma W X / \Sigma W$ (m) = 0.251

(2) Graded Concrete

$Wp = 2.35 \times 0.07 = 0.165$ t/m^2

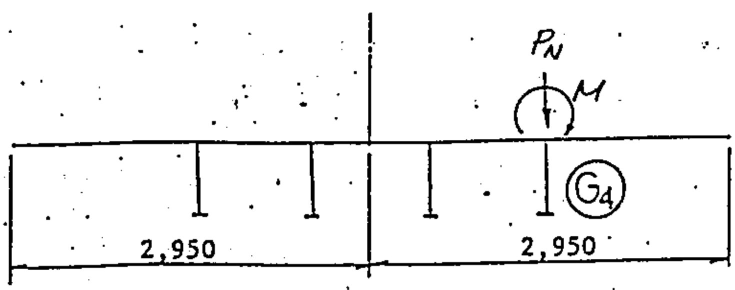


(3) Electric pole and its supporting beam



Load/Load acting point

Total dead load	: ΣW (t/m)	= 5.024 = P_N
Total bending moment	: ΣW X(t-m/m)	= 6.166
	$M = M' + \Sigma W \cdot X$	= 9.166



3. Dead load calculations of surcharge

(1) Surcharge load of ballast

Calculated as a uniformly distributed load.

$$W_B = 1.9\ t/m^3 \times (h_B - h_p) = 0.914\ t/m^2$$

(2) Surcharge load of track assembly

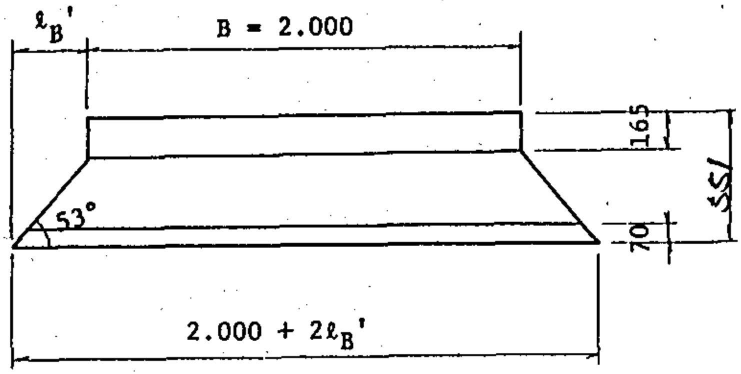
Load of track assembly is assumed to be distributed on the bridge slab with the width between two points on the slab, where lines drawn from the both ends of sleeper bottom with 53 deg. inclination towards outward-downward, crossing the slab surface.

- Load of track assembly : ΣW_R = 0.450 t/m
- Width of sleeper : B = 2.000 m
- Thickness of sleeper : h_M = 0.165 m
- Height between the girder top and the sleeper top : h_B = 0.551 m
- Average thickness of graded concrete for drainage : h_p = 0.070 m

$$2\ell_B' = 2(h_B - h_M) \cdot \text{Cot } 53° = 0.582\ m$$

- Load distribution width:

$$\ell_B = B + 2\ell_B' = 2.582\ m$$



Uniformly distributed load:

$$W_R = \frac{\Sigma W_R}{\ell_B} = 0.174\ t/m^2$$

4. Uniformly distributed load, equivalent to the train loading

Bending moment calculation:

For the bending moment calculation, the equivalent uniformly distributed load at the 1/4 span point will be employed and confirmed as calculated below.

$$M\ell = \{M\ell_{min} + \frac{\ell - \ell_{min}}{\ell_{max} - \ell_{min}} \cdot (M\ell_{max} - M\ell_{min})\} \ \gamma \cdot \beta \times \frac{1}{18}$$

where, $\ell = 24.200$, $\ell_{max} = 24.500$, $\ell_{min} = 24.000$

$\gamma = 2$ $\qquad \beta = 16$

$M\ell(\ell/4)_{min} = 224.3 \ t{\cdot}m$, $M\ell(\ell/4)_{max} = 233.5 \ t{\cdot}m$

$M\ell(\ell/2)_{min} = 293.7 \ t{\cdot}m$, $M\ell(\ell/2)_{max} = 304.7 \ t{\cdot}m$

$$M\ell(\ell/4) = \{224.3 + \frac{24.2-24.0}{24.5-24.0} \times (233.5-224.3)\} \ 2 \times 16 \times \frac{1}{18}$$
$$= 405.298 \ t{\cdot}m$$

$$M\ell(\ell/2) = \{293.7 + \frac{24.2-24.0}{24.5-24.0} \times (304.7-293.7)\} \ 2 \times 16 \times \frac{1}{18}$$
$$= 529.956 \ t{\cdot}m$$

Equivalent uniformly distributed load at $\ell/4$ span point, which is Wm, will be

$$W_m = \frac{32}{3} \times \frac{M\ell(\ell/4)}{\ell^2} = 7.382$$

Employed the above Wm value and applied for the bending moment calculation at $\ell/2$ point.

$$M'_{\ell/2} = W_m \cdot \frac{\ell^2}{8} = 540.399 \ t{\cdot}m$$
$$> M\ell_{(\ell/2)} = 529.956 \ t{\cdot}m$$

The result is larger than the value of $M_{\ell/2}$.

$$Wm = 7.382 \quad t/m$$

Train loading for bending moment:

$$W\ell = Wm(1 + i) = 10.017 \quad t/m$$

Train loading for bending moment: calculation

Train loading is distributed expanded with 53 deg. inclination from the both ends of sleeper bottom.

Uniformly distributed load: $W\ell$

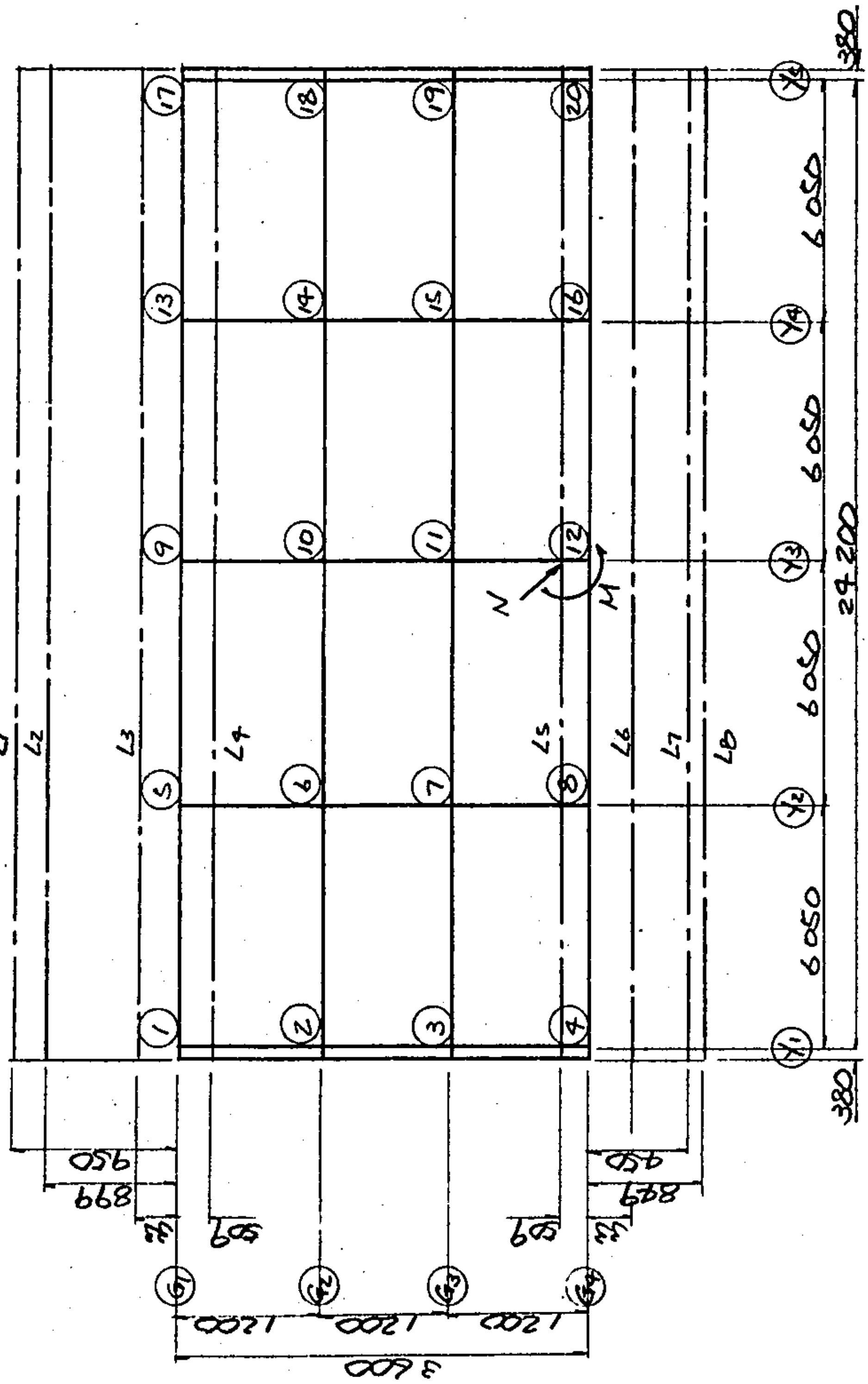
$$W\ell = \frac{Wm\ (1 + i)}{\ell_B} = 3.880 \quad t/m^2$$

5. Load/Loading point of various loadings

(1) Summary of loads

Load	Cases	Title	Load distribution area: Width	Load distribution area: Length	Intensity of load	Category of load
Dead load of surcharge and structure	Case 1	VANJO $-D_1$	L_8	$Y_1 \sim Y_5$	1.127 t/m	Canti. slab, handrail conc., etc.
			L_2	$Y_1 \sim Y_5$	0.878 〃	
			$L_1 \sim L_7$	$Y_1 \sim Y_5$	0.165 t/m²	Graded conc.
			$L_3 \sim L_6$	$Y_1 \sim Y_5$	0.914 〃	Ballast
			$L_4 \sim L_5$	$Y_1 \sim Y_5$	0.174 〃	Track assembly
Electric pole, etc.	Case 2	DENCHU $-D_1$	G_4	Y_3	N = 5.024 t M = 9.166 tm	Electric pole and its supporting beam
Train load	Case 3	L_1	$L_4 \sim L_5$	$Y_1 \sim Y_5$	3.880 t/m²	Live load intensity applied for bending moment calculation
	Case 4	L_2	$L_4 \sim L_5$	$Y_1 \sim Y_5$	3.880 t/m²	

(2) Loading conditions



6. Combined loading

(1) Case 1: Dead load of surcharge

(2) Case 2: Dead load of electric pole

(3) Case 3: Train load, loaded on full span

(4) Case 4: Train load, loaded on half span

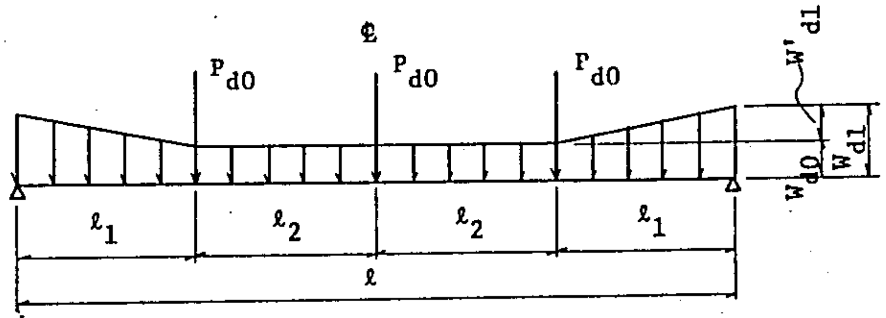
(5) Case 5: Case 1 + Case 2

(6) Case 6: Case 5 + Case 3

(7) Case 7: Case 5 + Case 4

Chapter 4. Design calculations of Main girder cross section

§1. Bending moment caused by own weight of Main girder



Bending moment (at center of span)

$$M_{d0} = \frac{1}{8}\cdot W_{d0}\cdot \ell^2 + \frac{1}{6}\cdot W_{d1}'\cdot \ell_1{}^2 + P_{d0}\cdot\{\frac{n}{2}(\ell_1 + \ell_2) - \ell_2\}$$

W_{d0} : Per meter weight of the section at the center (t/m) = 2.499

W_{d1} : Per meter weight of the section at the point of support (t/m) = 3.012

$W_{d1}' = W_{d1} - W_{d0}$ = 0.513

P_{d0} : Weight of intermediate diaphragm (t) = 0.221

ℓ : Span (m) = 24.200

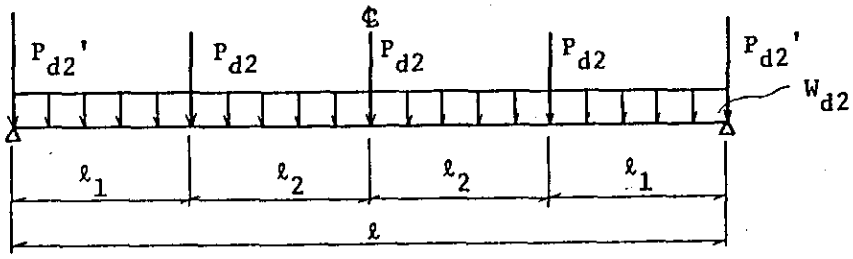
ℓ_1 : Length of the widened part of web (m) = 6.050

ℓ_2 : Location of diaphragm (m) = 6.050

n : Number of intermediate diaphragms

M_{d0} = 188.743 tm

§2. Stress calculations of Cross beam cross section



- Bending moment (at center of span)

$$M_{d0} = \frac{1}{8} \cdot W_{d2} \cdot \ell^2 + P_{d2} \cdot \{ \frac{n}{2} \cdot (\ell_1 + \ell_2) - \ell_2 \}$$

where,

W_{d2} : Own weight of bridge slab between girders (t/m)
= 0.150

P_{d2} : Own weight of intermediate Cross beam (t)
= 0.176

P_{d2}': Own weight of end Cross beam (t)
= 0.593

ℓ : Span (m) = 24.200

ℓ_1, ℓ_2: Location of Cross beam (m) { ℓ_1 = 6.050, ℓ_2 = 6.050

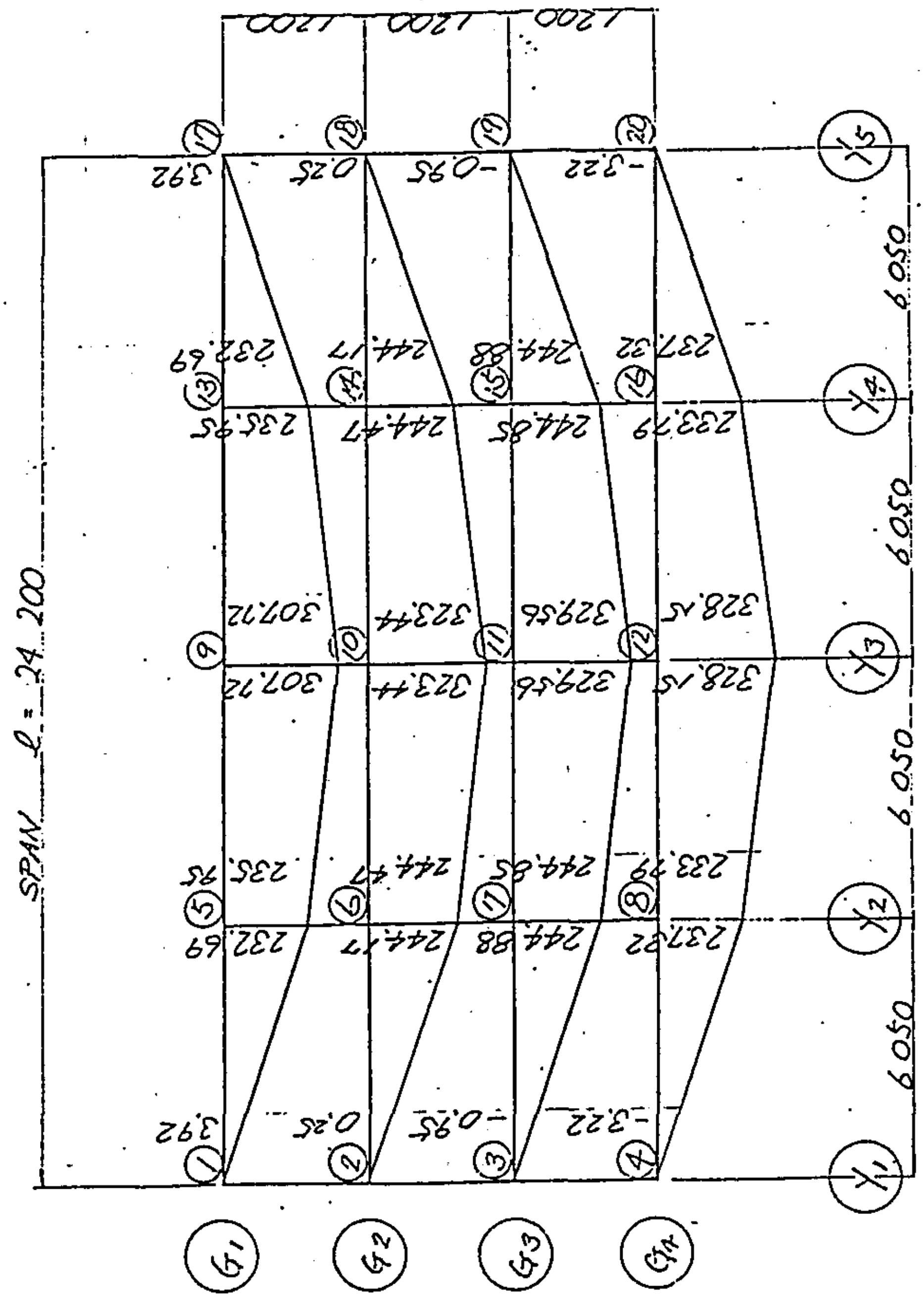
n : Number of intermediate Cross beam = 3

M_{d0} = 13.110 tm

§3. Stress caused by Static and Live load acting at the top of bridge slab

(Computer calculation with grid-system)

Bending moment diagram (Unit: t·m)



§4. Summary of bending moment calculations (at section of mid-span)

(Unit: t m)

Load / Main girder	Own Wt. (1) M.girder	(2) Concrete betw. girders	(3) Ballast Track	(4) Electric pole	(5)=Σ(1)~(4) D. load total	Live load Mℓ (6)	Live load Case	Total ((5) + (6))
G_1	188.743	13.110	127.512	-0.197	329.168	180.403	6	509.571
G_2	"	"	133.012	4.142	339.007	186.286	6	525.293
G_3	"	"	133.992	9.286	345.131	186.286	6	531.417
G_4	"	"	130.577	17.165	349.595	180.403	6	529.998

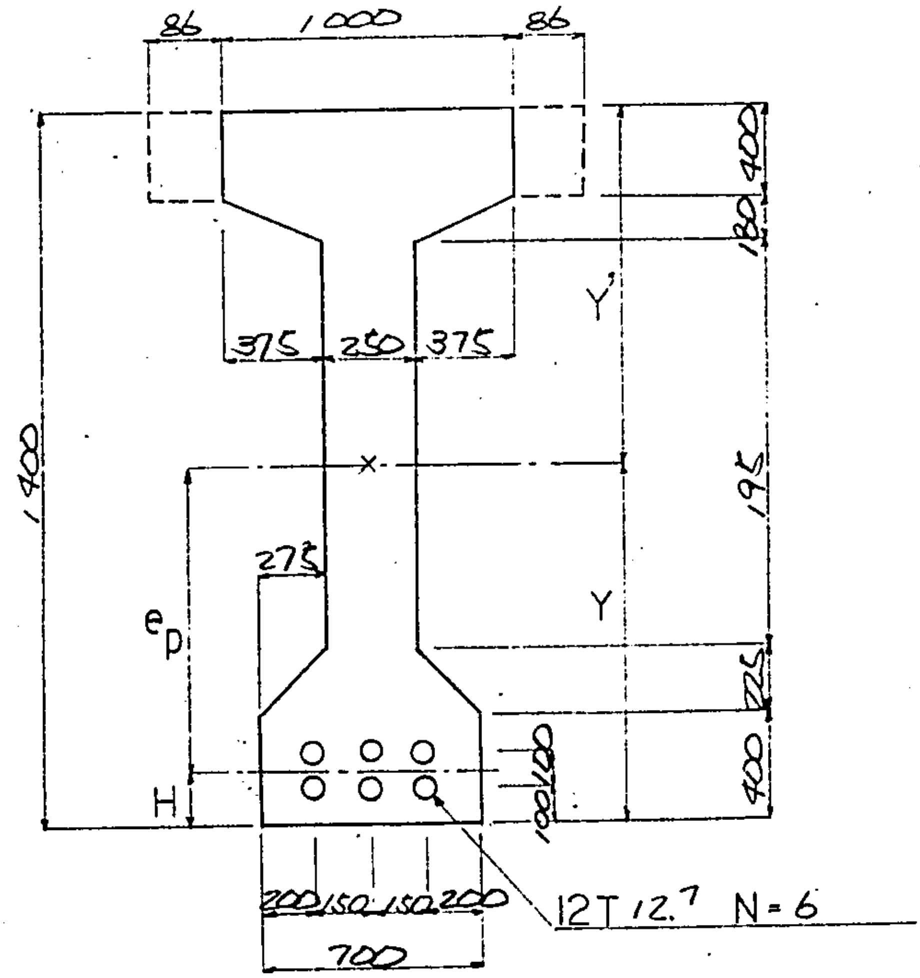
Developed the calculations in the preceding paragraphs, it became known that Maximum bending moment is exerted on Main girder.

Hence, further design calculations for Main girders will be represented by G_3 girder.

Chapter 5. Main girder design

§1. Basis for the design calculations

1. Configuration and Dimensions of the girder section of mid span



A : Cross sectional area (cm^2)

I : Moment of inertia (cm^4)

Z : Section modulus (cm^3)

r : Radius of gyration (cm)

ep: Location of cables (cm)

N : Number of cables

6pt: Tensile stress immediate after the practice of pre-stressing (kg/mm^2)

Pt: total tensile stressimmediate after the practice of pre-stressing

n : Ratio of Young's modulus between Modulus of P.C. cables and that of concrete

ψ : Coefficient of creep

ε_s: Drying contraction rate of conerete

η : Effective factor

2. Summary of sectional values (mid span)

(1) Gross cross section

- A_c = 9 993.8 cm^2
- I_c = 19.9645 $\times 10^6$ cm^4
- Y_c = 74.3 cm
- Y_c' = 65.7 cm
- $Z_c = I_c/Y_c$ = 2.6870 $\times 10^5$ cm^3
- $Z_c' = I_c/Y_c'$ = 3.0387 $\times 10^5$ cm^3
- $\gamma_c^2 = I_c/A_c$ = 1.9977 $\times 10^3$ cm^2
- $e_{pc} = Y_c - H$ = 59.3 cm

(2) Net cross section

- A_0 = 9 794.72 cm^2
- I_0 = 19.246 $\times 10^6$ cm^4
- Y_0 = 75.5 cm
- Y_0' = 64.5 cm
- $Z_0 = I_0/Y_0$ = 2.5491 $\times 10^5$ cm^3
- $Z_0' = I_0/Y_0'$ = 2.9839 $\times 10^5$ cm^3
- $\gamma_0^2 = I_0/A_0$ = 1.9649 $\times 10^3$ cm^2
- $e_{p0} = Y_0 - H$ = 60.5 cm
- $Z_{0g} = I_0/e_{p0}$ = 3.1812 $\times 10^5$ cm^3

(3) Equivalent cross section

- $n = E_p/E_c = \frac{2.0 \times 10^6}{3.5 \times 10^5} = 5.71$
- $n \cdot A_{pl} = 5.71 \times 11.85 = 67.664$ cm^2
- $A_{cl} = 10200.7$ cm^2
- $I_{\ell 1} = 20.683 \times 10^6$ cm^4
- $Y_{\ell 1} = \Sigma A_{e1} \cdot Y / \Sigma A_{e1} = 73.1$ cm
- $Y_{e1}' = h - Y_{e1} = 66.9$ cm
- $Z_{e1} = I_{e1}/Y_{e1} = 2.8294 \times 10^5$ cm^3
- $Z_{e1}' = I_{e1}/Y_{e1}' = 3.0916 \times 10^5$ cm^3
- $\gamma_{e1}^2 = I_{e1}/A_{e1} = 2.0276 \times 10^3$ cm^2
- $e_{pe1} = Y_{e1} - H = 58.1$ cm
- $Z_{e1g} = I_{e1}/e_{pe1} = 3.5599 \times 10^5$ cm^3

(4) Equivalent cross section (including concrete between Girders)

- $A_{ez} = 10888.7$ cm^2
- $I_{e2} = 22.192 \times 10^6$ cm^4
- $Y_{e2} = \Sigma A_{e2} \cdot Y / \Sigma A_{e2} = 76.1$ cm
- $Y_{e2}' = h - Y_{e2} = 63.9$ cm
- $Z_{e2} = I_{e2}/Y_{e2} = 2.9162 \times 10^5$ cm^3
- $Z_{e2}' = I_{e2}/Y_{e2}' = 3.4729 \times 10^5$ cm^3
- $\gamma_{e2}^2 = I_{e2}/A_{e2} = 2.0381 \times 10^3$ cm^2
- $e_{pe2} = Y_{e2} - H = 61.1$ cm
- $Z_{e2g} = I_{e2}/e_{pe2} = 3.6321 \times 10^5$ cm^3

§2. Summary of Bending stress calculations at mid span

Loads	Bending moment (x 10^5 kg·cm)	Section modulus (x 10^5 cm^3)		Bending stress (kg/cm^2) At top fibre	At bottom fibre	At the gravity center of cables
Own weight of Main girder	M_{d0} = 188.743	Z_0'	2.9839	63.3	——	——
		Z_0	-2.5491	——	-74.0	——
		Z_{0g}	-3.1812	——	——	-59.3
Concrete between girders	M_{d1} = 13.110	Z_{e1}'	3.0916	4.2	——	——
		Z_{e1}	-2.8294	——	-4.6	——
		Z_{e1g}	-3.5599	——	——	-3.7
Static load (Ballast track Electric pole)	M_{d2} = 143.278	Z_{e2}'	3.4729	41.3	——	——
		Z_{e2}	-2.9162	——	-49.1	——
		Z_{e2g}	-3.6321	——	——	-39.4
Dead load Total	ΣM_d = 345.131	—	——	108.8	-127.7	-102.4
Live load	$M\ell$ = 186.286	Z_{e2}'	3.4729	53.6	——	——
		Z_{e2}	-2.9162	——	-63.9	——
		Z_{e2g}	-3.6321	——	——	-51.3
Total	ΣM = 531.417	—	——	162.4	-191.6	-153.7

§3. Summary of stress calculations caused by pre-stressing at mid span

States	Items			Unit	Values
Immediate after the practice of pre-stressing	σ_{pt}			kg/mm^2	98
	A_p			mm^2	1185
	N				6
	A_0			$x10^3\ cm^2$	9.7947
	e_{p0}			m	-0.605
	Section modulus		Z_0'	$x10^5\ cm^3$	2.9839
			Z_0	"	-2.5491
			Z_{0g}	"	-3.1812
	P_t			$x10^3$ kg	696.78
	Stress	Top fibre	σ_{ct}'	kg/cm^2	-70.1
		Bottom fibre	σ_{ct}	"	236.5
		Grav. Center of cables	σ_{0pt}	"	203.7
Effective pre-stress	n				6.71
	ψ				2.6
	γ				0.05
	$\Sigma\sigma dg$			kg/cm^2	-102.4
	E_p			$x10^5 kg/cm^2$	20.0
	ε_s			$x10^{-5}$	20.00
	$\Delta\sigma_{p\gamma}$			kg/mm^2	4.90
	$\Delta\sigma_{p\psi}$			"	13.76
	σ_{pe}			"	79.33
	η				0.810
	Stress	Top fibre	σ_{ce}'	kg/cm^2	-56.8
		Bottom fibre	σ_{ce}	"	191.5
		Grav. Center of cables	σ_{cpe}	"	164.9

§4. Summary of combined Bending stress at mid span

Loads		Stresses (kg/cm²)	
		Top fibre	Bottom fibre
(1) Own weight of Main girder		63.3	-74.0
(2) Concrete between girders		4.2	-4.6
(3) Static load		41.3	-49.1
(4) Dead load total ((1) + (2) + (3))		108.8	-127.7
(5) Live load		53.6	-63.9
(6) Total load ((4) + (5))		162.4	-191.6
(7) Immediate after the pre-stressing		-70.1	236.5
(8) Effective pre-stress		-56.8	191.5
Combined stress Immediate after the pre-stressing	(1) + (7)	-6.8	162.5
	Allowable value	> - 15.0	< 180.0
Total Dead loading	(4) + (8)	52.0	63.8
Design loading	(6) + (8)	105.6	-0.1
	Allowable value	140.0	> -10.0

NO. 4 P.C. GIRDERS

SUPER-STRUCTURE

DESIGN CALCULATION

B03 - PC06 $L = 30^{m}$, $H = 1.80^{m}$

(Right Angle)

CONTENTS

Chapter 1. Design criteria

1. Basis for design and loading conditions

- Kind of bridge: Pre-stressed concrete railroad bridge.
- Type of Bridge/Girders: Bridge superstructure is a simple beam, consisted of 4 main girders aligned in parallel.
  Girder is made of post-tensioned concrete of I type section.
- Length of girder: 29.960 m
- Span of main girder: 29.200 m
- Live load : KS-16
- Impact coefficient : i = 0.342
- Crossing angle: { at younger change: 90°00′00″
  at elder change: 90°00′00″
- Railroad curve: STRAIGHT

2. Strength of materials for design

2-1. Concrete

(1) Concrete used for main girder

- Standard strength for design (28 day value)
  : σ_{CK} = 400 kg/cm^2
- Allowable compressive strength for bending calculation
  : σ_{ca} = 140 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 180 kg/cm^2
- Allowable tensile strength for bending calculation applied for,
  - design loading : σ_{cat} = -10 kg/cm^2
  - dead load : σ_{cat}' = 0 kg/cm^2
  - immediate after the pre-stressing: σ_{cat}'' = -15 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_c=3.5×10^5 kg/cm^2

(2) Concrete used for lateral connection

- Standard strength for design (28 day value)
  : σ_{ck} = 300 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 110 kg/cm^2
- Allowable tensile strength for bending calculation : σ_{ca}' = -8 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 140 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_c=3.0x10^{5}kg/cm^2

(3) Cantilever part of bridge slab, edge coaming and handrail concrete

- Standard strength for design (28 day value)
  : σ_{ck} = 240 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 80 kg/cm^2

2-2. Steel materials used for P.C. concrete

(1) P.C. Cable (SWPR-7B) 12T 12.7 mm

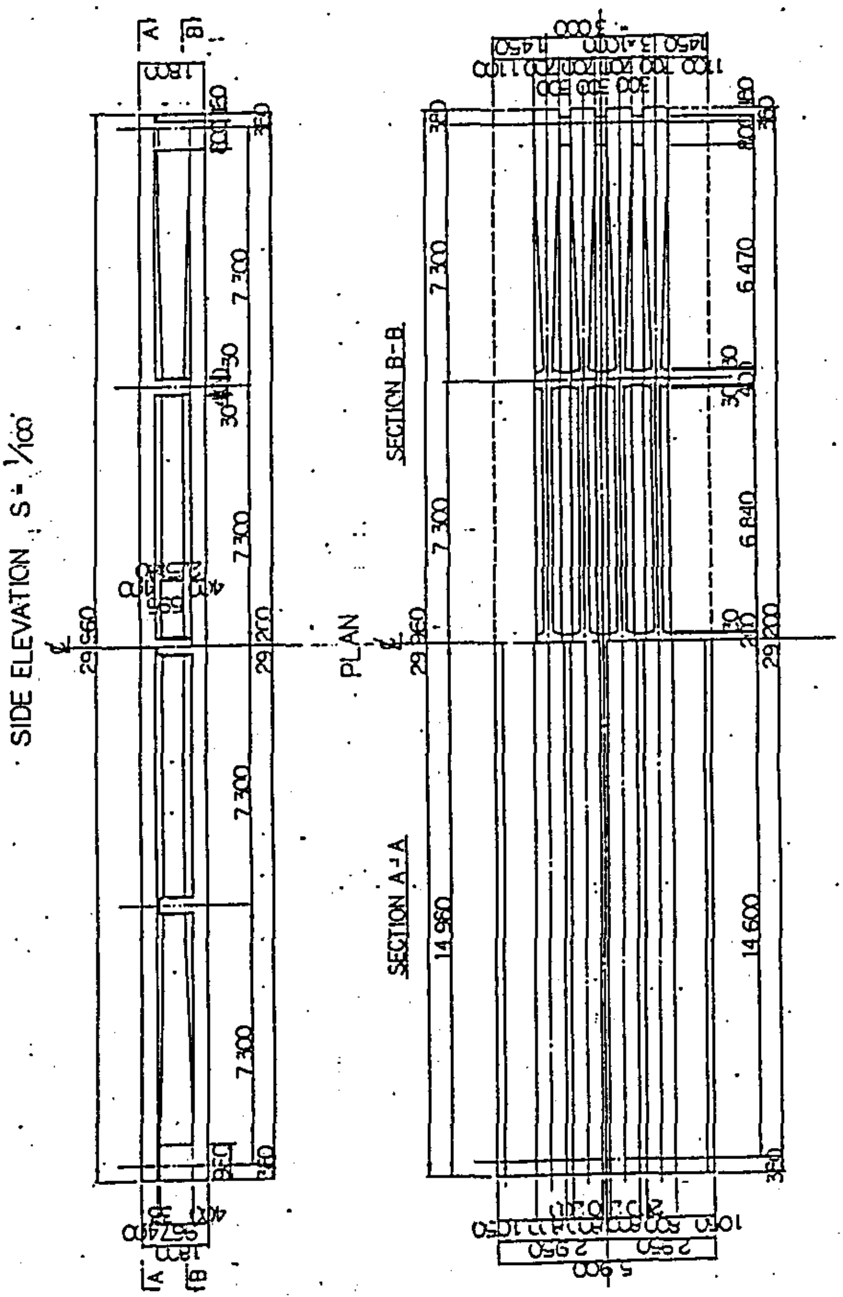
- Tensile strength : σ_{pu} = 190 kg/mm^2
- Yielding point : σ_{py} = 160 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 114 kg/mm^2
  - immediate after the pre-stressing: σ_{pat} = 133 kg/mm^2
  - during pre-stressing : σ_{pai} = 145 kg/mm^2
- Young's modulus of P.C. steel material
  : $E_p = 2.0 \times 10^6$ kg/cm^2

(2) P.C. steel bar (SBPR 95/110) ϕ 23 mm

- Tensile strength : σ_{pu} = 110 kg/mm^2
- Yielding point : σ_{py} = 95 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 66 kg/mm^2
  - immediate after the pre-stressing: σ_{pat} = 77 kg/mm^2
  - during pre-stressing : σ_{pai} = 85.5 kg/mm^2
- Young's modulus of P.C. steel material
  : $E_p = 2.0 \times 10^6$ kg/mm^2

2-3. Reinforcing Bar : SD 30

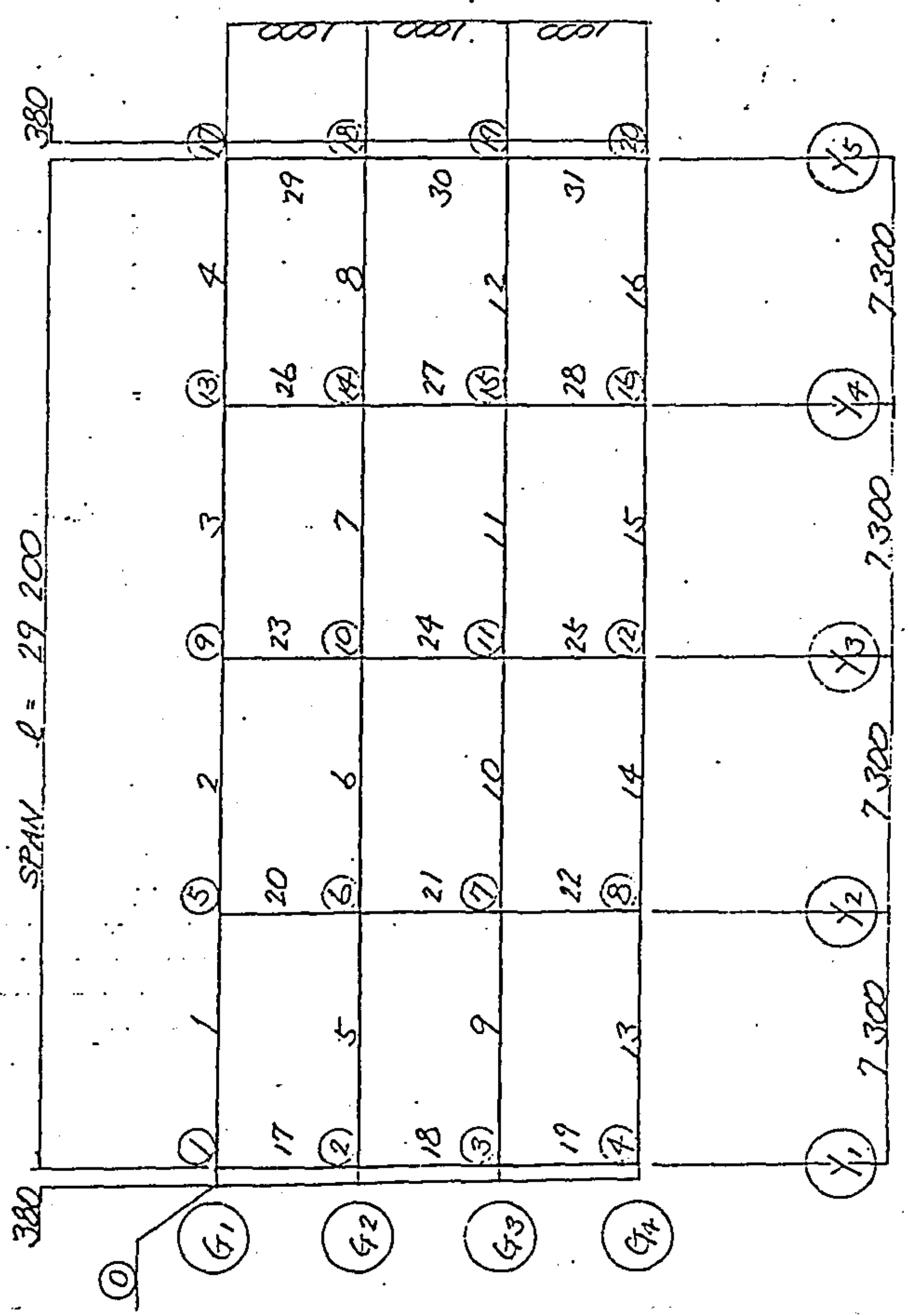
Chapter 2. Configuration and Dimensions of Bridge



Chapter 3. Input for Grid-system calculation

§1. Numbering & Coordinates of Skeleton Point

1. Member numbering & Skeleton point numbering



2. Coordinates calculations of Skeleton points

Assumed the Skeleton point (0) as fundamental point, coordinates of other skeleton points are calculated as listed below.

(Unit: m)

Skeleton point number	Skeleton point coordinates x	y	Skeleton point number	Skeleton point coordinates x	y
(1)	0.380	0	(15)	22.280	-2.000
(2)	〃	-1.000	(16)	〃	-3.000
(3)	〃	-2.000	(17)	29.580	0
(4)	〃	-3.000	(18)	〃	-1.000
(5)	7.680	0	(19)	〃	-2.000
(6)	〃	-1.000	(20)	〃	-3.000
(7)	〃	-2.000	( )		
(8)	〃	-3.000	( )		
(9)	14.980	0	( )		
(10)	〃	-1.000	( )		
(11)	〃	-2.000	( )		
(12)	〃	-3000	( )		
(13)	22.280	0	( )		
(14)	〃	-1.000	( )		

§2. Support conditions and Young's modulus of Concrete

1. Support conditions

Skeleton number	Rotation around		Z direction
	Y axis	X axis	
①	free	free	restricted
②	"	"	"
③	"	"	"
④	"	"	"
⑰	"	"	"
⑱	"	"	"
⑲	"	"	"
⑳	"	"	"

2. Young's modulus of concrete

(1) Young's modulus

Main girder : $E\ell = 3.50 \times 10^5 \text{ kg/cm}^2 = 35.0 \times 10^5 \text{ t/m}^2$

Cross beam : $Et = 3.00 \times 10^5 \text{ kg/cm}^2 = 30.0 \times 10^5 \text{ t/m}^2$

(2) Young's modulus corresponding to shearing

$G = 0.43E$

Main girder : $G\ell = 0.43 \times 35.0 \times 10^5 = 15.05 \times 10^5 \text{ t/m}^2$

Cross beam : $Gt = 0.43 \times 30.0 \times 10^5 = 12.90 \times 10^5 \text{ t/m}^2$

§3. Configuration and Dimensions of Main girder and Cross beam

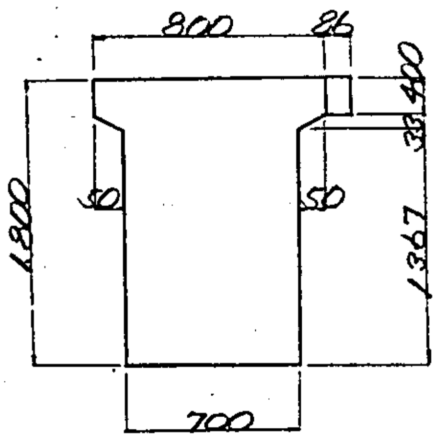
1. Configuration and Dimensions of Main girder

Dimension of concrete between Girders are as shown.

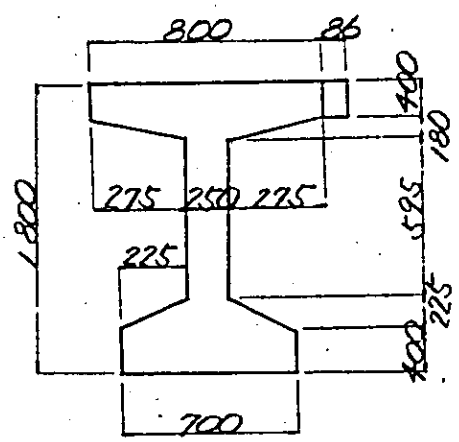
$$Et/E\ell = \frac{30.0 \times 10^5}{35.0 \times 10^5} = 0.857 \fallingdotseq 0.86$$

$$b \doteq 0.200 \times 0.86 \times \frac{1}{2} = 0.086$$

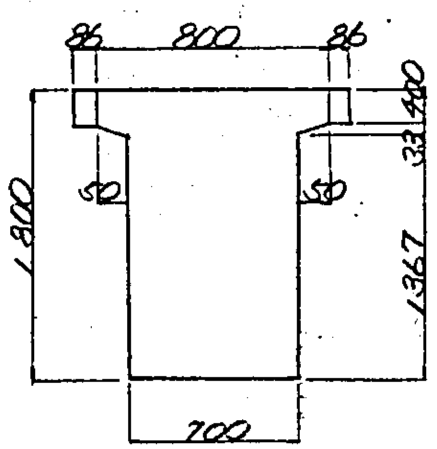
SECTION
NUMBER ①: G1, G4 (Y_1, Y_5)



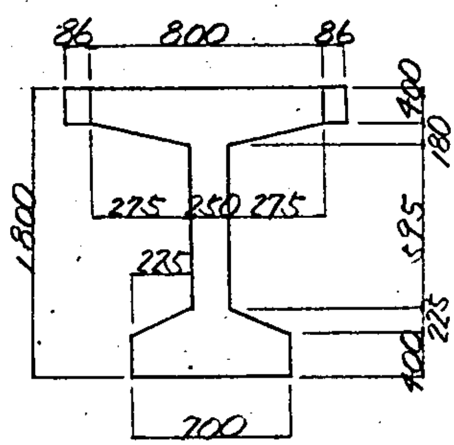
SECTION
NUMBER ②: G1, G4 (Y_2 ~ Y_4)



SECTION
NUMBER ③: G2 G3 (Y_1, Y_5)

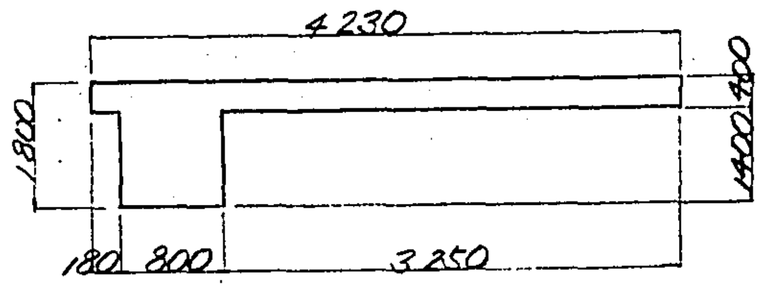


SECTION
NUMBER ④: G2 G3 (Y_2 ~ Y_4)

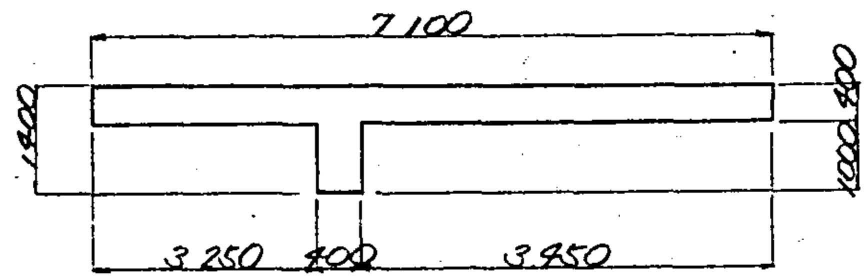


2. Configuration and Dimensions of Cross beam

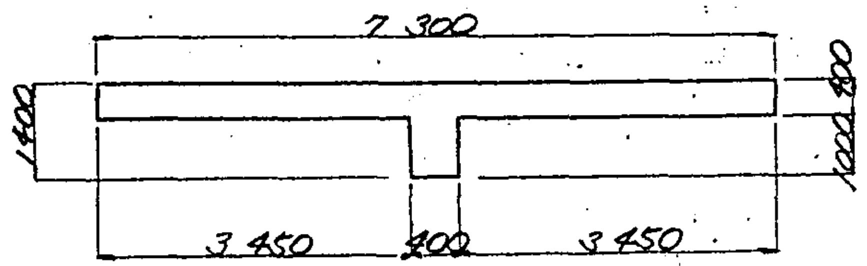
SECTION NUMBER ⑤ (y_1, y_5)



SECTION NUMBER ⑥ (y_2 y_4)



SECTION NUMBER ⑦ (y_3)



3. Applicable section number for various Girder, Beam/location

Girders		Location of number	Section number	Notes
Main girder	G_1, G_4	Location of Cross beam : y_1 , y_5	①	
		〃 : $y_2 \sim y_4$	②	
	G_2, G_3	〃 : y_1 , y_5	③	
		〃 : $y_2 \sim y_4$	④	
Cross beam		y_1 , y_5	⑤	
		y_2 , y_4	⑥	
		y_3	⑦	

4. Moment of inertia of the section

(Unit: m^4)

Girders		Members	Moment of inertia (Average)
Main girder	G_1 G_4	1, 4, 13, 16	0.36615
		2, 3, 14, 15	0.35630
	G_2 G_3	5, 8, 9, 12	0.38084
		6, 7, 10, 11	0.37068
Cross beam		17, 18, 19, 29, 30, 31	0.75136
		20, 21, 22, 26, 27, 28	0.24300
		23, 24, 25	0.24466

§4. Loads and Loading conditions

1. Application of loads for calculation

(1) Application of static load

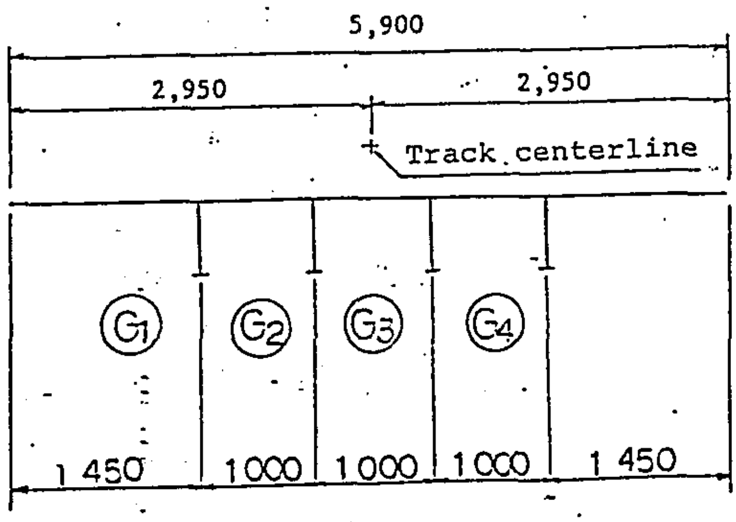
As the grid-system are carried out based on influence lines, the static load loading is applied in dual ways, one is a lined loading and the other is a uniformly distributed loading, to determine the loading length and width.

(2) Application of combined train loading

(a) Train load loading

Train load is assumed to be transmitted through sleepers downwards and distributed to the enlarged width within inclined lines with 53 deg. starting at both end points of sleeper bottom.

Distribution of loads through track is shown in the sketch drawing.



(b) Combined loading of train load

(i) Train load is supposed to distribute entire length of the span.

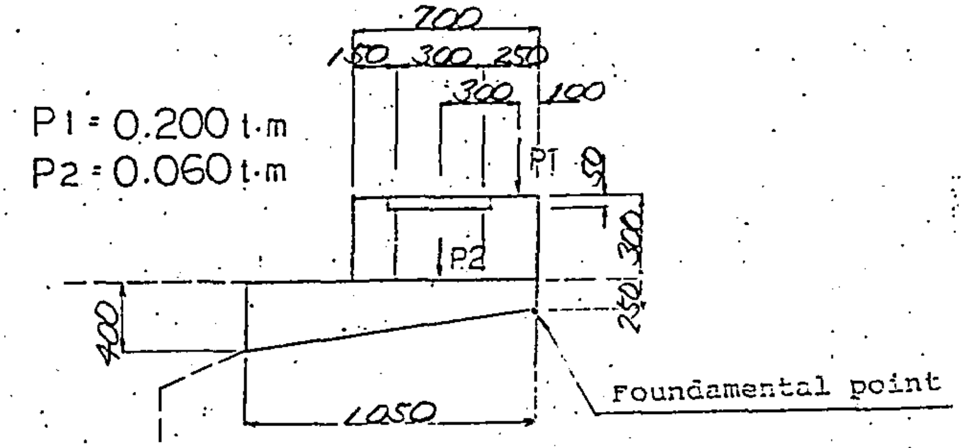
(ii) Train load is supposed to distribute limited to one side of span with 1/2 ℓ length.

Train load is applied combined the above (i) and (ii) loadings. Thus, further calculations are made for the sectional strength.

2. Dead load calculations of the own weight of structure

(1) Cantilever part of bridge slab, edge coaming and handrail concrete ...

(a) G4 girder side



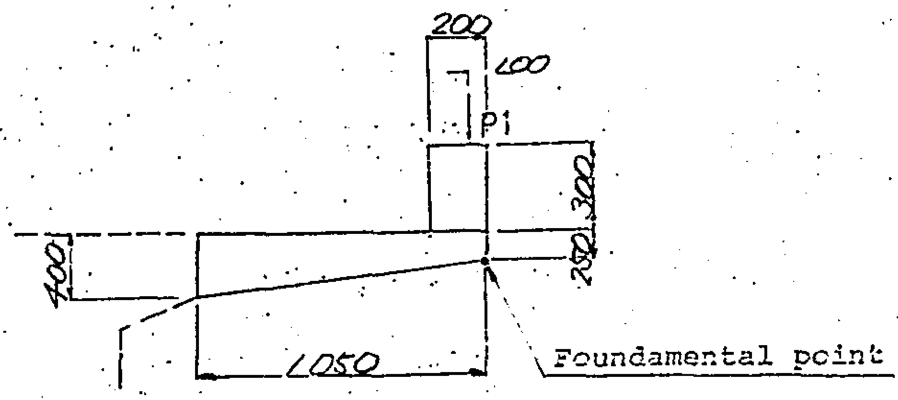
Load/Load acting point

Total dead load : ΣW (t/m) = 1.452

Total bending moment : ΣW X(t-m/m) = 0.852

Acting point of resultant force : $X=\Sigma W X/\Sigma W$ (m) = 0.587

(b) G1 girder side



Load/Load acting point

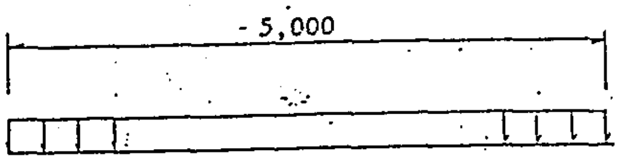
Total dead load : ΣW (t/m) = 1.203

Total bending moment : ΣW X(t-m/m) = 0.517

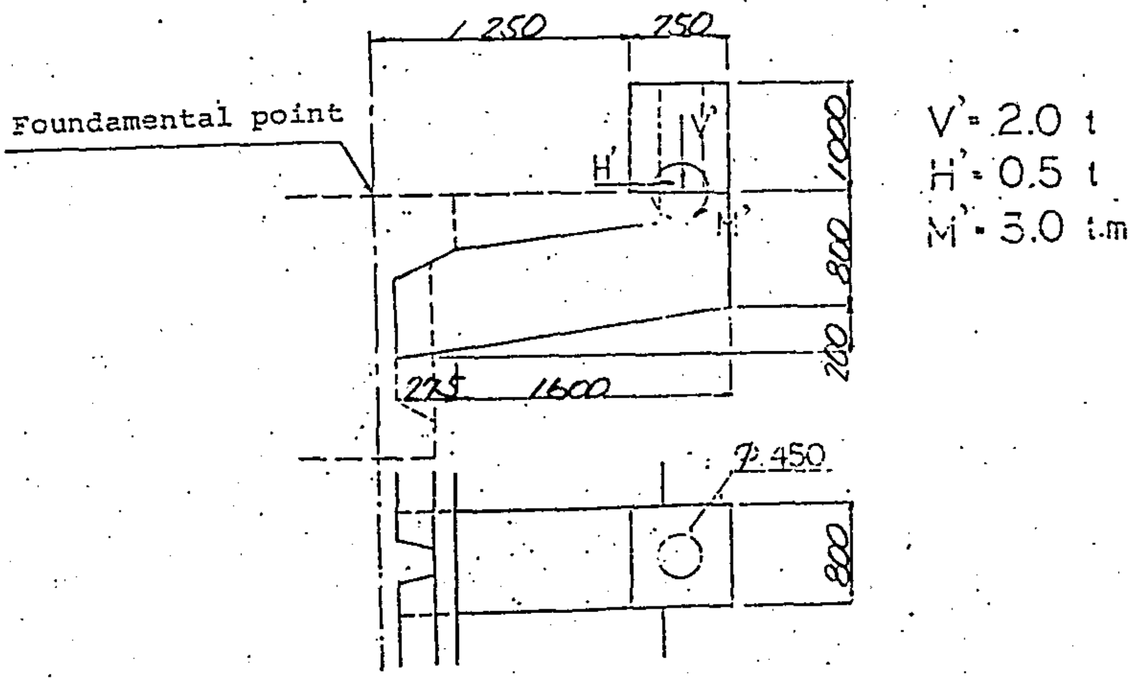
Acting point of resultant force : $X=\Sigma W X/\Sigma W$ (m) = 0.430

(2) Graded Concrete

$Wp = 2.35 \times 0.07 = 0.165\ t/m^2$



(3) Electric pole and its supporting beam

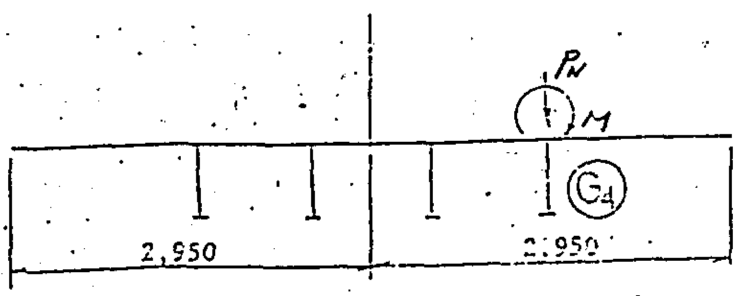


Load/Load acting point

Total dead load : ΣW (t/m) = 5.463 = P_N

Total bending moment : $\Sigma W\ X$ (t-m/m) = 7.809

$M = M' + \Sigma WX$ = 10.309



3. Dead load calculations of surcharge

(1) Surcharge load of ballast

Calculated as a uniformly distributed load.

$$W_B = 1.9\ t/m^3 \times (h_B - h_p) = 0.914\ t/m^2$$

(2) Surcharge load of track assembly

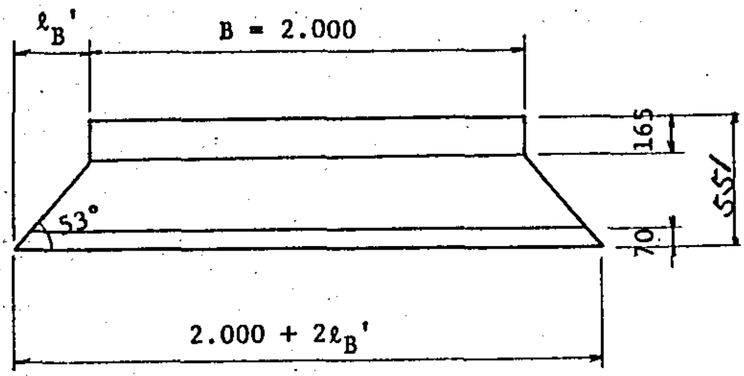
Load of track assembly is assumed to be distributed on the bridge slab with the width between two points on the slab, where lines drawn from the both ends of sleeper bottom with 53 deg. inclination towards outward-downward, crossing the slab surface.

- Load of track assembly : $\Sigma W_R = 0.450$ t/m
- Width of sleeper : $B = 2.000$ m
- Thickness of sleeper : $h_M = 0.165$ m
- Height between the girder top and the sleeper top : $h_B = 0.551$ m
- Average thickness of graded concrete for drainage : $h_p = 0.070$ m

$$2\ell_B' = 2(h_B - h_M) \cdot \text{Cot } 53° = 0.582\ m$$

- Load distribution width:

$$\ell_B = B + 2\ell_B' = 2.582\ m$$



Uniformly distributed load:

$$W_R = \frac{\Sigma W_R}{\ell_B} = 0.174\ t/m^2$$

4. Uniformly distributed load, equivalent to the train loading

Bending moment calculation:

For the bending moment calculation, the equivalent uniformly distributed load at the 1/4 span point will be employed and confirmed as calculated below.

$$M\ell = \{M\ell_{min} + \frac{\ell - \ell_{min}}{\ell_{max} - \ell_{min}} \cdot (M\ell_{max} - M\ell_{min})\}\ \gamma \cdot \beta \times \frac{1}{18}$$

where, $\ell = 29.200$, $\ell_{max} = 29.500$, $\ell_{min} = 29.000$

$\gamma = 2$ $\qquad \beta = 16$

$M\ell(\ell/4)_{min} = 323.2\ t \cdot m$, $M\ell(\ell/4)_{max} = 333.6\ t \cdot m$

$M\ell(\ell/2)_{min} = 412.9\ t \cdot m$, $M\ell(\ell/2)_{max} = 425.5\ t \cdot m$

$$M\ell(\ell/4) = \{323.2 + \frac{0.20}{0.50} \times (333.6 - 323.2)\}\ 2 \times 16 \times \frac{1}{18}$$
$$= 581.973$$

$$M\ell(\ell/2) = \{412.9 + \frac{0.20}{0.50} \times (425.2 - 412.9)\}\ 2 \times 16 \times \frac{1}{18}$$
$$= 743.004$$

Equivalent uniformly distributed load at $\ell/4$ span point, which is Wm, will be.

$$W_m = \frac{32}{3} \times \frac{M\ell(\ell/4)}{\ell^2} = 7.281$$

Employed the above Wm value and applied for the bending moment calculation at $\ell/2$ point.

$$M'_{\ell/2} = W_m \cdot \frac{\ell^2}{8} = 776.009\ t \cdot m$$
$$> M\ell_{(\ell/2)} = 743.004\ t \cdot m$$

The result is larger than the value of $M_{\ell/2}$.

$Wm = 7.281$ t/m

Train loading for bending moment:

$W\ell = Wm(1 + i) = 9.771$ t/m

Train loading for bending moment: calculation

Train loading is distributed expanded with 53 deg. inclination from the both ends of sleeper bottom.

Uniformly distributed load: $W\ell$

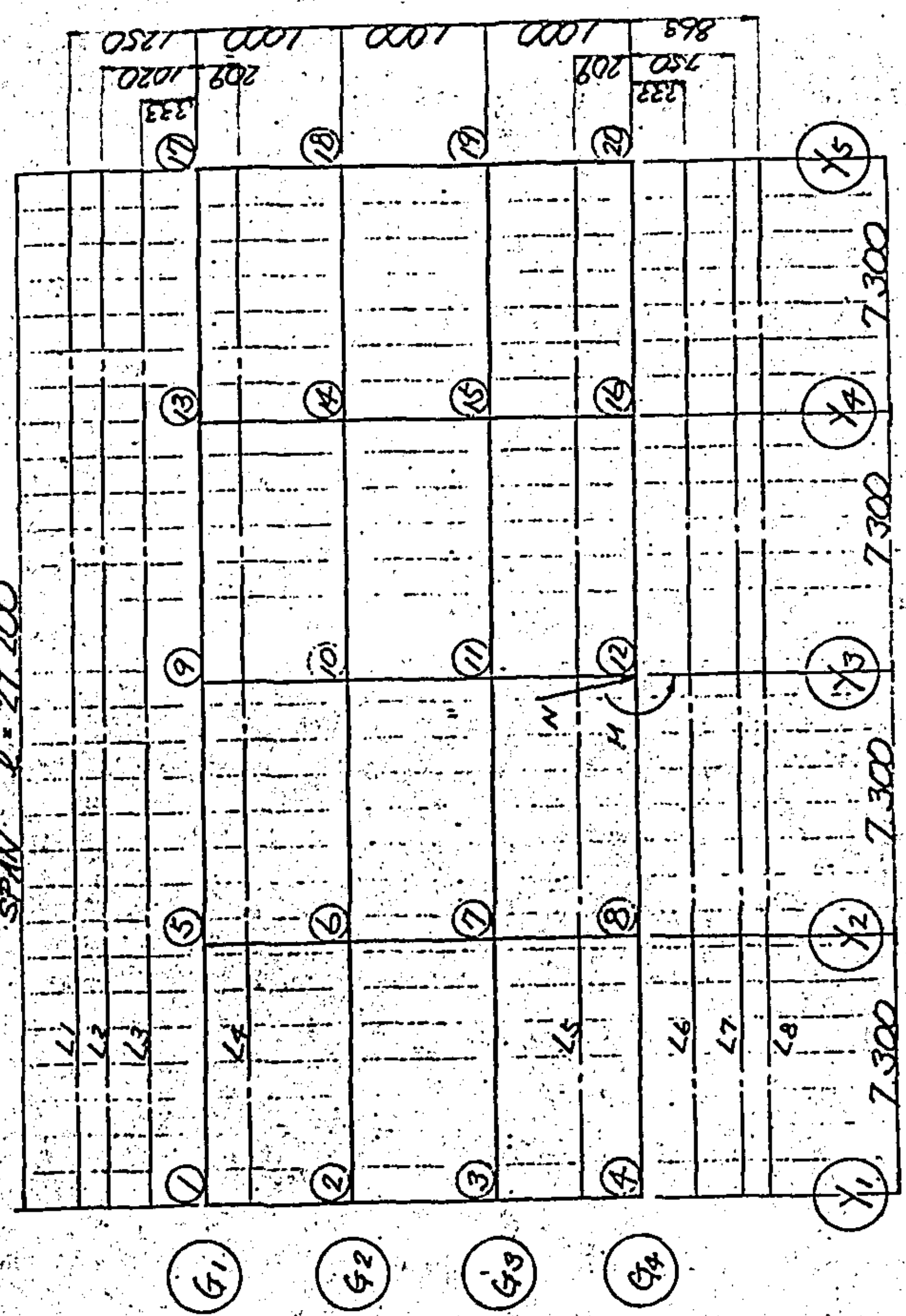
$$W\ell = \frac{Wm\ (1 + i)}{\ell_B} = 3.784 \ t/m^2$$

5. Load/Loading point of various loadings

(1) Summary of loads

Load	Cases	Title	Load distribution area: Width	Load distribution area: Length	Intensity of load	Category of load
Dead load of surcharge and structure	Case 1	VANJO $-D_1$	L_8	$Y_1 \sim Y_5$	1.452 t/m	Canti. slab, handrail conc., etc.
			L_2	$Y_1 \sim Y_5$	1.203 "	
			$L_1 \sim L_7$	$Y_1 \sim Y_5$	0.165 t/m²	Graded conc.
			$L_3 \sim L_6$	$Y_1 \sim Y_5$	0.914 "	Ballast
			$L_4 \sim L_5$	$Y_1 \sim Y_5$	0.174 "	Track assembly
Electric pole, etc.	Case 2	DENCHU $-D_1$	G_4	Y_3	N = 5.401 t M = 10.809 t·m	Electric pole and its supporting beam
Train load	Case 3	L_1	$L_4 \sim L_5$	$Y_1 \sim Y_5$	3.784 t/m²	Live load intensity applied for bending moment calculation
	Case 4	L_2	$L_4 \sim L_5$	$Y_1 \sim Y_3$	3.784 "	

(2) Loading conditions



6. Combined loading

(1) Case 1: Dead load of surcharge

(2) Case 2: Dead load of electric pole

(3) Case 3: Train load, loaded on full span

(4) Case 4: Train load, loaded on half span

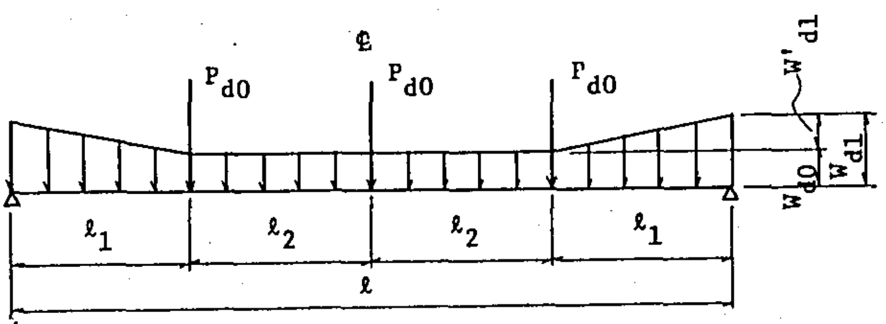
(5) Case 5: Case 1 + Case 2

(6) Case 6: Case 5 + Case 3

(7) Case 7: Case 5 + Case 4

Chapter 4. Design calculations of Main girder cross section

§1. Bending moment caused by own weight of Main girder



Bending moment (at center of span)

$$M_{d0} = \frac{1}{8}\cdot W_{d0}\cdot \ell^2 + \frac{1}{6}\cdot W_{d1}'\cdot \ell_1{}^2 + P_{d0}\cdot\{\frac{n}{2}(\ell_1 + \ell_2) - \ell_2\}$$

W_{d0} : Per meter weight of the section at the center (t/m) = 2.375

W_{d1} : Per meter weight of the section at the point of support (t/m) = 3.254

$W_{d1}' = W_{d1} - W_{d0} = 0.879$

P_{d0} : Weight of intermediate diaphragm (t) = 0.378

ℓ : Span (m) = 29.200

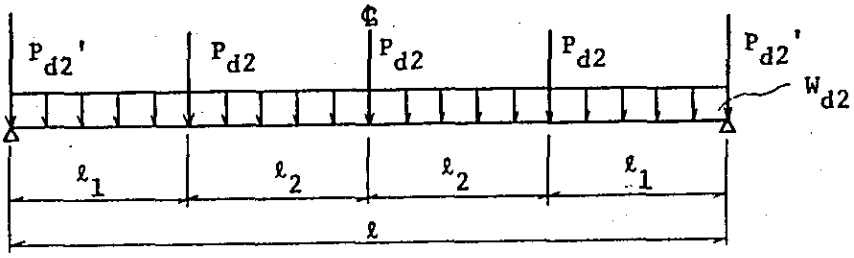
ℓ_1 : Length of the widened part of web (m) = 7.300

ℓ_2 : Location of diaphragm (m) = 7.300

n : Number of intermediate diaphragms

M_{d0} = 266.453 t·m

§2. Stress calculations of Cross beam cross section



· Bending moment (at center of span)

$$M_{d0} = \frac{1}{8} \cdot W_{d2} \cdot \ell^2 + P_{d2} \cdot \{ \frac{n}{2} \cdot (\ell_1 + \ell_2) - \ell_2 \}$$

where,

W_{d2} : Own weight of bridge slab between girders (t/m)
= 0.150

P_{d2} : Own weight of intermediate Cross beam (t)
= 0.224

P_{d2}': Own weight of end Cross beam (t)
= 0.628

ℓ : Span (m) = 29.200

ℓ_1, ℓ_2: Location of Cross beam (m) { ℓ_1 = 7.300, ℓ_2 = 7.300

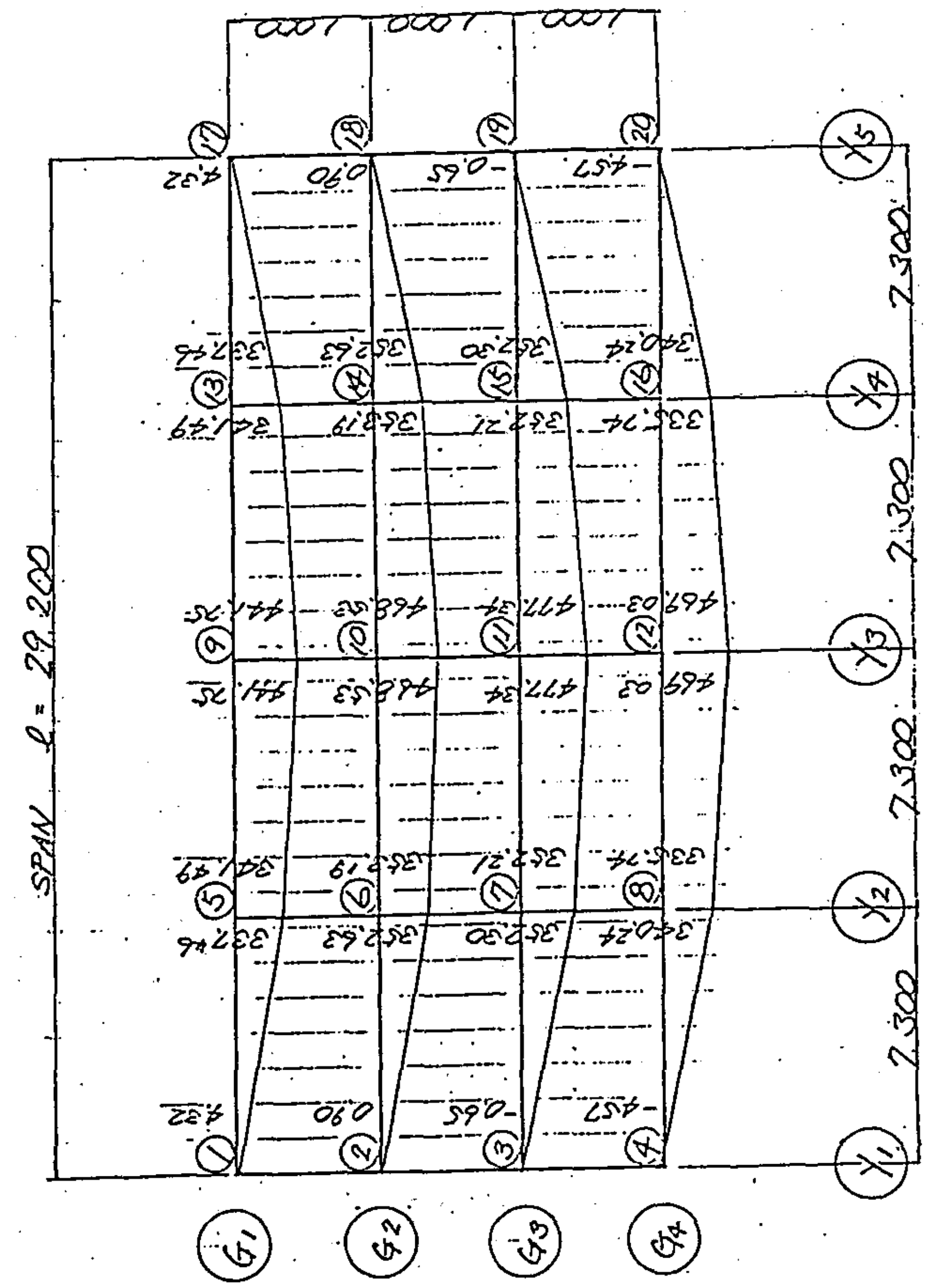
n : Number of intermediate Cross beam = 3

M_{d0} = 19.257 t·m

§3. Stress caused by Static and Live load acting at the top of bridge slab

(Computer calculation with grid-system)

Bending moment diagram (Unit: t·m)



§4. Summary of bending moment calculations (at section of mid-span)

(Unit: t m)

Load / Main girder	(1) Own Wt. M.girder	(2) Concrete betw. girders	(3) Ballast Track	(4) Electric pole	(5)=Σ(1)~(4) D. load total	Live load Mℓ (6)	Live load Case	Total ((5) + (6))
G_1	266.45	19.26	188.84	-2.35	472.20	255.26	6	727.46
G_2	〃	〃	197.57	5.56	488.84	265.40	6	754.24
G_3	〃	〃	198.32	13.61	497.64	265.41	6	763.05
G_4	〃	〃	191.17	22.60	499.48	255.26	6	754.74

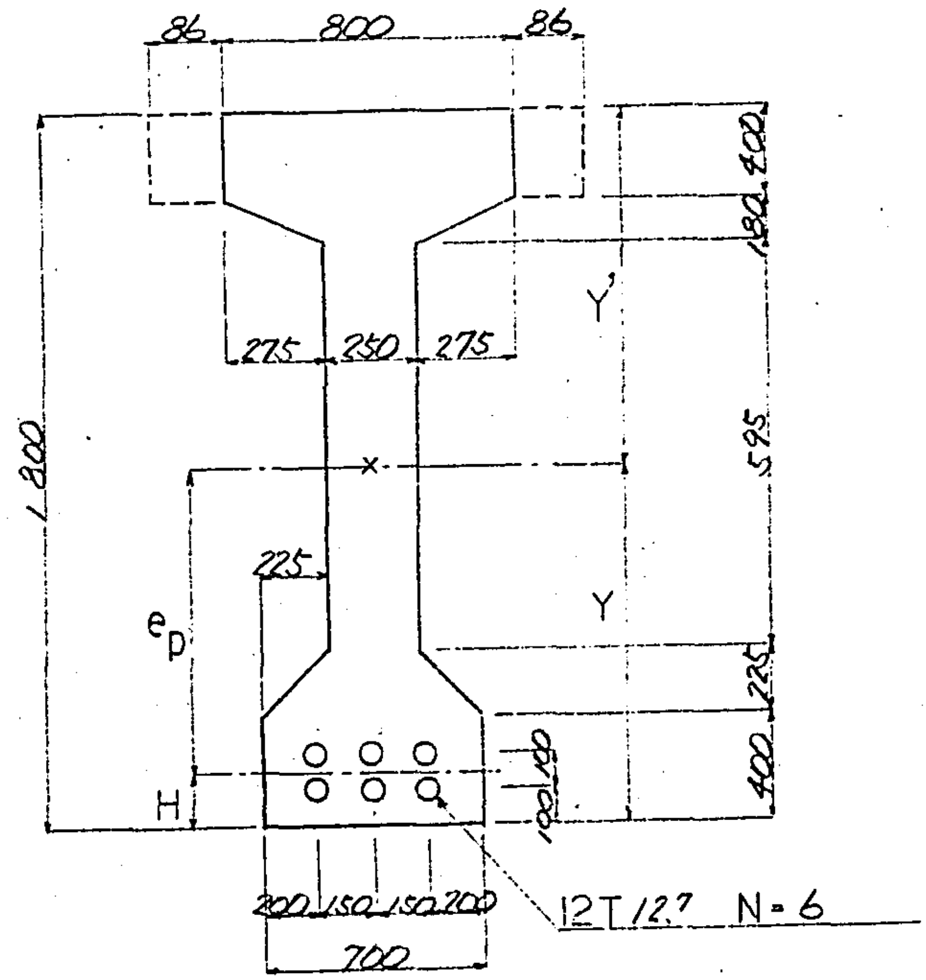
Developed the calculations in the preceding paragraphs, it became known that Maximum bending moment is exerted on Main girder.

Hence, further design calculations for Main girders will be represented by G_3 girder.

Chapter 5. Main girder design

§1. Basis for the design calculations

1. Configuration and Dimensions of the girder section of mid span



A : Cross sectional area (cm^2)

I : Moment of inertia (cm^4)

Z : Section modulus (cm^3)

r : Radius of gyration (cm)

ep: Location of cables (cm)

N : Number of cables

6pt: Tensile stress immediate after the practice of pre-stressing (kg/mm^2)

Pt: total tensile stressimmediate after the practice of pre-stressing

n : Ratio of Young's modulus between Modulus of P.C. cables and that of concrete

ψ : Coefficient of creep

ε_s: Drying contraction rate of conerete

η : Effective factor

2. Summary of sectional values (mid span)

(1) Gross cross section

- A_c = 9501.25 cm^2
- I_c = 34.092 x 10^6 cm^4
- Y_c = 93.0 cm
- Y_c' = 87.0 cm
- $Z_c = I_c/Y_c$ = 3.666 x 10^5 cm^3
- $Z_c' = I_c/Y_c'$ = 3.919 x 10^5 cm^3
- $\gamma_c^2 = I_c/A_c$ = 3.588 x 10^3 cm^2
- $e_{pc} = Y_c - H$ = 78.0 cm

(2) Net cross section

- A_0 = 9302.17 cm^2
- I_0 = 32.850 x 10^6 cm^4
- Y_0 = 94.6 cm
- Y_0' = 85.4 cm
- $Z_0 = I_0/Y_0$ = 3.473 x 10^5 cm^3
- $Z_0' = I_0/Y_0'$ = 3.847 x 10^5 cm^3
- $\gamma_0^2 = I_0/A_0$ = 3.531 x 10^3 cm^2
- $e_{p0} = Y_0 - H$ = 79.6 cm
- $Z_{0g} = I_0/e_{p0}$ = 4.127 x 10^5 cm^3

(3) Equivalent cross section

- $n = E_p/E_c = \frac{2.0 \times 10^6}{3.5 \times 10^5} = 5.71$
- $n \cdot A_{pl} = 5.71 \times 11.85 = 67.664\ cm^2$
- $A_{el} = 9708.15\ cm^2$
- $I_{\ell 1} = 35.325 \times 10^6\ cm^4$
- $Y_{\ell 1} = \Sigma A_{el} \cdot Y/\Sigma A_{el} = 91.3\ cm$
- $Y_{el}' = h - Y_{el} = 88.7\ cm$
- $Z_{el} = I_{el}/Y_{el} = 3.869 \times 10^5\ cm^3$
- $Z_{el}' = I_{el}/Y_{el}' = 3.983 \times 10^5\ cm^3$
- $\gamma_{el}^2 = I_{el}/A_{el} = 3.639 \times 10^3\ cm^2$
- $e_{pel} = Y_{el} - H = 76.3\ cm$
- $Z_{elg} = I_{el}/e_{pel} = 4.630 \times 10^5\ cm^3$

(4) Equivalent cross section (including concrete between Girders)

- $A_{ez} = 10.396.15\ cm^2$
- $I_{e2} = 38.449 \times 10^6\ cm^4$
- $Y_{e2} = \Sigma A_{e2} \cdot Y/\Sigma A_{e2} = 95.8\ cm$
- $Y_{e2}' = h - Y_{e2} = 84.2\ cm$
- $Z_{e2} = I_{e2}/Y_{e2} = 4.013 \times 10^5\ cm^3$
- $Z_{e2}' = I_{e2}/Y_{e2}' = 4.566 \times 10^5\ cm^3$
- $\gamma_{e2}^2 = I_{e2}/A_{e2} = 3.698 \times 10^3\ cm^2$
- $e_{pe2} = Y_{e2} - H = 80.8\ cm$
- $Z_{e2g} = I_{e2}/e_{pe2} = 4.759 \times 10^5\ cm^3$

§2. Summary of Bending stress calculations at mid span

Loads	Bending moment (x 10^5 kg·cm)	Section modulus (x 10^5 cm^3)		Bending stress (kg/cm^2)		
				At top fibre	At bottom fibre	At the gravity center of cables
Own weight of Main girder	M_{d0} = 266.45	Z_0'	3.847	69.3	——	——
		Z_0	- 3.473	——	-76.7	——
		Z_{0g}	- 4.127	——	——	-64.6
Concrete between girders	M_{d1} = 19.26	Z_{e1}'	3.983	4.8	——	——
		Z_{e1}	- 3.869	——	-5.0	——
		Z_{e1g}	- 4.630	——	——	- 4.2
Static load (Ballast track Electric pole)	M_{d2} = 211.93	Z_{e2}'	4.566	46.4	——	——
		Z_{e2}	- 4.013	——	-52.8	——
		Z_{e2g}	- 4.759	——	——	-44.5
Dead load Total	ΣM_d = 497.64	—	————	120.5	-134.5	-113.3
Live load	$M\ell$ = 265.41	Z_{e2}'	4.566	58.1	——	——
		Z_{e2}	- 4.013	——	-66.1	——
		Z_{e2g}	- 4.759	——	——	-55.8
Total	ΣM = 763.05	—	————	178.6	-200.6	-169.1

33
35

§3. Summary of stress calculations caused by pre-stressing at mid span

States	Items			Unit	Values
Immediate after the practice of pre-stressing	σ_{pt}			kg/mm^2	100
	A_p			mm^2	1185
	N				6
	A_0			$x10^3\ cm^2$	9.302
	e_{p0}			m	-0.796
	Section modulus	Z_0'		$x10^5\ cm^3$	3.847
		Z_0		"	-3.473
		Z_{0g}		"	-4.127
	P_t			$x10^3$ kg	711.00
	Stress	Top fibre	σ_{ct}'	kg/cm^2	-70.7
		Bottom fibre	σ_{ct}	"	239.4
		Grav. Center of cables	σ_{0pt}	"	213.5
Effective pre-stress	n				5.71
	ψ				2.60
	γ				0.05
	$\Sigma\sigma_{dg}$			kg/cm^2	-113.3
	E_p			$x10^5 kg/cm^2$	20
	ε_s			$x10^{-5}$	20
	$\Delta\sigma_{p\gamma}$			kg/mm^2	-5.0
	$\Delta\sigma_{p\psi}$			"	-13.51
	σ_{pe}			"	81.49
	η				0.815
	Stress	Top fibre	σ_{ce}'	kg/cm^2	-57.6
		Bottom fibre	σ_{ce}	"	195.1
		Grav. Center of cables	σ_{cpe}	"	174.0

34
85

§4. Summary of combined Bending stress at mid span

Loads		Stresses (kg/cm²) Top fibre	Stresses (kg/cm²) Bottom fibre
(1) Own weight of Main girder		69.3	-76.7
(2) Concrete between girders		4.8	-5.0
(3) Static load		46.4	-52.8
(4) Dead load total ((1) + (2) + (3))		120.5	-134.5
(5) Live load		58.1	-66.1
(6) Total load ((4) + (5))		178.6	-200.6
(7) Immediate after the pre-stressing		-70.7	239.4
(8) Effective pre-stress		-57.6	195.1
Combined stress Immediate after the pre-stressing	(1) + (7)	-1.4	162.7
	Allowable value	> - 15.0	< 180.0
Total Dead loading	(4) + (8)	62.9	60.6
Design loading	(6) + (8)	121.0	-5.5
	Allowable value	< 140.0	> -10.0

NO. 5 P.C. GIRDERS

SUPER-STRUCTURE

DESIGN CALCULATION

B05 - PC15 L = 35^m, H = 2.00^m

(Right Angle)

CONTENTS

Chapter 1. Design criteria

1. Basis for design and loading conditions

- Kind of bridge: Pre-stressed concrete railroad bridge.
- Type of Bridge/Girders: Bridge superstructure is a simple beam, consisted of 4 main girders aligned in parallel.
  Girder is made of post-tensioned concrete of I type section.
- Length of girder: 34.960 m
- Span of main girder: 34.200 m
- Live load : KS-16
- Impact coefficient : i = 0.332
- Crossing angle: { at younger change: 90° 00' 00"
  at elder change: 90° 00' 00"
- Railroad curve: STRAIGHT

2. Strength of materials for design

2-1. Concrete

(1) Concrete used for main girder

- Standard strength for design (28 day value):
  : σ_{CK} = 400 kg/cm^2
- Allowable compressive strength for bending calculation
  : σ_{ca} = 140 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 180 kg/cm^2
- Allowable tensile strength for bending calculation applied for,
  - design loading : σ_{cat} = -10 kg/cm^2
  - dead load : σ_{cat}' = 0 kg/cm^2
  - immediate after the pre-stressing: σ_{cat}''= -15 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_c=3.5×10^5 kg/cm^2

(2) Concrete used for lateral connection

- Standard strength for design (28 day value)
  : σ_{ck} = 300 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 110 kg/cm^2
- Allowable tensile strength for bending calculation : σ_{ca}' = -8 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 140 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_c=3.0x10^{5}kg/cm^2

(3) Cantilever part of bridge slab, edge coaming and handrail concrete

- Standard strength for design (28 day value) : $\sigma_{ck} = 240$ kg/cm^2
- Allowable compressive strength for bending calculation : $\sigma_{ca} = 80$ kg/cm^2

2-2. Steel materials used for P.C. concrete

(1) P.C. Cable (SWPR-7A) 12T 15.2 mm

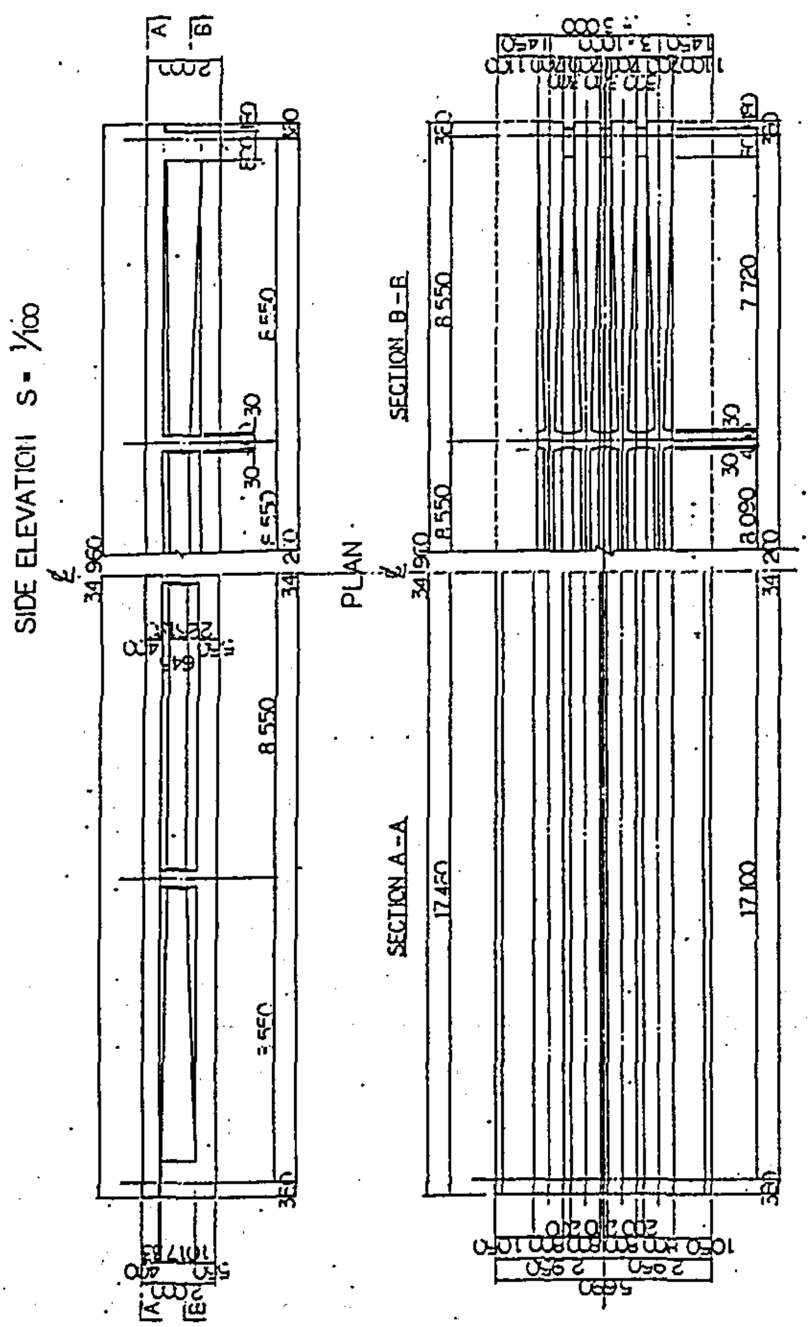
- Tensile strength : $\sigma_{pu} = 165$ kg/mm^2
- Yielding point : $\sigma_{py} = 140$ kg/mm^2
- Allowable tensile strength applied for,
  - design loading : $\sigma_{pa} = 99$ kg/mm^2
  - immediate after the pre-stressing: $\sigma_{pat} = 116$ kg/mm^2
  - during pre-stressing : $\sigma_{pai} = 126$ kg/mm^2
- Young's modulus of P.C. steel material : $E_p = 2.0 \times 10^6$ kg/cm^2

(2) P.C. steel bar (SBPR 95/110) ϕ 23 mm

- Tensile strength : $\sigma_{pu} = 110$ kg/mm^2
- Yielding point : $\sigma_{py} = 95$ kg/mm^2
- Allowable tensile strength applied for,
  - design loading : $\sigma_{pa} = 66$ kg/mm^2
  - immediate after the pre-stressing: $\sigma_{pat} = 77$ kg/mm^2
  - during pre-stressing : $\sigma_{pai} = 85.5$ kg/mm^2
- Young's modulus of P.C. steel material : $E_p = 2.0 \times 10^6$ kg/mm^2

2-3. Reinforcing Bar : SD 30

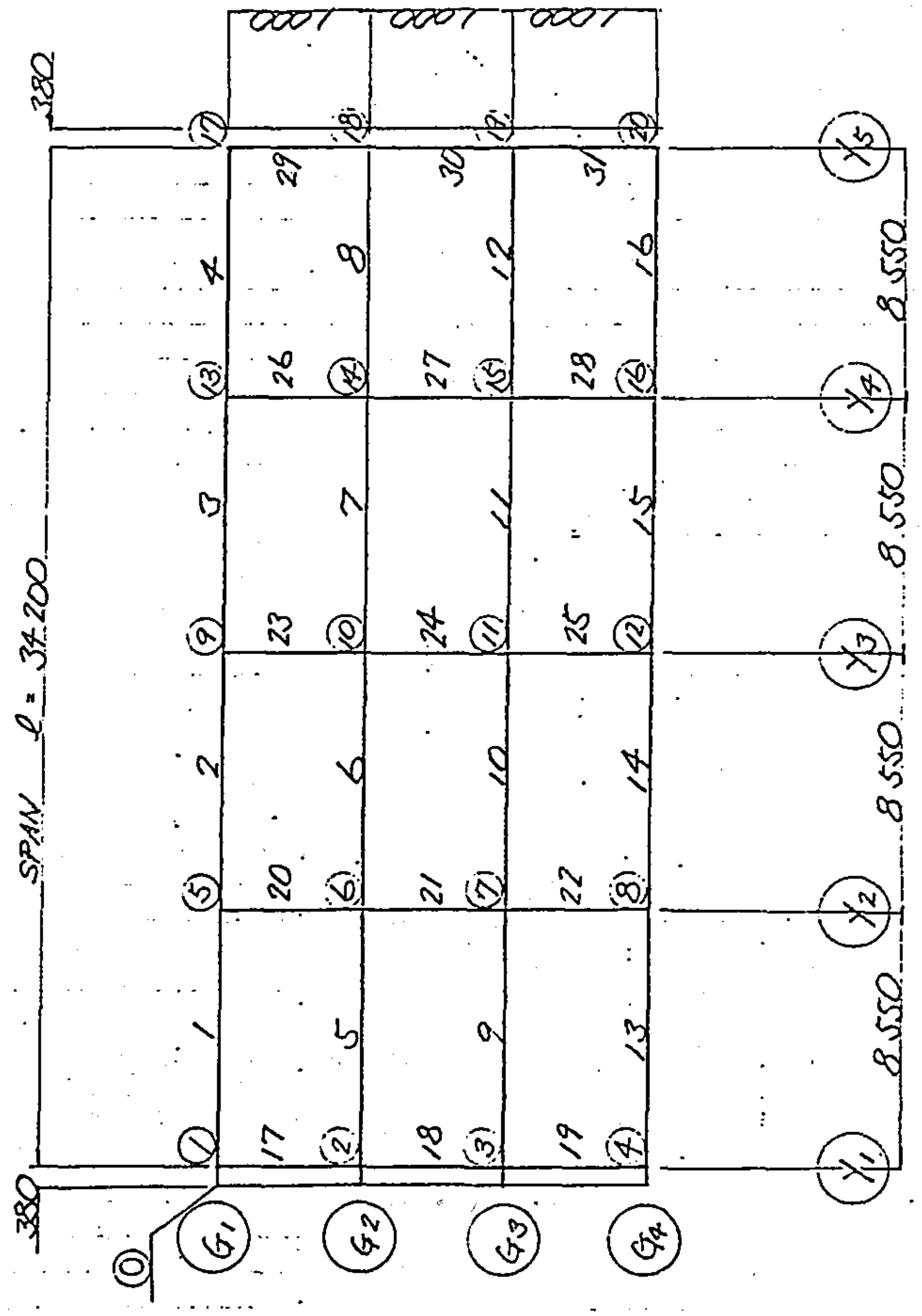
Chapter 2. Configuration and Dimensions of Bridge



Chapter 3.. Input for Grid-system calculation

§1. Numbering & Coordinates of Skeleton Point

1. Member numbering & Skeleton point numbering



2. Coordinates calculations of Skeleton points

Assumed the Skeleton point (0) as fundamental point, coordinates of other skeleton points are calculated as listed below.

(Unit: m)

Skeleton point number	Skeleton point coordinates		Skeleton point number	Skeleton point coordinates	
	x	y		x	y
(1)	0.380	0	(15)	26.030	-2.000
(2)	"	-1.000	(16)	"	-3.000
(3)	"	-2.000	(17)	34.580	0
(4)	"	-3.000	(18)	"	-1.000
(5)	8.930	0	(19)	"	-2.000
(6)	"	-1.000	(20)	"	-3.000
(7)	"	-2.000	( )		
(8)	"	-3.000	( )		
(9)	17.480	0	( )		
(10)	"	-1.000	( )		
(11)	"	-2.000	( )		
(12)	"	-3.000	( )		
(13)	26.030	0	( )		
(14)	"	-1.000	( )		

§2. Support conditions and Young's modulus of Concrete

1. Support conditions

Skeleton number	Rotation around		Z direction
	Y axis	X axis	
①	free	free	restricted
②	"	"	"
③	"	"	"
④	"	"	"
⑰	"	"	"
⑱	"	"	"
⑲	"	"	"
⑳	"	"	"

2. Young's modulus of concrete

(1) Young's modulus

Main girder : $E\ell = 3.50 \times 10^5 \ kg/cm^2 = 35.0 \times 10^5 \ t/m^2$

Cross beam : $Et = 3.00 \times 10^5 \ kg/cm^2 = 30.0 \times 10^5 \ t/m^2$

(2) Young's modulus corresponding to shearing

$G = 0.43E$

Main girder : $G\ell = 0.43 \times 35.0 \times 10^5 = 15.05 \times 10^5 \ t/m^2$

Cross beam : $Gt = 0.43 \times 30.0 \times 10^5 = 12.90 \times 10^5 \ t/m^2$

§3. Configuration and Dimensions of Main girder and Cross beam

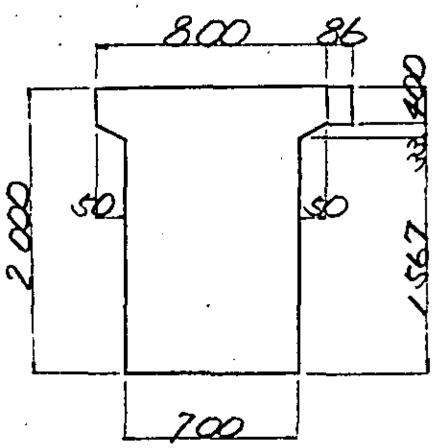
1. Configuration and Dimensions of Main girder

Dimension of concrete between Girders are as shown.

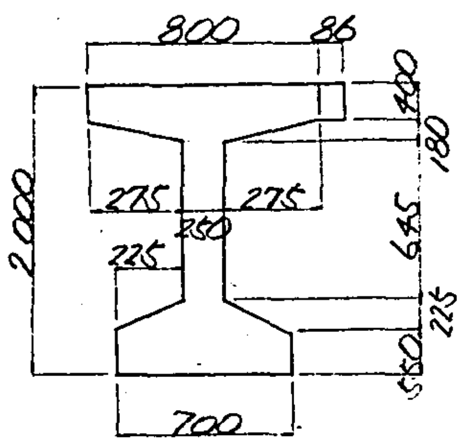
$$Et/E\ell = \frac{30.0 \times 10^5}{35.0 \times 10^5} = 0.857 \fallingdotseq 0.86$$

$$b = 0.200 \times 0.86 \times \frac{1}{2} = 0.086$$

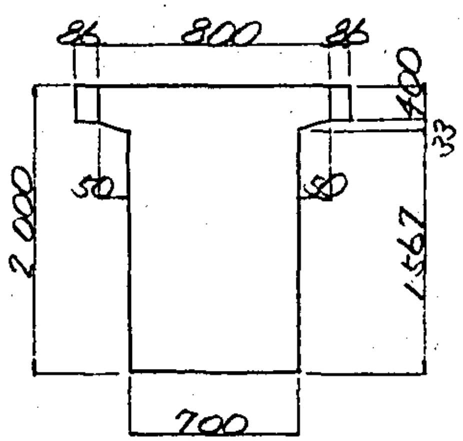
SECTION NUMBER ①: G1, G4 (Y1, Y5)



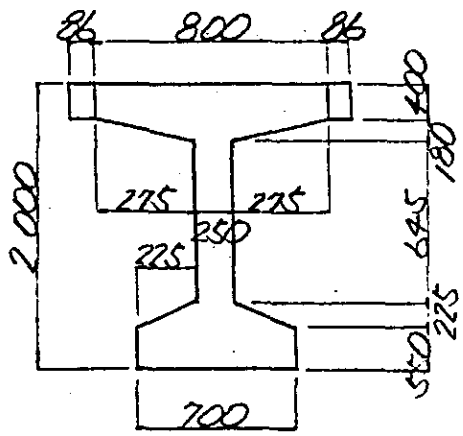
SECTION NUMBER ②: G1, G4 (Y2 ~ Y4)



SECTION NUMBER ③: G2 G3 (Y1, Y5)

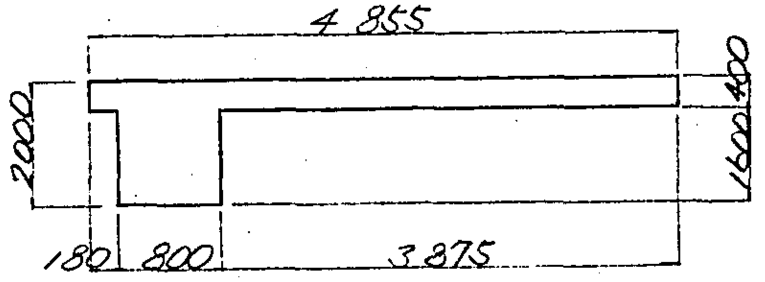


SECTION NUMBER ④: G2 G3 (Y2 ~ Y4)

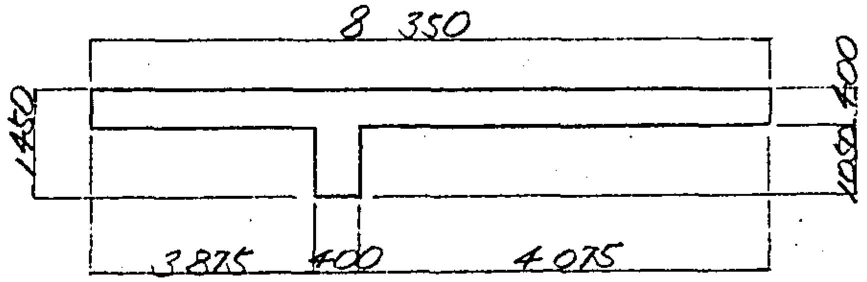


2. Configuration and Dimensions of Cross beam

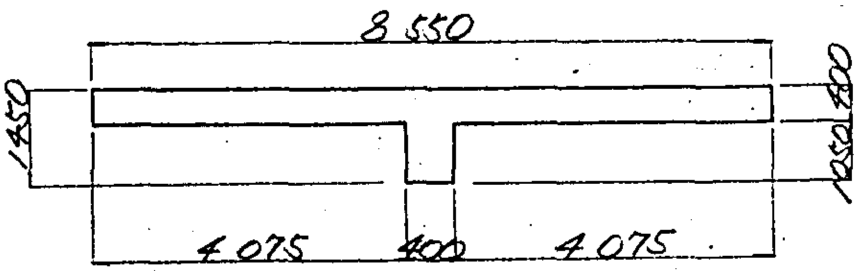
SECTION NUMBER ⑤ (y_1, y_5)



SECTION NUMBER ⑥ (y_2 y_4)



SECTION NUMBER ⑦ (y_3)



3. Applicable section number for various Girder, Beam/location

Girders		Location of number	Section number	Notes
Main girder	G_1, G_4	Location of Cross beam : y_1 , y_5	①	
		〃 : $y_2 \sim y_4$	②	
	G_2, G_3	〃 : y_1 , y_5	③	
		〃 : $y_2 \sim y_4$	④	
Cross beam		y_1 , y_5	⑤	
		y_2 , y_4	⑥	
		y_3	⑦	

4. Moment of inertia of the section

(Unit: m^4)

Girders		Members	Moment of inertia (Average)
Main girder	G_1 G_4	1. 4. 13. 16	0.50173
		2. 3. 14. 15	0.49005
	G_2 G_3	5. 8. 9. 12	0.52179
		6. 7. 10. 11	0.51034
Cross beam		17. 18. 19. 29. 30. 31	1.07046
		20. 21. 22. 26. 27. 28	0.27922
		23. 24. 25	0.28080

§4. Loads and Loading conditions

1. Application of loads for calculation

(1) Application of static load

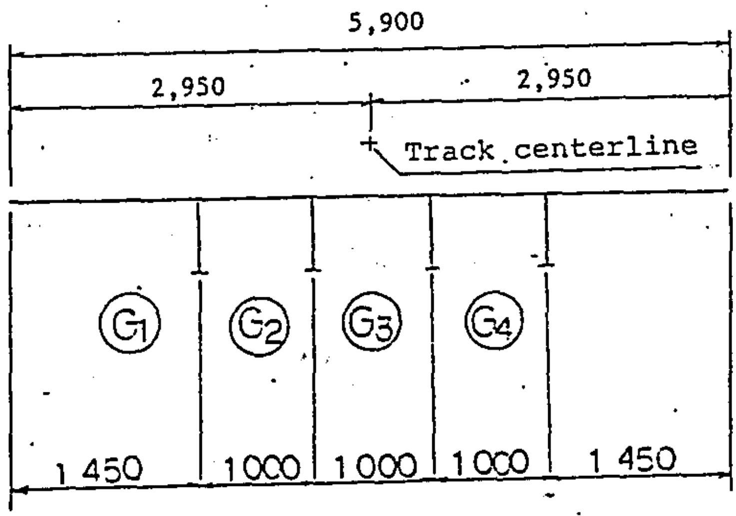
As the grid-system are carried out based on influence lines, the static load loading is applied in dual ways, one is a lined loading and the other is a uniformly distributed loading, to determine the loading length and width.

(2) Application of combined train loading

(a) Train load loading

Train load is assumed to be transmitted through sleepers downwards and distributed to the enlarged width within inclined lines with 53 deg. starting at both end points of sleeper bottom.

Distribution of loads through track is shown in the sketch drawing.



(b) Combined loading of train load

(i) Train load is supposed to distribute entire length of the span.

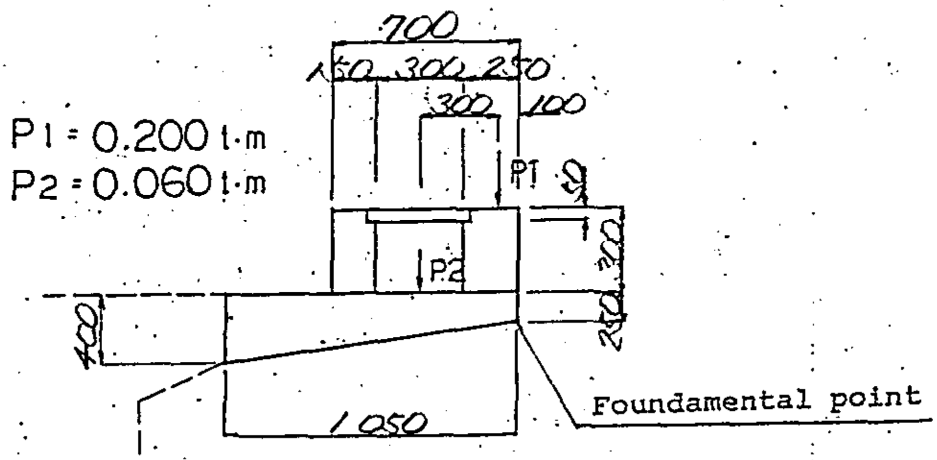
(ii) Train load is supposed to distribute limited to one side of span with 1/2 ℓ length.

Train load is applied combined the above (i) and (ii) loadings. Thus, further calculations are made for the sectional strength.

2. Dead load calculations of the own weight of structure

(1) Cantilever part of bridge slab, edge coaming and handrail concrete

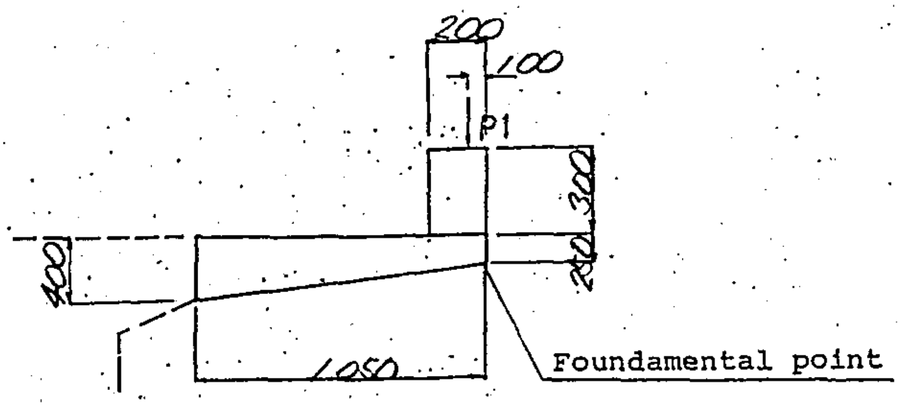
(a) G4 girder side



Load/Load acting point

Total dead load : ΣW (t/m) = 1.452
Total bending moment : $\Sigma W X$ (t-m/m) = 0.852
Acting point of resultant force : $X = \Sigma W X / \Sigma W$ (m) = 0.587

(b) G1 girder side

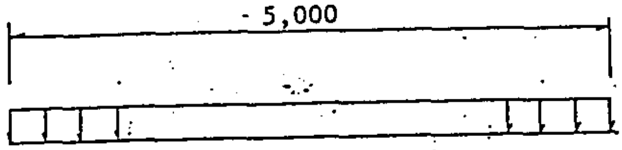


Load/Load acting point

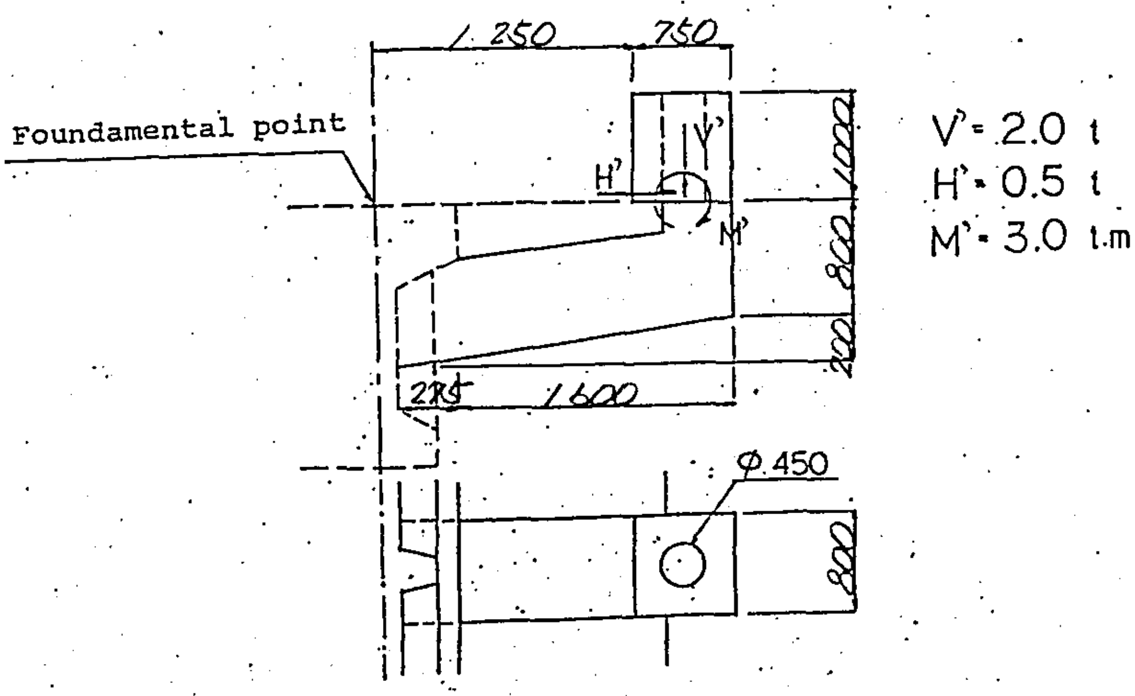
Total dead load : ΣW (t/m) = 1.203
Total bending moment : $\Sigma W X$ (t-m/m) = 0.517
Acting point of resultant force : $X = \Sigma W X / \Sigma W$ (m) = 0.430

(2) Graded Concrete

$W_p = 2.35 \times 0.07 = 0.165\ t/m^2$



(3) Electric pole and its supporting beam

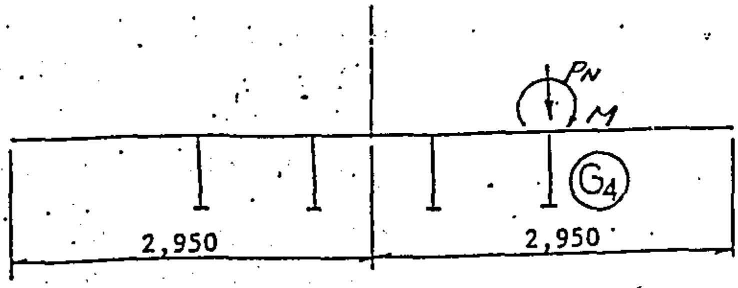


Load/Load acting point

Total dead load : ΣW (t/m) = 5.403 = P_N

Total bending moment : $\Sigma W X$ (t-m/m) = 7.809

$M = M' + \Sigma WX$ = 10.809



3. Dead load calculations of surcharge

(1) Surcharge load of ballast

Calculated as a uniformly distributed load.

$$W_B = 1.9\ t/m^3 \times (h_B - h_p) = 0.914\ t/m^2$$

(2) Surcharge load of track assembly

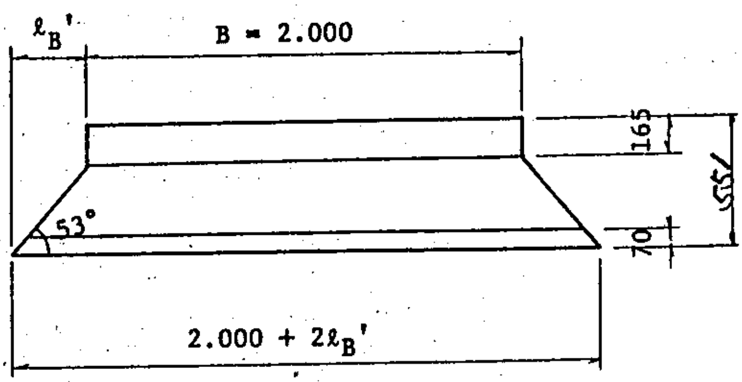
Load of track assembly is assumed to be distributed on the bridge slab with the width between two points on the slab, where lines drawn from the both ends of sleeper bottom with 53 deg. inclination towards outward-downward, crossing the slab surface.

- Load of track assembly : ΣW_R = 0.450 t/m
- Width of sleeper : B = 2.000 m
- Thickness of sleeper : h_M = 0.165 m
- Height between the girder top and the sleeper top : h_B = 0.551 m
- Average thickness of graded concrete for drainage : h_p = 0.070 m

$$2\ell_B' = 2(h_B - h_M) \cdot \text{Cot } 53° = 0.582\ m$$

- Load distribution width:

$$\ell_B = B + 2\ell_B' = 2.582\ m$$



Uniformly distributed load:

$$W_R = \frac{\Sigma W_R}{\ell_B} = 0.174\ t/m^2$$

4 Uniformly distributed load, equivalent to the train loading

Bending moment calculation:

For the bending moment calculation, the equivalent uniformly distributed load at the 1/4 span point will be employed and confirmed as calculated below.

$$M\ell = \{M\ell_{min} + \frac{\ell - \ell_{min}}{\ell_{max} - \ell_{min}} \cdot (M\ell_{max} - M\ell_{min})\}\ \gamma \cdot \beta \times \frac{1}{18}$$

where, $\ell = 34.200$, $\ell_{max} = 35.000$, $\ell_{min} = 34.000$

$\gamma = 2$ $\beta = 16$

$M\ell(\ell/4)_{min} = 435.4$, $M\ell(\ell/4)_{max} = 458.5$

$M\ell(\ell/2)_{min} = 558.0$, $M\ell(\ell/2)_{max} = 592.0$

$$M\ell(\ell/4) = \{435.4 + \frac{0.20}{1.00} \times (458.5 - 435.4)\}\ 2 \times 16 \times \frac{1}{18}$$

$$= 782.258$$

$$M\ell(\ell/2) = \{558.0 + \frac{0.20}{1.00} \times (592.0 - 558.0)\}\ 2 \times 16 \times \frac{1}{18}$$

$$= 1.004.089$$

Equivalent uniformly distributed load at $\ell/4$ span point, which is Wm, will be

$$W_m = \frac{32}{3} \times \frac{M\ell(\ell/4)}{\ell^2} = 7.134$$

Employed the above Wm value and applied for the bending moment calculation at $\ell/2$ point.

$$M'_{\ell/2} = W_m \cdot \frac{\ell^2}{8} = 1043.026\ t.m$$

$$> M\ell_{(\ell/2)} = 1.004.089\ t.m$$

The result is larger than the value of $M_{\ell/2}$.

$$Wm = 7.134 \ t/m$$

Train loading for bending moment:

$$W\ell = Wm(1 + i) = 9.502 \ t/m$$

Train loading for bending moment: calculation

Train loading is distributed expanded with 53 deg. inclination from the both ends of sleeper bottom.

Uniformly distributed load: $W\ell$

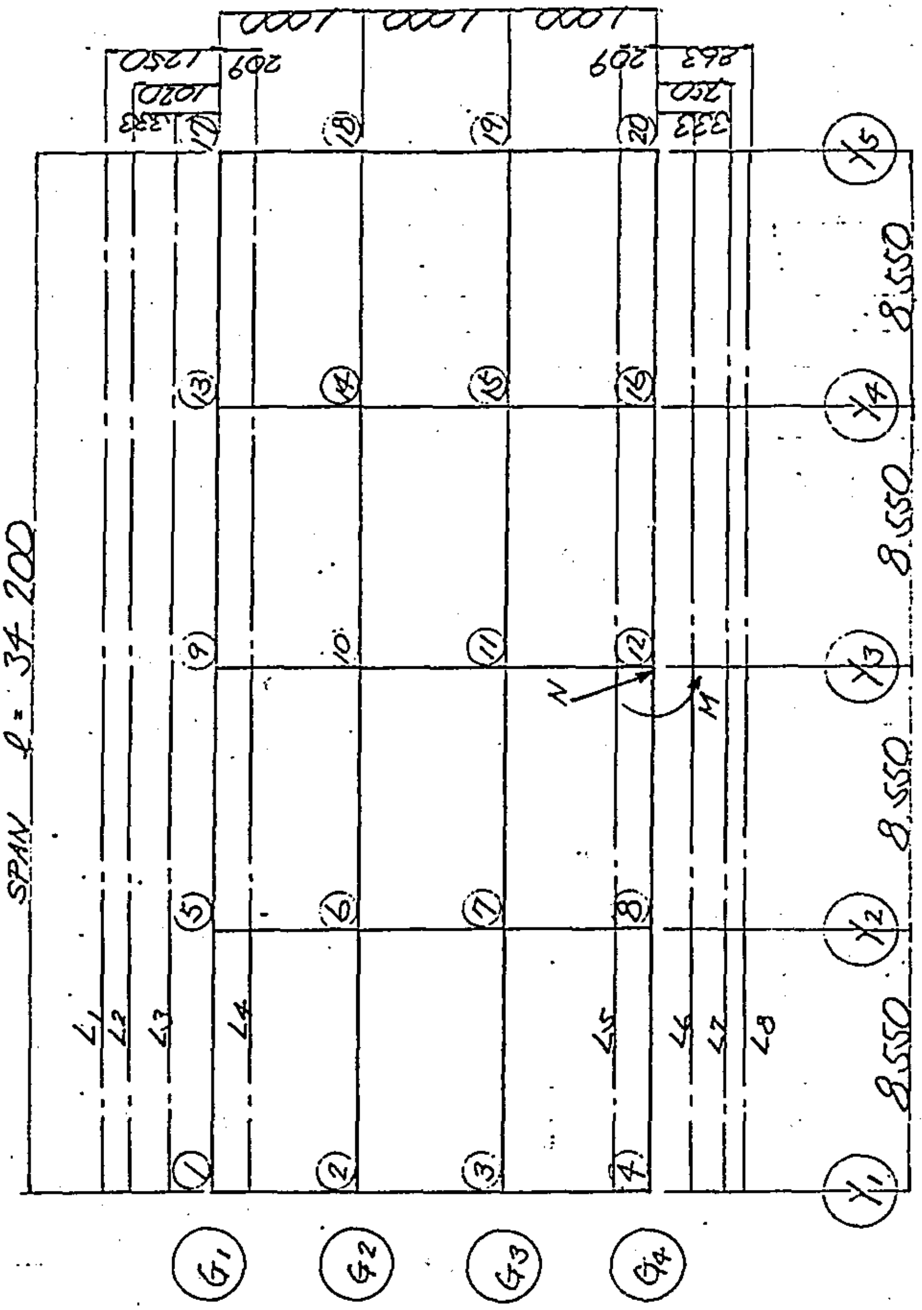
$$W\ell = \frac{Wm \ (1 + i)}{\ell_B} = 3.680 \ t/m^2$$

5. Load/Loading point of various loadings

(1) Summary of loads

Load	Cases	Title	Load distribution area: Width	Load distribution area: Length	Intensity of load	Category of load
Dead load of surcharge and structure	Case 1	VANJO $-D_1$	L_8	$Y_1 \sim Y_5$	1.452 t/m	Canti. slab, handrail conc., etc.
			L_2	$Y_1 \sim Y_5$	1.203 "	
			$L_1 \sim L_7$	$Y_1 \sim Y_5$	0.165 t/m²	Graded conc.
			$L_3 \sim L_6$	$Y_1 \sim Y_5$	0.914 "	Ballast
			$L_4 \sim L_5$	$Y_1 \sim Y_5$	0.174 "	Track assembly
Electric pole, etc.	Case 2	DENCHU $-D_1$	G_4	Y_3	N = 5.403 t	Electric pole and its supporting beam
					M = 10.809 t·m	
Train load	Case 3	L_1	$L_4 \sim L_5$	$Y_1 \sim Y_5$	3.680 t/m²	Live load intensity applied for bending moment calculation
	Case 4	L_2	$L_4 \sim L_5$	$Y_1 \sim Y_3$	3.680 "	

(2) Loading conditions



6. Combined loading

(1) Case 1: Dead load of surcharge

(2) Case 2: Dead load of electric pole

(3) Case 3: Train load, loaded on full span

(4) Case 4: Train load, loaded on half span

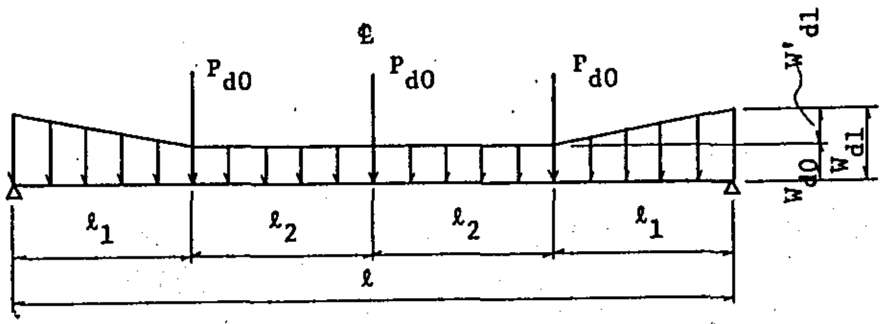
(5) Case 5: Case 1 + Case 2

(6) Case 6: Case 5 + Case 3

(7) Case 7: Case 5 + Case 4

Chapter 4. Design calculations of Main girder cross section

§1. Bending moment caused by own weight of Main girder



Bending moment (at center of span)

$$M_{d0} = \frac{1}{8}\cdot W_{d0}\cdot \ell^2 + \frac{1}{6}\cdot W_{d1}'\cdot \ell_1{}^2 + P_{d0}\cdot\{\frac{n}{2}(\ell_1 + \ell_2) - \ell_2\}$$

W_{d0} : Per meter weight of the section at the center (t/m) = 2.669

W_{d1} : Per meter weight of the section at the point of support (t/m) = 3.604

$W_{d1}' = W_{d1} - W_{d0}$ = 0.935

P_{d0} : Weight of intermediate diaphragm (t) = 0.402

ℓ : Span (m) = 34.200

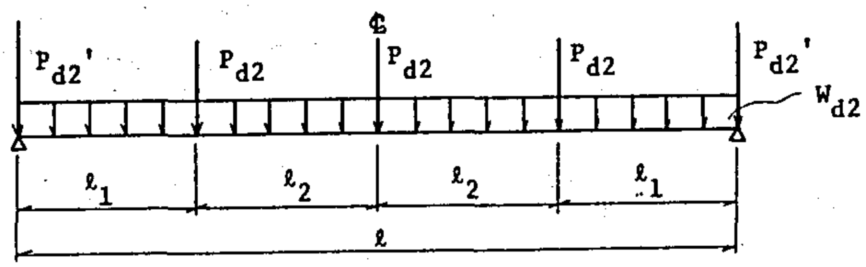
ℓ_1 : Length of the widened part of web (m) = 8.550

ℓ_2 : Location of diaphragm (m) = 8.550

n : Number of intermediate diaphragms

M_{d0} = [illegible].487 t·m

§2. Stress calculations of Cross beam cross section



- Bending moment (at center of span)

$$M_{d0} = \frac{1}{8} \cdot W_{d2} \cdot \ell^2 + P_{d2} \cdot \{ \frac{n}{2} \cdot (\ell_1 + \ell_2) - \ell_2 \}$$

where,

W_{d2} : Own weight of bridge slab between girders (t/m) = 0.150

P_{d2} : Own weight of intermediate Cross beam (t) = 0.235

P_{d2}': Own weight of end Cross beam (t) = 0.718

ℓ : Span (m) = 34.200

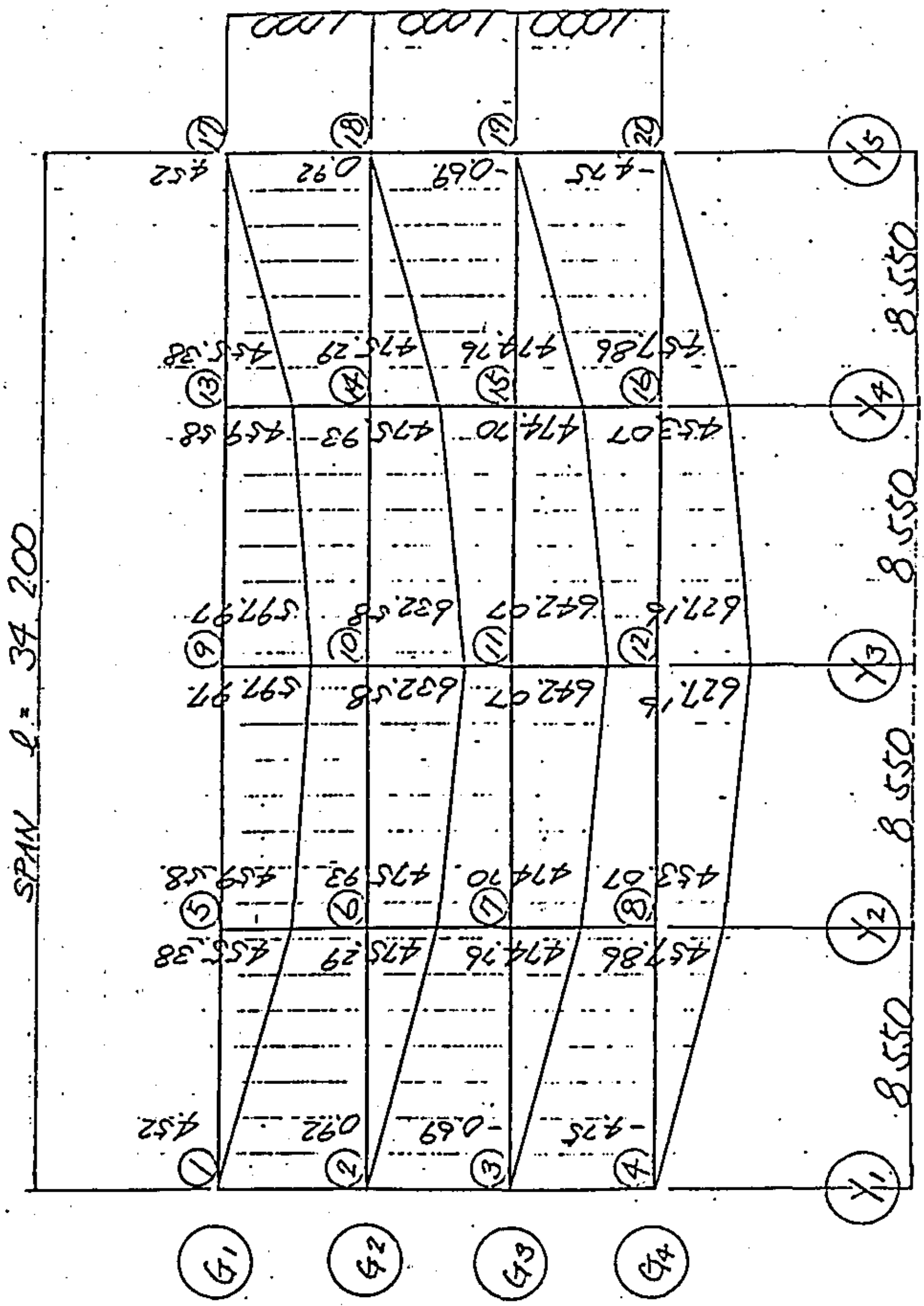
ℓ_1, ℓ_2: Location of Cross beam (m) { ℓ_1 = 8.550, ℓ_2 = 8.550

n : Number of intermediate Cross beam = 3

M_{d0} = 25.949 t·m

§3. Stress caused by Static and Live load acting at the top of bridge slab

(Computer calculation with grid-system)
Bending moment diagram (Unit: t·m)



§4, Summary of bending moment calculations (at section of mid-span)

(Unit: t m)

Load / Main girder	Own Wt. M.girder (1)	Concrete betw. girders (2)	Ballast Track (3)	Electric pole (4)	(5)=Σ(1)~(4) D. load total	Live load Mℓ (6)	Live load Case	Total ((5) + (6))
G_1	408.487	25.949	259.142	-1.480	692.098	340.307	6	1032.405
G_2	"	"	271.204	7.077	712.717	354.295	6	1067.012
G3	"	"	272.107	15.668	722.211	354.295	6	1076.506
G4	"	"	261.919	24.931	721.286	340.307	6	1061.593

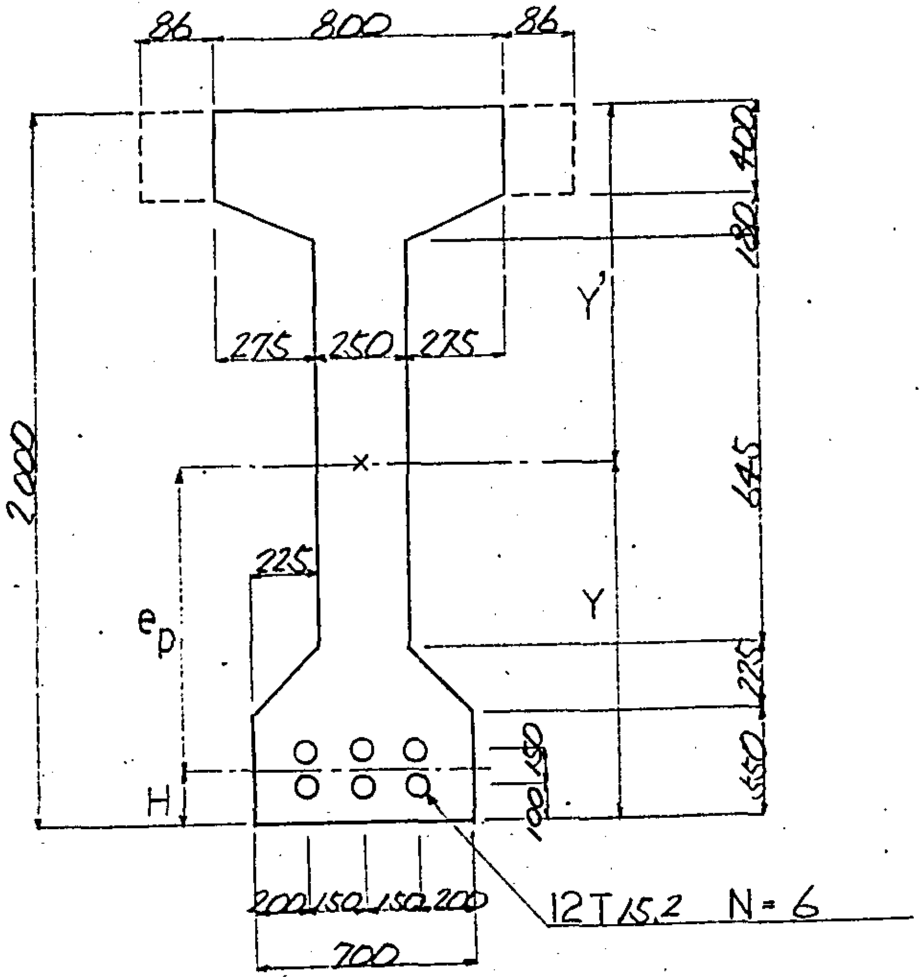
Developed the calculations in the preceding paragraphs, it became known that Maximum bending moment is exerted on Main girder.

Hence, further design calculations for Main girders will be represented by G_3 girder.

Chapter 5. Main girder design

§1. Basis for the design calculations

1. Configuration and Dimensions of the girder section of mid span



A : Cross sectional area (cm^2)

I : Moment of inertia (cm^4)

Z : Section modulus (cm^3)

r : Radius of gyration (cm)

ep: Location of cables (cm)

N : Number of cables

6pt: Tensile stress immediate after the practice of pre-stressing (kg/mm^2)

Pt: total tensile stressimmediate after the practice of pre-stressing

n : Ratio of Young's modulus between Modulus of P.C. cables and that of concrete

ψ : Coefficient of creep

ε_s: Drying contraction rate of conerete

η : Effective factor

2. Summary of sectional values (mid span)

(1) Gross cross section

- A_c = 10.676.3 cm^2
- I_c = 46.848 $\times 10^6$ cm^4
- Y_c = 100.4 cm
- Y_c' = 99.6 cm
- $Z_c = I_c/Y_c$ = 4.666 $\times 10^5$ cm^3
- $Z_c' = I_c/Y_c'$ = 4.704 $\times 10^5$ cm^3
- $\gamma_c^2 = I_c/A_c$ = 4.388 $\times 10^3$ cm^2
- $e_{pc} = Y_c - H$ = 82.9 cm

(2) Net cross section

- A_0 = 10.411.2 cm^2
- I_0 = 44.965 $\times 10^6$ cm^4
- Y_0 = 102.5 cm
- Y_0' = 97.5 cm
- $Z_0 = I_0/Y_0$ = 4.387 $\times 10^5$ cm^3
- $Z_0' = I_0/Y_0'$ = 4.612 $\times 10^5$ cm^3
- $\gamma_0^2 = I_0/A_0$ = 4.319 $\times 10^3$ cm^2
- $e_{p0} = Y_0 - H$ = 85.0 cm
- $Z_{0g} = I_0/e_{p0}$ = 5.290 $\times 10^5$ cm^3

(3) Equivalent cross section

- $n = E_p/E_c = \dfrac{2.0 \times 10^6}{3.5 \times 10^5} = 5.71$
- $n \cdot A_{p1} = 5.71 \times 16.64 = 95.01\ cm^2$
- $A_{e1} = 10.981.3\ cm^2$
- $I_{\ell 1} = 48.902 \times 10^6\ cm^4$
- $Y_{\ell 1} = \Sigma A_{e1} \cdot Y / \Sigma A_{e1} = 98.1\ cm$
- $Y_{e1}' = h - Y_{e1} = 101.9\ cm$
- $Z_{e1} = I_{e1}/Y_{e1} = 4.985 \times 10^5\ cm^3$
- $Z_{e1}' = I_{e1}/Y_{e1}' = 4.799 \times 10^5\ cm^3$
- $\gamma_{e1}^2 = I_{e1}/A_{e1} = 4.464 \times 10^3\ cm^2$
- $e_{pe1} = Y_{e1} - H = 80.5\ cm$
- $Z_{e1g} = I_{e1}/e_{pe1} = 6.075 \times 10^5\ cm^3$

(4) Equivalent cross section (including concrete between Girders)

- $A_{ez} = 11.669.3\ cm^2$
- $I_{e2} = 53.337 \times 10^6\ cm^4$
- $Y_{e2} = \Sigma A_{e2} \cdot Y / \Sigma A_{e2} = 102.9\ cm$
- $Y_{e2}' = h - Y_{e2} = 97.1\ cm$
- $Z_{e2} = I_{e2}/Y_{e2} = 5.183 \times 10^5\ cm^3$
- $Z_{e2}' = I_{e2}/Y_{e2}' = 5.493 \times 10^5\ cm^3$
- $\gamma_{e2}^2 = I_{e2}/A_{e2} = 4.571 \times 10^3\ cm^2$
- $e_{pe2} = Y_{e2} - H = 85.4\ cm$
- $Z_{e2g} = I_{e2}/e_{pe2} = 6.246 \times 10^5\ cm^3$

§2. Summary of Bending stress calculations at mid span

Loads	Bending moment (x 10^5 kg·cm)	Section modulus (x 10^5 cm^3)		Bending stress (kg/cm^2) At top fibre	At bottom fibre	At the gravity center of cables
Own weight of Main girder	M_{d0} = 408.49	Z_0'	4.612	88.6	—	—
		Z_0	-4.387	—	-93.1	—
		Z_{0g}	-5.290	—	—	-77.2
Concrete between girders	M_{d1} = 25.95	Z_{e1}'	4.799	5.4	—	—
		Z_{e1}	-4.985	—	-5.2	—
		Z_{e1g}	-6.075	—	—	-4.3
Static load (Ballast track Electric pole)	M_{d2} = 287.77	Z_{e2}'	5.493	52.4	—	—
		Z_{e2}	-5.183	—	-55.5	—
		Z_{e2g}	-6.246	—	—	-46.1
Dead load Total	ΣM_d = 722.21	—	—	146.4	-153.8	-127.6
Live load	$M\ell$ = 354.30	Z_{e2}'	5.493	64.5	—	—
		Z_{e2}	-5.183	—	-68.4	—
		Z_{e2g}	-6.246	—	—	-56.7
Total	ΣM = 1076.51	—	—	210.9	-222.2	-184.3

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§3. Summary of stress calculations caused by pre-stressing at mid span

States	Items			Unit	Values
Immediate after the practice of pre-stressing	σ_{pt}			kg/mm^2	94
	A_p			mm^2	1664
	N				6
	A_0			$\times 10^3\ cm^2$	10.411
	e_{p0}			m	-0.850
	Section modulus	Z_0'		$\times 10^5\ cm^3$	4.612
		Z_0		"	-4.387
		Z_{0g}		"	-5.290
	P_t			$\times 10^3$ kg	938.50
	Stress	Top fibre	σ_{ct}'	kg/cm^2	-82.9
		Bottom fibre	σ_{ct}	"	271.9
		Grav.Center of cables	σ_{0pt}	"	240.9
Effective pre-stress	n				5.71
	ψ				2.6
	γ				0.05
	$\Sigma\sigma dg$			kg/cm^2	-127.6
	E_p			$\times 10^5 kg/cm^2$	20
	ε_s			$\times 10^{-5}$	20
	$\Delta\sigma_{p\gamma}$			kg/mm^2	-4.7
	$\Delta\sigma_{p\psi}$			"	-14.3
	σ_{pe}			"	75.0
	η				0.798
	Stress	Top fibre	σ_{ce}'	kg/cm^2	-66.2
		Bottom fibre	σ_{ce}	"	217.0
		Grav.Center of cables	σ_{cpe}	"	192.2

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§4. Summary of combined Bending stress at mid span

Loads		Stresses (kg/cm^2) Top fibre	Bottom fibre
(1) Own weight of Main girder		88.6	-93.1
(2) Concrete between girders		5.4	-5.2
(3) Static load		52.4	-55.5
(4) Dead load total ((1) + (2) + (3))		146.4	-153.8
(5) Live load		64.5	-68.4
(6) Total load ((4) + (5))		210.9	-222.2
(7) Immediate after the pre-stressing		-82.9	271.9
(8) Effective pre-stress		-66.2	217.0
Combined stress Immediate after the pre-stressing	(1) + (7)	5.7	178.8
	Allowable value	> - 15.0	< 180.0
Total Dead loading	(4) + (8)	80.2	63.2
Design loading	(6) + (8)	144.7	-5.2
	Allowable value	≒ 140.0	> -10.0

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NO. 6 P.C. GIRDERS

SUPER-STRUCTURE

DESIGN CALCULATION

B11 - PC28 L = 30m, H = 2.15m

(Curve R = 500m)

CONTENTS

Chapter 1. Design criteria

1. Basis for design and loading conditions

- Kind of bridge: Pre-stressed concrete railroad bridge.
- Type of Bridge/Girders: Bridge superstructure is a simple beam, consisted of 4 main girders aligned in parallel.
  Girder is made of post-tensioned concrete of I type section.
- Length of girder: 29.960 m
- Span of main girder: 29.200 m
- Live load : KS-16
- Impact coefficient : i = 0.342
- Crossing angle: { at younger change: 90° 00′ 00″
  at elder change: 90° 00′ 00″
- Railroad curve: R = 500 m

2. Strength of materials for design

2-1. Concrete

(1) Concrete used for main girder

- Standard strength for design (28 day value)
  : σ_{CK} = 400 kg/cm^2
- Allowable compressive strength for bending calculation
  : σ_{ca} = 140 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 180 kg/cm^2
- Allowable tensile strength for bending calculation applied for,
  - design loading : σ_{cat} = -10 kg/cm^2
  - dead load : σ_{cat}' = 0 kg/cm^2
  - immediate after the pre-stressing: σ_{cat}'' = -15 kg/cm^2
- Young's modulus corresponding to the standard strength for design : $E_c = 3.5\times10^5$ kg/cm^2

(2) Concrete used for lateral connection

- Standard strength for design (28 day value)
  : σ_{ck} = 300 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 110 kg/cm^2
- Allowable tensile strength for bending calculation : σ_{ca}' = -8 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 140 kg/cm^2
- Young's modulus corresponding to the standard strength for design : $E_c = 3.0\times10^5$ kg/cm^2

(3) Cantilever part of bridge slab, edge coaming and handrail concrete

- Standard strength for design (28 day value)
  : σ_{ck} = 240 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 80 kg/cm^2

2-2. Steel materials used for P.C. concrete

(1) P.C. Cable (SWPR-7B) 12T12.7 mm

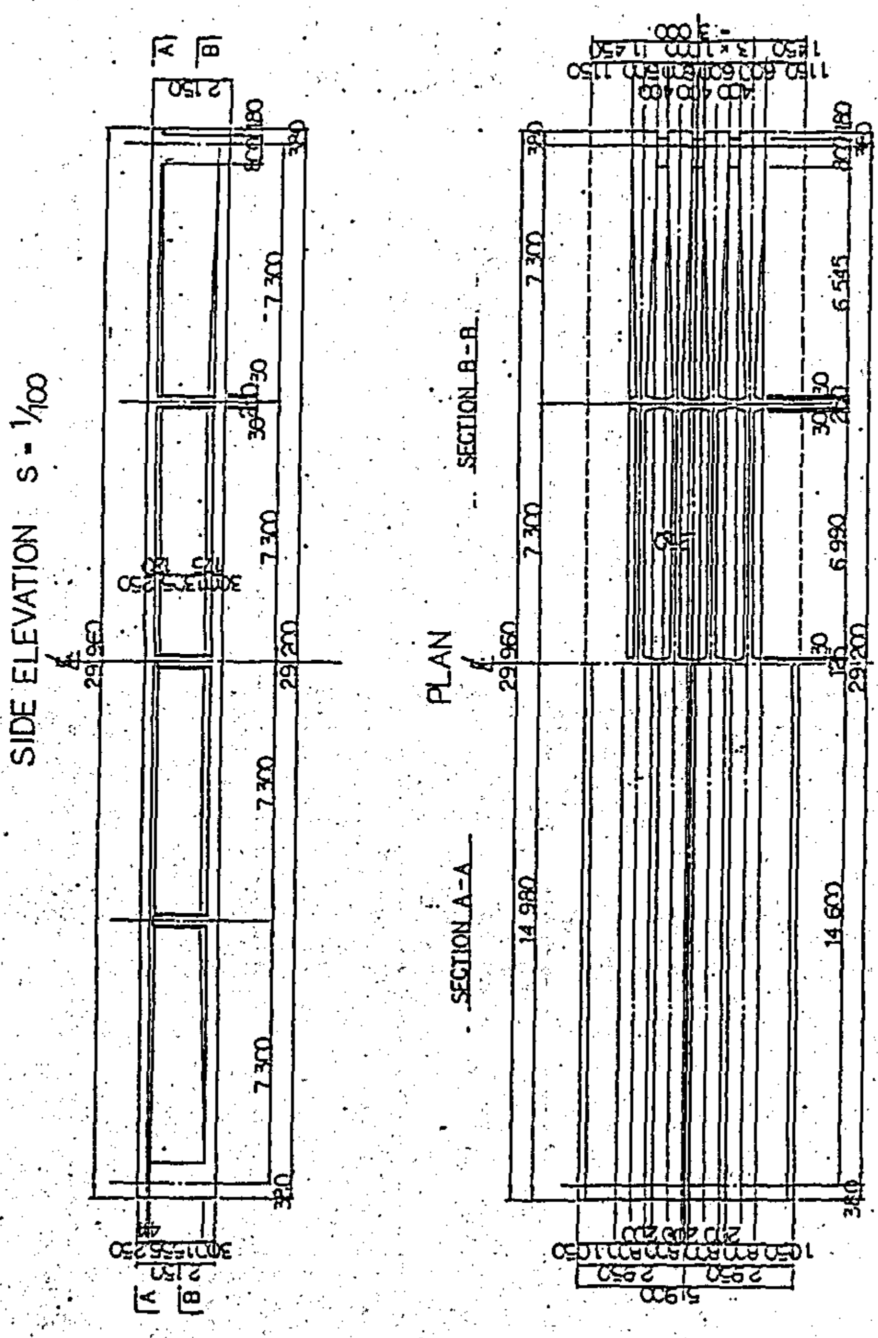
- Tensile strength : σ_{pu} = 190 kg/mm^2
- Yielding point : σ_{py} = 160 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 114 kg/mm^2
  - immediate after the pre-stressing: σ_{pat} = 133 kg/mm^2
  - during pre-stressing : σ_{pai} = 145 kg/mm^2
- Young's modulus of P.C. steel material
  : $E_p = 2.0 \times 10^6$ kg/cm^2

(2) P.C. steel bar (SBPR 95/110) ϕ 23 mm

- Tensile strength : σ_{pu} = 110 kg/mm^2
- Yielding point : σ_{py} = 95 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 66 kg/mm^2
  - immediate after the pre-stressing: σ_{pat} = 77 kg/mm^2
  - during pre-stressing : σ_{pai} = 85.5 kg/mm^2
- Young's modulus of P.C. steel material
  : $E_p = 2.0 \times 10^6$ kg/mm^2

2-3. Reinforcing Bar : SD 30

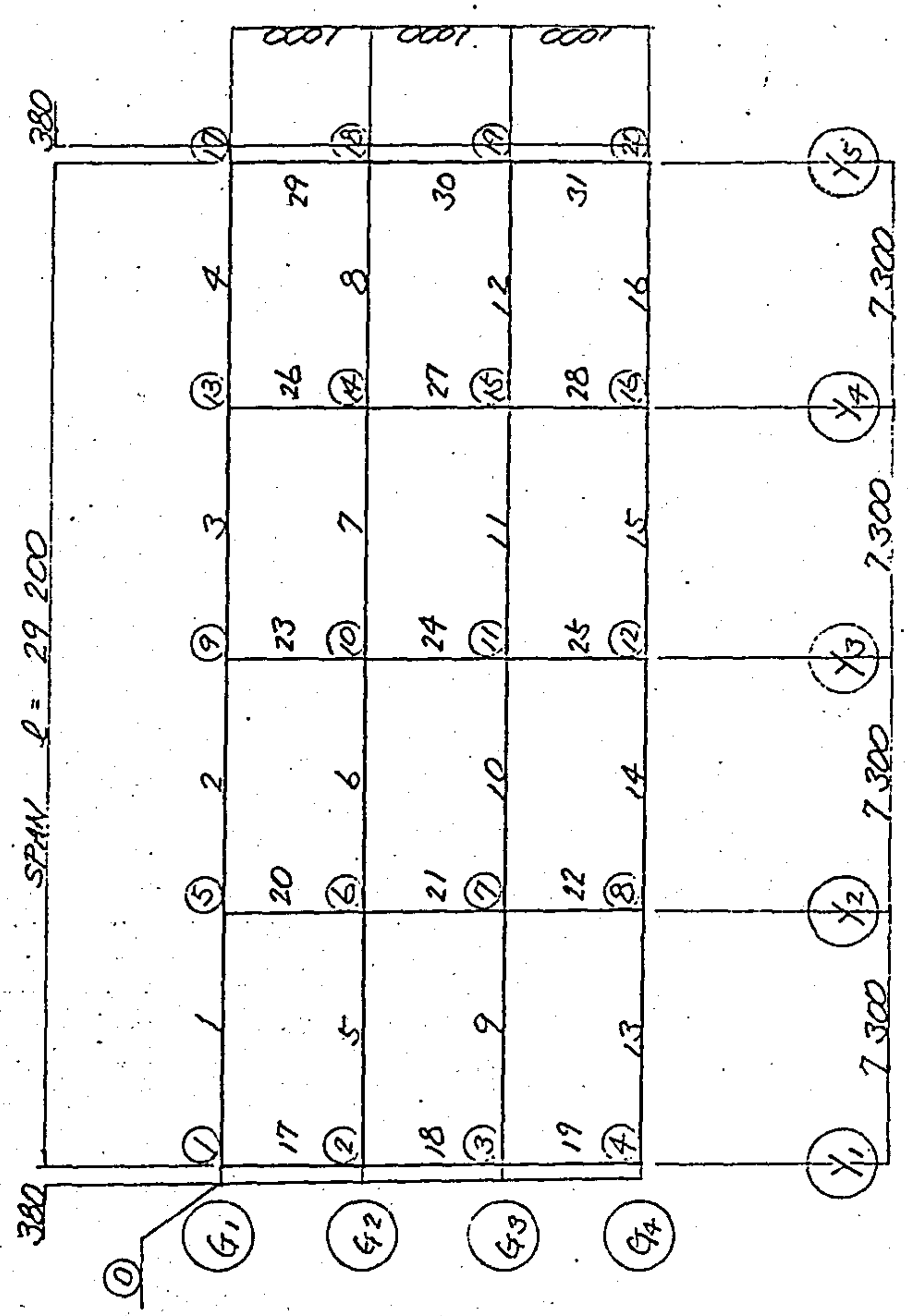
Chapter 2. Configuration and Dimensions of Bridge



Chapter 3. Input for Grid-system calculation

§1. Numbering & Coordinates of Skeleton Point

1. Member numbering & Skeleton point numbering



2. Coordinates calculations of Skeleton points

- Assumed the Skeleton point (0) as fundamental point, coordinates of other skeleton points are calculated as listed below.

(Unit: m)

Skeleton point number	Skeleton point coordinates x	y	Skeleton point number	Skeleton point coordinates x	y
(1)	0.380	0	(15)	22.280	-2.000
(2)	〃	-1.000	(16)	〃	-3.000
(3)	〃	-2.000	(17)	29.580	0
(4)	〃	-3.000	(18)	〃	-1.000
(5)	7.680	0	(19)	〃	-2.000
(6)	〃	-1.000	(20)	〃	-3.000
(7)	〃	-2.000	( )		
(8)	〃	-3.000	( )		
(9)	14.980	0	( )		
(10)	〃	-1.000	( )		
(11)	〃	-2.000	( )		
(12)	〃	-3000	( )		
(13)	22.280	0	( )		
(14)	〃	-1.000	( )		

§2. Support conditions and Young's modulus of Concrete

1. Support conditions

Skeleton number	Rotation around		Z direction
	Y axis	X axis	
①	free	free	restricted
②	"	"	"
③	"	"	"
④	"	"	"
⑰	"	"	"
⑱	"	"	"
⑲	"	"	"
⑳	"	"	"

2. Young's modulus of concrete

(1) Young's modulus

Main girder : $E\ell = 3.50 \times 10^5\ kg/cm^2 = 35.0 \times 10^5\ t/m^2$

Cross beam : $Et = 3.00 \times 10^5\ kg/cm^2 = 30.0 \times 10^5\ t/m^2$

(2) Young's modulus corresponding to shearing

$G = 0.43E$

Main girder : $G\ell = 0.43 \times 35.0 \times 10^5 = 15.05 \times 10^5\ t/m^2$

Cross beam : $Gt = 0.43 \times 30.0 \times 10^5 = 12.90 \times 10^5\ t/m^2$

§3. Configuration and Dimensions of Main girder and Cross beam

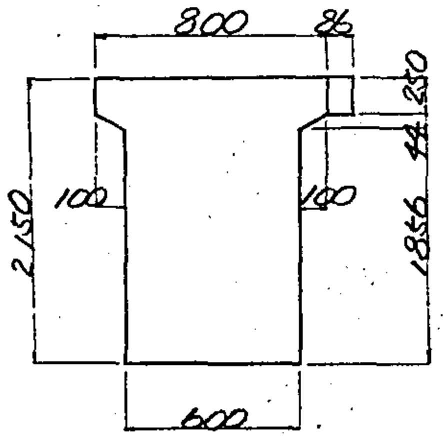
1. Configuration and Dimensions of Main girder

Dimension of concrete between Girders are as shown.

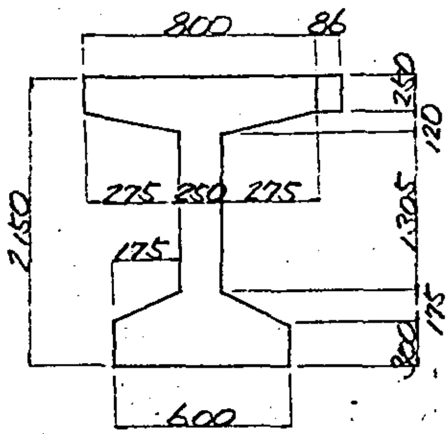
$$Et/E\ell = \frac{30.0 \times 10^5}{35.0 \times 10^5} = 0.857 \fallingdotseq 0.86$$

$$b = 0.200 \times 0.86 \times \frac{1}{2} = 0.086$$

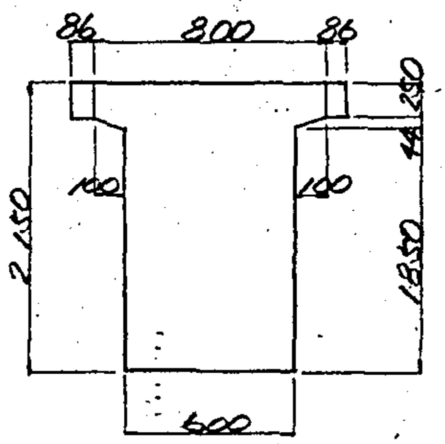
SECTION NUMBER ①: G1.G4 (Y1, Y5)



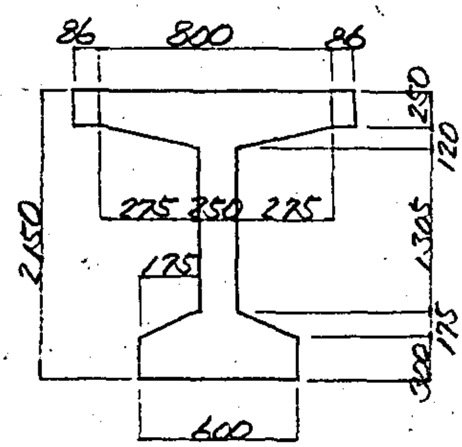
SECTION NUMBER ②: G1,G4 (Y2 ~ Y4)



SECTION NUMBER ③: G2 G3 (Y1, Y5)

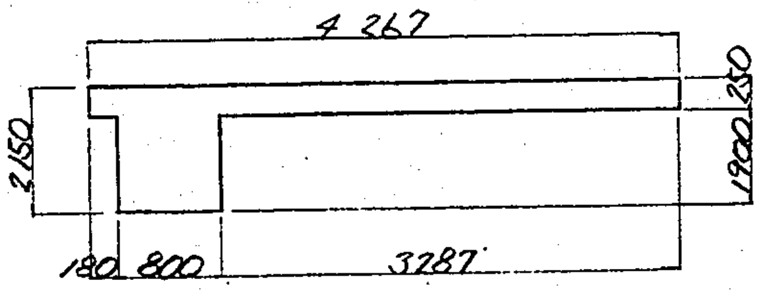


SECTION NUMBER ④: G2 G3 (Y2 ~ Y4)

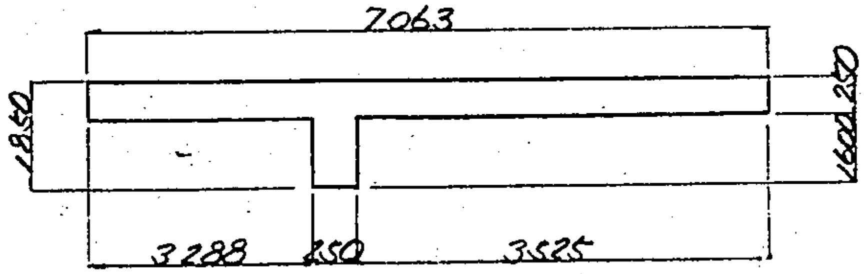


2. Configuration and Dimensions of Cross beam

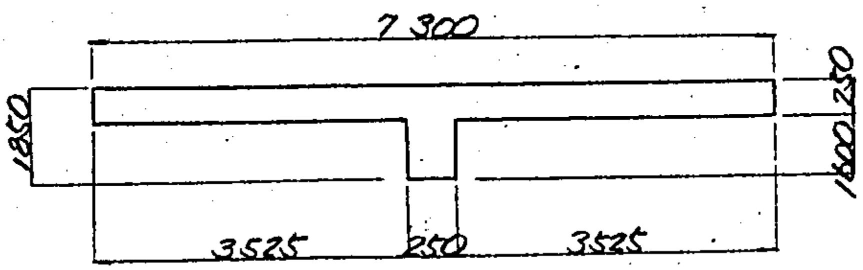
SECTION NUMBER ⑤ (y_1, y_5)



SECTION NUMBER ⑥ (y_2 y_4)



SECTION NUMBER ⑦ (y_3)



3. Applicable section number for various Girder, Beam/location

Girders		Location of number	Section number	Notes
Main girder	G_1, G_4	Location of Cross beam : y_1 , y_5	①	
		〃 : $y_2 \sim y_4$	②	
	G_2, G_3	〃 : y_1 , y_5	③	
		〃 : $y_2 \sim y_4$	④	
Cross beam		y_1 , y_5	⑤	
		y_2 , y_4	⑥	
		y_3	⑦	

4. Moment of inertia of the section

(Unit: m^4)

Girders		Members	Moment of inertia (Average)
Main girder	G_1 G_4	1, 4, 13, 16	0.51762
		2, 3, 14, 15	0.47427
	G_2 G_3	5, 8, 9, 12	0.53444
		6, 7, 10, 11	0.49074
Cross beam		17, 18, 19, 29, 30, 31	1.18724
		20, 21, 22, 26, 27, 28	0.37357
		23, 24, 25	0.37556

§4. Loads and Loading conditions

1. Application of loads for calculation

(1) Application of static load

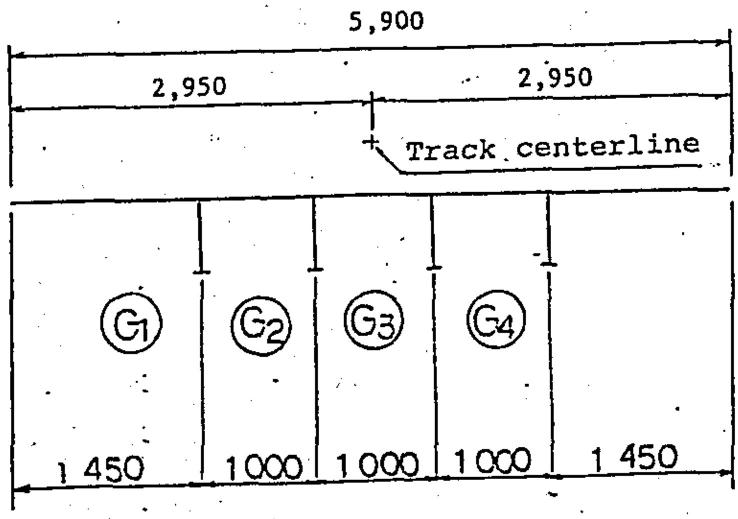
As the grid-system are carried out based on influence lines, the static load loading is applied in dual ways, one is a lined loading and the other is a uniformly distributed loading, to determine the loading length and width.

(2) Application of combined train loading

(a) Train load loading

Train load is assumed to be transmitted through sleepers downwards and distributed to the enlarged width within inclined lines with 53 deg. starting at both end points of sleeper bottom.

Distribution of loads through track is shown in the sketch drawing.



(b) Combined loading of train load

(i) Train load is supposed to distribute entire length of the span.

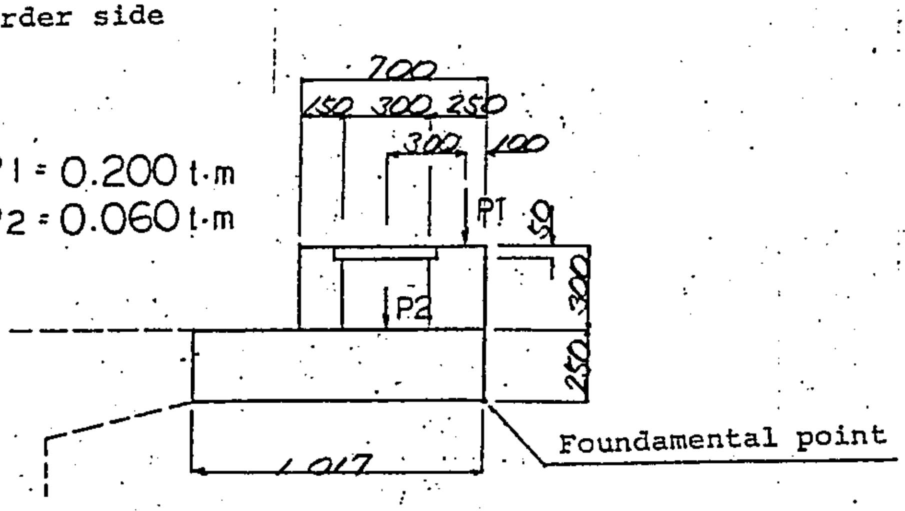
(ii) Train load is supposed to distribute limited to one side of span with 1/2 ℓ length.

Train load is applied combined the above (i) and (ii) loadings. Thus, further calculations are made for the sectional strength.

2. Dead load calculations of the own weight of structure

(1) Cantilever part of bridge slab, edge coaming and handrail concrete

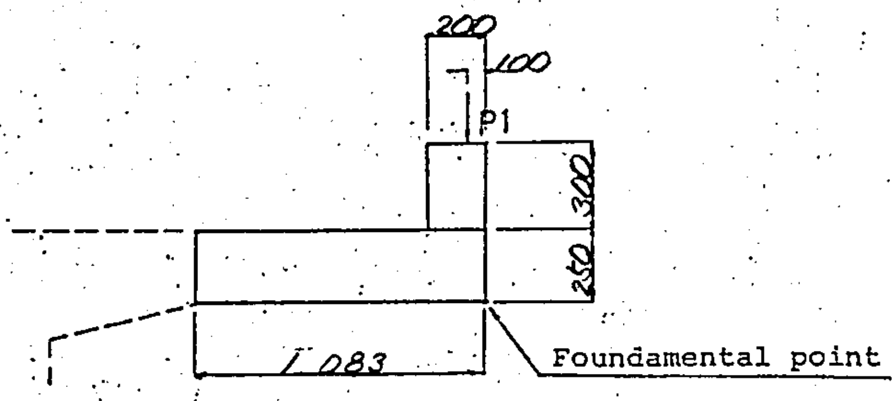
(a) G4 girder side



Load/Load acting point

Total dead load : ΣW (t/m) = 1.235
Total bending moment : $\Sigma W X$ (t-m/m) = 0.694
Acting point of resultant force : $X = \Sigma W X / \Sigma W$ (m) = 0.562

(b) G1 girder side

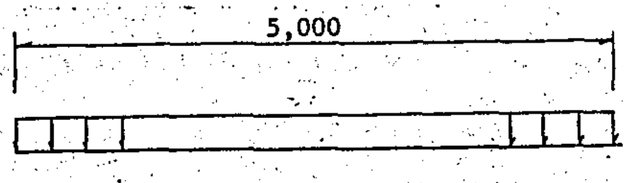


Load/Load acting point

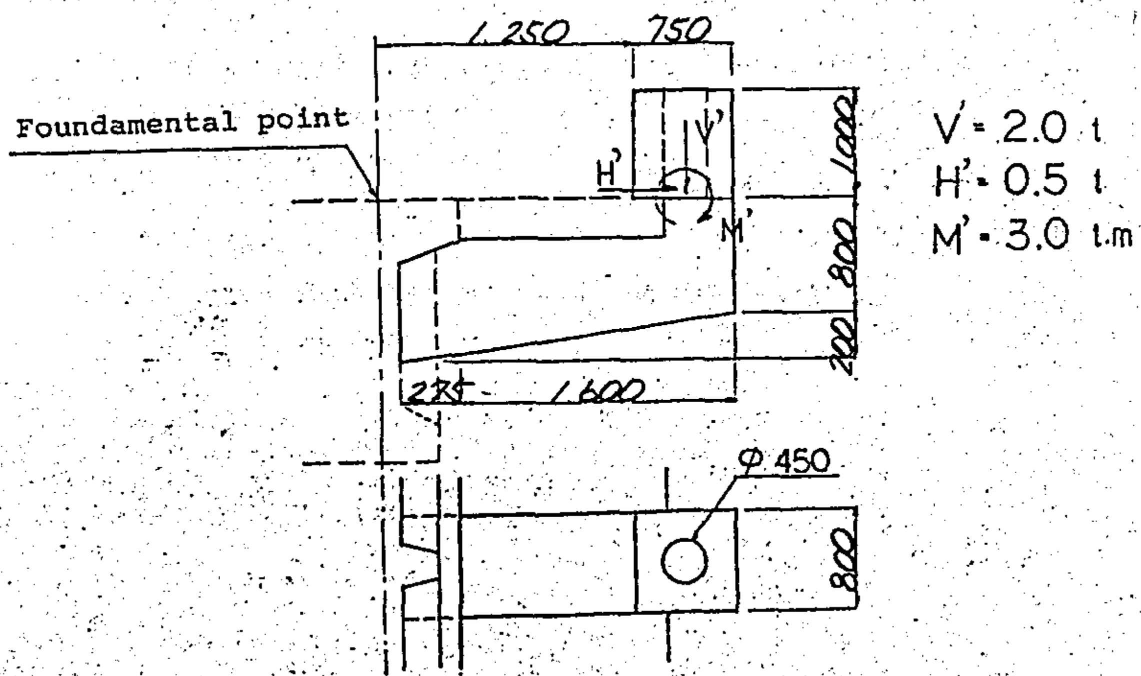
Total dead load : ΣW (t/m) = 1.027
Total bending moment : $\Sigma W X$ (t-m/m) = 0.402
Acting point of resultant force : $X = \Sigma W X / \Sigma W$ (m) = 0.391

(2) Graded Concrete

$W_p = 2.35 \times 0.07 = 0.165\ t/m^2$



(3) Electric pole and its supporting beam

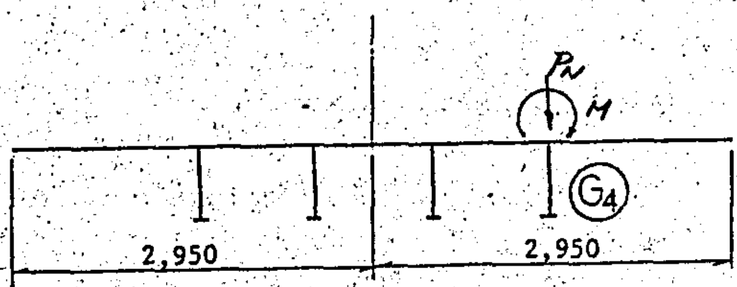


Load/Load acting point

Total dead load : ΣW (t/m) = 5.697 = P_N

Total bending moment : $\Sigma W X$ (t-m/m) = 7.962

$M = M' + \Sigma WX$ = 10.962



3. Dead load calculations of surcharge

(1) Surcharge load of ballast

Calculated as a uniformly distributed load.

$$W_B = 1.9\ t/m^3 \times (h_B - h_p) = 1.056\ t/m^2$$

(2) Surcharge load of track assembly

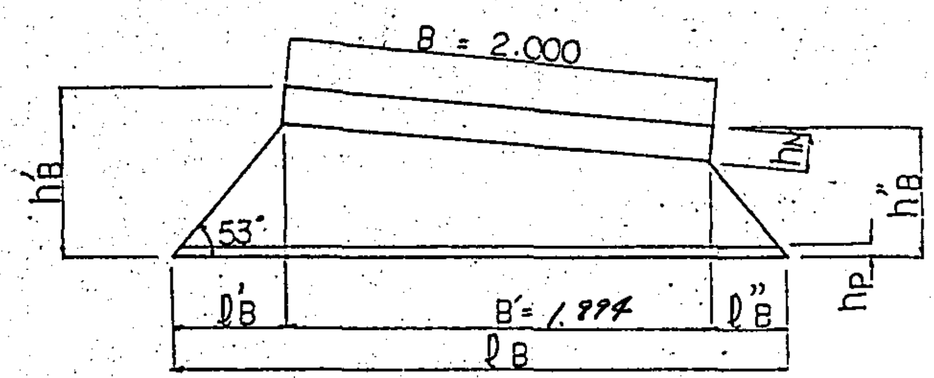
Load of track assembly is assumed to be distributed on the bridge slab with the width between two points on the slab, where lines drawn from the both ends of sleeper bottom with 53 deg. inclination towards outward-downward, crossing the slab surface.

- Load of track assembly : $\Sigma W_R = 0.450$ t/m
- Width of sleeper : $B = 2.000$ m
- Thickness of sleeper : $h_M = 0.165$ m
- Height between the girder top and the sleeper top : $h_B = 0.660$ m, 0.518 m
- Average thickness of graded concrete for drainage : $h_p = 0.070$ m

$$\ell_B' + \ell_B'' = (h_B - h_M) \cdot \text{Cot } 53° = 0.639\ m$$

- Load distribution width:

$$\ell_B = B' + \ell_B' + \ell_B'' = 2.633\ m$$



Uniformly distributed load:

$$W_R = \frac{\Sigma W_R}{\ell_B} = 0.171\ t/m^2$$

4. Live load calculations of train loading

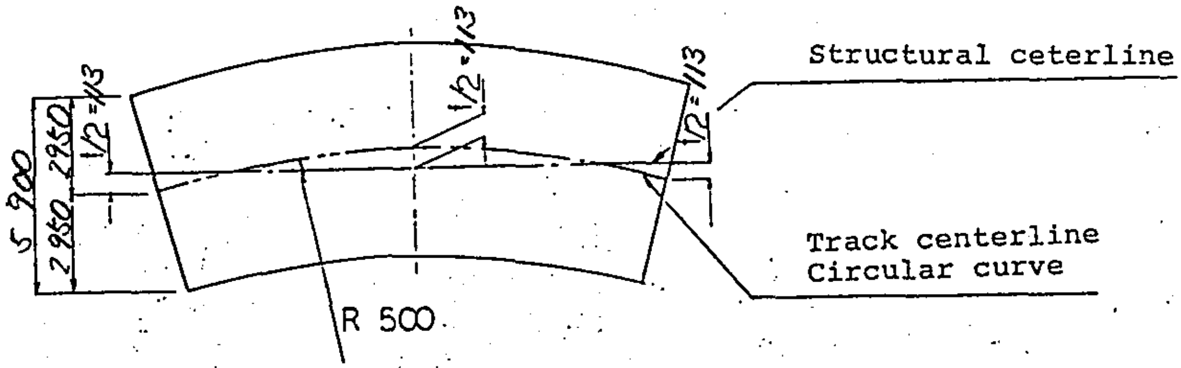
(1) Impact coefficient

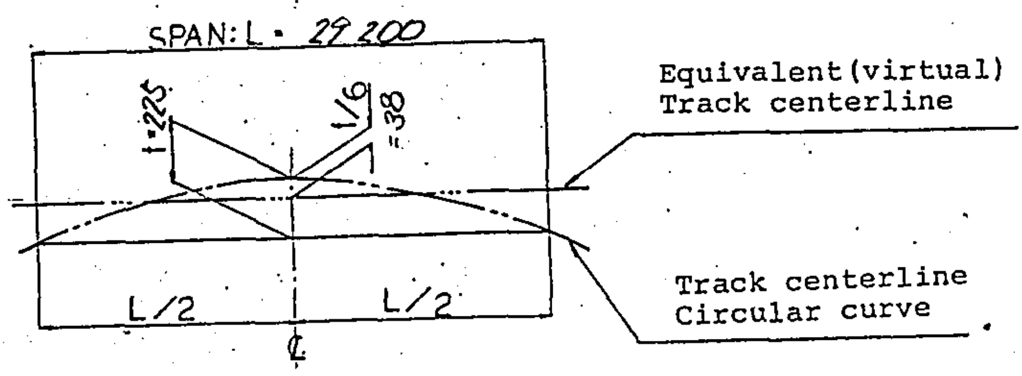
Span : ℓ = 29.200 m

Impact coefficient : i = 0.342

(2) Equivalent loading centerline of the track

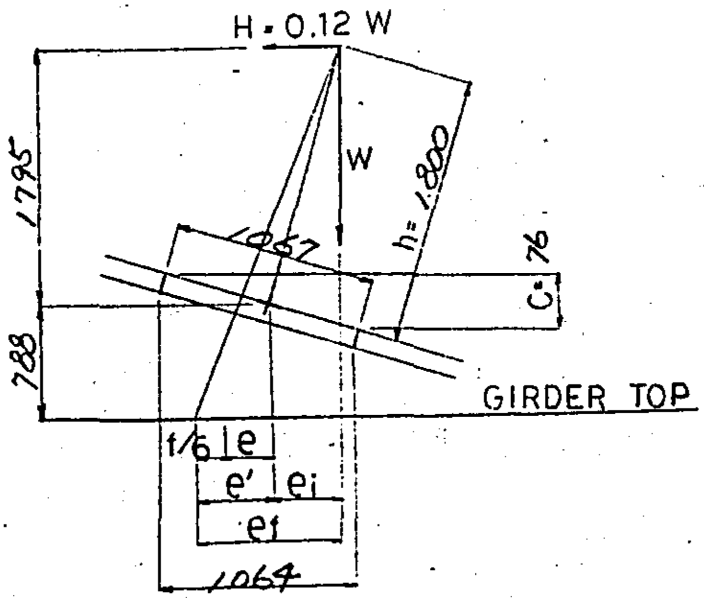
The bridge is located within a curve however, for the sake of practical design calculation, the loading centerline of track is assumed as a virtual track centerline drawn tangent at the mid span with f/6 shift.





(3) Acting point of resultant force, which is the combined force of the train load and the load caused by centrifugal force

The centrifugal force is assumed to have the magnitude equivalent to the value of train load times the coefficient of centrifugal load $\alpha = 0.12$, acting horizontally at the point 1.80 m above the rail level in the section transversal to the track.



e_i = 0.128 m

e_f = 0.310 m

e' = 0.182 m

e = 0.145 m

(4) Uniformly distributed load, equivalent to the train loading

Bending moment calculation:

For the bending moment calculation, the equivalent uniformly distributed load at the 1/4 span point will be employed and confirmed as calculated below.

$$M\ell = \{M\ell_{min} + \frac{\ell - \ell_{min}}{\ell_{max} - \ell_{min}} \cdot (M\ell_{max} - M\ell_{min})\}\ \gamma \cdot \beta \times \frac{1}{18}$$

where, $\ell = 29200$, $\ell_{max} = 29500$, $\ell_{min} = 29000$

$\gamma = 2$ $\beta = 16$

$M\ell(\ell/4)_{min} = 323.2\ t\cdot m$, $M\ell(\ell/4)_{max} = 333.6\ t\cdot m$

$M\ell(\ell/2)_{min} = 412.9\ t\cdot m$, $M\ell(\ell/2)_{max} = 425.5\ t\cdot m$

$$M\ell(\ell/4) = \{323.2 + \frac{0.20}{0.50} \times (333.6 - 323.2)\}\ 2 \times 16 \times \frac{1}{18}$$
$$= 581.973$$

$$M\ell(\ell/2) = \{412.9 + \frac{0.20}{0.50} \times (425.5 - 412.9)\}\ 2 \times 16 \times \frac{1}{18}$$
$$= 743.004$$

Equivalent uniformly distributed load at $\ell/4$ span point, which is Wm, will be

$$W_m = \frac{32}{3} \times \frac{M\ell(\ell/4)}{\ell^2} = 7.281$$

Employed the above Wm value and applied for the bending moment calculation at $\ell/2$ point.

$$M'_{\ell/2} = W_m \cdot \frac{\ell^2}{8} = 776.009\ t\cdot m$$
$$> M\ell_{(\ell/2)} = 743.004\ t\cdot m$$

The result is larger than the value of $M_{\ell/2}$.

$Wm = 7.281$ t/m

Train loading for bending moment:

$W\ell = Wm(1 + i) = 9.771$ t/m

(5) Train loading for bending moment: calculation

Train loading is distributed expanded with 53 deg. inclination from the both ends of sleeper bottom.

Uniformly distributed load: $W\ell$

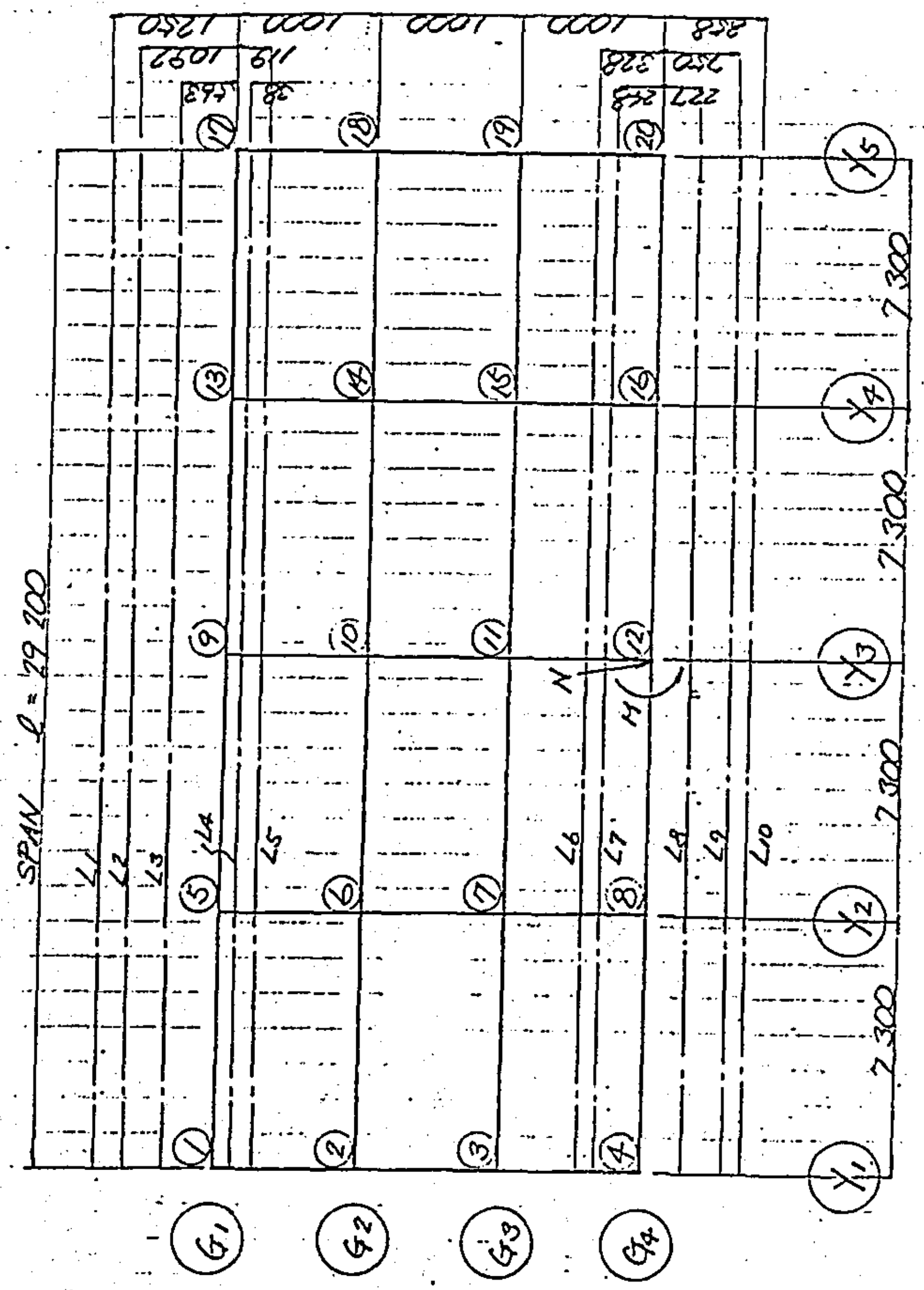
$$W\ell = \frac{Wm\ (1 + i)}{\ell_B} = 3.711 \text{ t/m}^2$$

5. Load/Loading point of various loadings

(1) Summary of loads

Load	Cases	Title	Load distribution area: Width	Load distribution area: Length	Intensity of load	Category of load
Dead load of surcharge and structure	Case 1	VANJO $-D_1$	L_{10}	$Y_1 \sim Y_5$	1.235 t/m	Canti. slab, handrail conc., etc.
			L_2	$Y_1 \sim Y_5$	1.027 〃	
			$L_1 \sim L_9$	$Y_1 \sim Y_5$	0.165 t/m²	Graded conc.
			$L_3 \sim L_8$	$Y_1 \sim Y_5$	1.056 〃	Ballast
			$L_5 \sim L_7$	$Y_1 \sim Y_5$	0.171 〃	Track assembly
Electric pole, etc.	Case 2	DENCHU $-D_1$	G_4	Y_3	N = 5.697 t M = 10.962 t·m	Electric pole and its supporting beam
Train load	Case 3	L_1	$L_4 \sim L_6$	$Y_1 \sim Y_5$	3.711 t/m²	Live load intensity applied for bending moment calculation
	Case 4	L_2	$L_4 \sim L_6$	$Y_1 \sim Y_3$	3.711 〃	

(2) Loading conditions



6. Combined loading

(1) Case 1: Dead load of surcharge

(2) Case 2: Dead load of electric pole

(3) Case 3: Train load, loaded on full span

(4) Case 4: Train load, loaded on half span

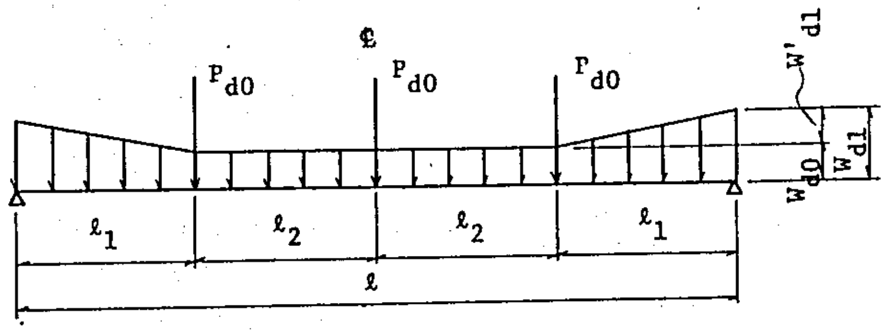
(5) Case 5: Case 1 + Case 2

(6) Case 6: Case 5 + Case 3

(7) Case 7: Case 5 + Case 4

Chapter 4. Design calculations of Main girder cross section

§1. Bending moment caused by own weight of Main girder



Bending moment (at center of span)

$$M_{d0} = \frac{1}{8}\cdot W_{d0}\cdot \ell^2 + \frac{1}{6}\cdot W_{d1}'\cdot \ell_1^{\,2} + P_{d0}\cdot \{\frac{n}{2}(\ell_1 + \ell_2) - \ell_2\}$$

W_{d0} : Per meter weight of the section at the center (t/m) = 2.109

W_{d1} : Per meter weight of the section at the point of support (t/m) = 3.361

$W_{d1}' = W_{d1} - W_{d0}$ = 1.252

P_{d0} : Weight of intermediate diaphragm (t) = 0.351

ℓ : Span (m) = 29.200

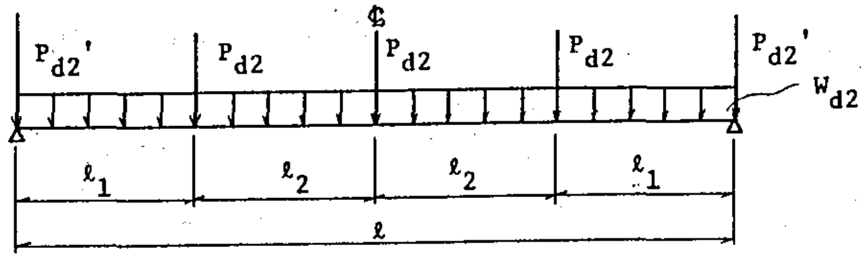
ℓ_1 : Length of the widened part of web (m) = 7.300

ℓ_2 : Location of diaphragm (m) = 7.300

n : Number of intermediate diaphragms

M_{d0} = ~~232~~.456 t.m

§2. Stress calculations of Cross beam cross section



- Bending moment (at center of span)

$$M_{d0} = \frac{1}{8} \cdot W_{d2} \cdot \ell^2 + P_{d2} \cdot \{ \frac{n}{2} \cdot (\ell_1 + \ell_2) - \ell_2 \}$$

where,

W_{d2} : Own weight of bridge slab between girders (t/m)
= 0.094

P_{d2} : Own weight of intermediate Cross beam (t)
= 0.298

P_{d2}': Own weight of end Cross beam (t)
= 1.133

ℓ : Span (m) = 29.200

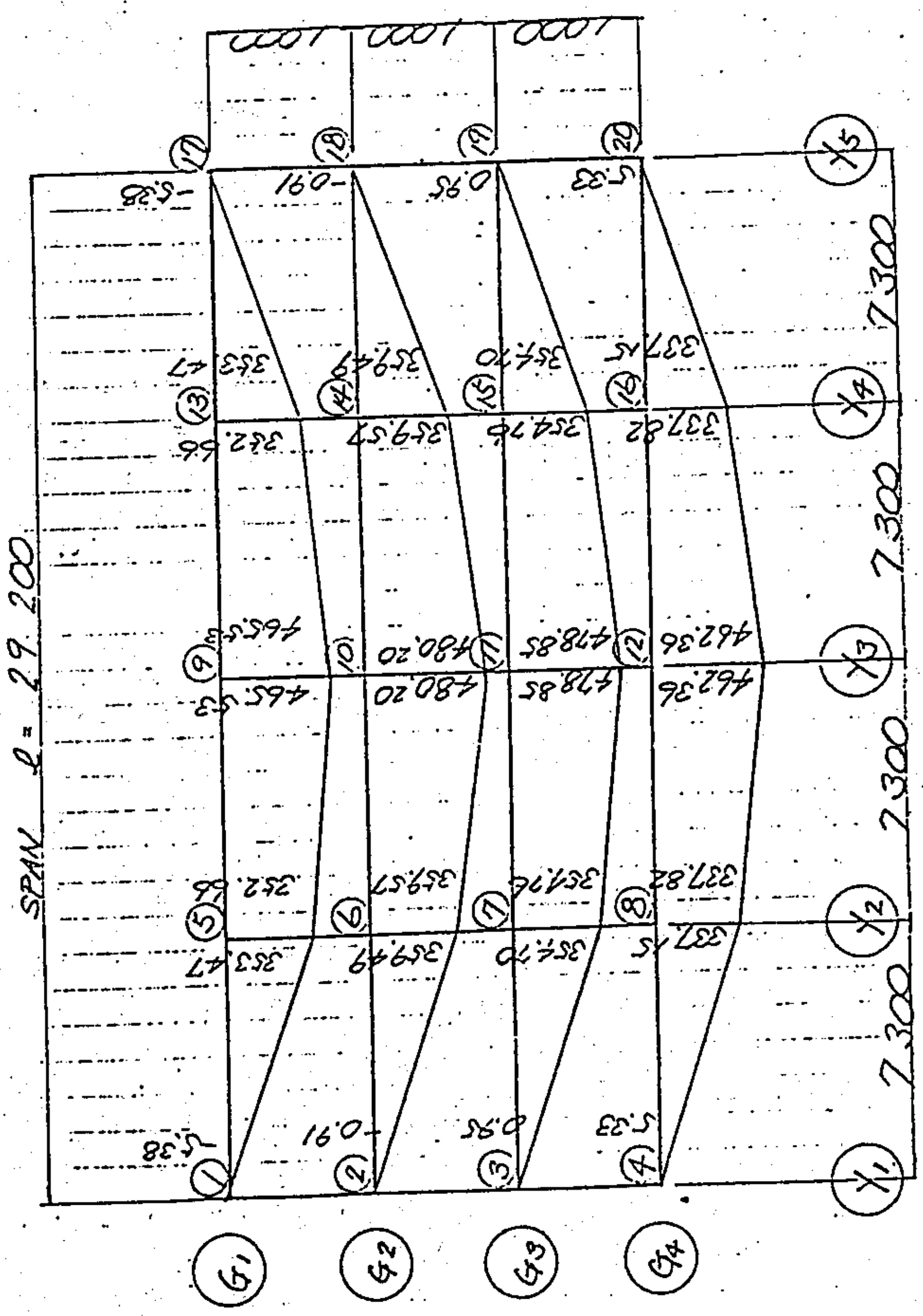
ℓ_1, ℓ_2: Location of Cross beam (m) $\{ \ell_1 = 7.300$, $\ell_2 = 7.300$

n : Number of intermediate Cross beam = 3

M_{d0} = 14.369 t·m

§3. Stress caused by Static and Live load acting at the top of bridge slab

(Computer calculation with grid-system)
Bending moment diagram (Unit: t·m)



§4. Summary of bending moment calculations (at section of mid-span)

(Unit: t m)

Load / Main girder	(1) Own Wt. M.girder	(2) Concrete betw. girders	(3) Ballast Track	(4) Electric pole	(5)=Σ(1)~(4) D. load total	Live load (6) Mℓ	Live load Case	Total ((5) + (6))
G_1	238.46	14.37	203.11	-6.12	449.82	268.55	6	718.37
G_2	"	"	206.52	4.51	463.86	269.17	6	733.03
G_3	"	"	202.48	15.84	471.15	260.53	6	731.68
G_4	"	"	191.45	27.30	471.58	243.55	6	715.13

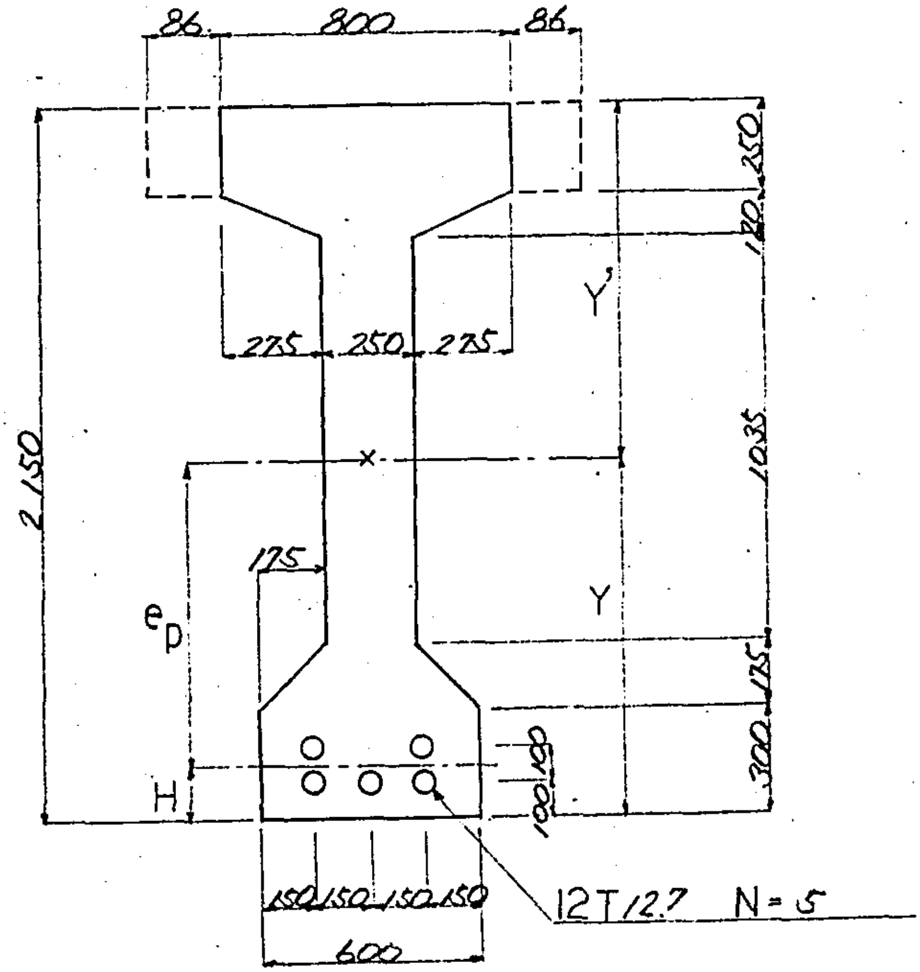
Developed the calculations in the preceding paragraphs, it became known that Maximum bending moment is exerted on Main girder.

Hence, further design calculations for Main girders will be represented by G_2 girder.

Chapter 5. Main girder design

§1. Basis for the design calculations

1. Configuration and Dimensions of the girder section of mid span



A :	Cross sectional area	(cm^2)
I :	Moment of inertia	(cm^4)
Z :	Section modulus	(cm^3)
r :	Radius of gyration	(cm)
ep:	Location of cables	(cm)
N :	Number of cables	
6pt:	Tensile stress immediate after the practice of pre-stressing (kg/mm^2)	
Pt:	total tensile stressimmediate after the practice of pre-stressing	
n :	Ratio of Young's modulus between Modulus of P.C. cables and that of concrete	
ψ :	Coefficient of creep	
ε_s:	Drying contraction rate of conerete	
η :	Effective factor	

2. Summary of sectional values (mid span)

(1) Gross cross section

- A_c = 8436.25 cm^2
- I_c = 45.697 $\times 10^6$ cm^4
- Y_c = 111.9 cm
- Y_c' = 103.1 cm
- $Z_c = I_c/Y_c$ = 4.084 $\times 10^5$ cm^3
- $Z_c' = I_c/Y_c'$ = 4.432 $\times 10^5$ cm^3
- $\gamma_c^2 = I_c/A_c$ = 5.417 $\times 10^3$ cm^2
- $e_{pc} = Y_c - H$ = 97.9 cm

(2) Net cross section

- A_0 = 8270.35 cm^2
- I_0 = 44.071 $\times 10^6$ cm^4
- Y_0 = 113.9 cm
- Y_0' = 101.1 cm
- $Z_0 = I_0/Y_0$ = 3.869 $\times 10^5$ cm^3
- $Z_0' = I_0/Y_0'$ = 4.359 $\times 10^5$ cm^3
- $\gamma_0^2 = I_0/A_0$ = 5.329 $\times 10^3$ cm^2
- $e_{p0} = Y_0 - H$ = 99.9 cm
- $Z_{0g} = I_0/e_{p0}$ = 4.412 $\times 10^5$ cm^3

(3) Equivalent cross section

- $n = E_p/E_c = \frac{2.0 \times 10^6}{3.5 \times 10^5} = 5.71$
- $n \cdot A_{pl} = 5.71 \times 11.85 = 67.664$ cm²
- $A_{el} = 8608.67$ cm²
- $I_{\ell 1} = 47.323 \times 10^6$ cm⁴
- $Y_{\ell 1} = \Sigma A_{el} \cdot Y / \Sigma A_{el} = 110.0$ cm
- $Y_{el}' = h - Y_{el} = 105.0$ cm
- $Z_{el} = I_{el}/Y_{el} = 4.302 \times 10^5$ cm³
- $Z_{el}' = I_{el}/Y_{el}' = 4.507 \times 10^5$ cm³
- $\gamma_{el}^2 = I_{el}/A_{el} = 5.497 \times 10^3$ cm²
- $e_{pel} = Y_{el} - H = 96.0$ cm
- $Z_{elg} = I_{el}/e_{pel} = 4.930 \times 10^5$ cm³

(4) Equivalent cross section (including concrete between Girders)

- $A_{ez} = 9038.67$ cm²
- $I_{e2} = 50.850 \times 10^6$ cm⁴
- $Y_{e2} = \Sigma A_{e2} \cdot Y / \Sigma A_{e2} = 114.4$ cm
- $Y_{e2}' = h - Y_{e2} = 100.6$ cm
- $Z_{e2} = I_{e2}/Y_{e2} = 4.445 \times 10^5$ cm³
- $Z_{e2}' = I_{e2}/Y_{e2}' = 5.055 \times 10^5$ cm³
- $\gamma_{e2}^2 = I_{e2}/A_{e2} = 5.626 \times 10^3$ cm²
- $e_{pe2} = Y_{e2} - H = 100.4$ cm
- $Z_{e2g} = I_{e2}/e_{pe2} = 5.065 \times 10^5$ cm³

§2. Summary of Bending stress calculations at mid span

Loads	Bending moment ($\times 10^5$ kg·cm)	Section modulus ($\times 10^5$ cm^3)		Bending stress (kg/cm^2) At top fibre	At bottom fibre	At the gravity center of cables
Own weight of Main girder	M_{d0} = 238.46	Z_0'	4.359	54.7	—	—
		Z_0	- 3.869	—	-61.6	—
		Z_{0g}	- 4.412	—	—	-54.1
Concrete between girders	M_{d1} = 14.37	Z_{e1}'	4.507	3.2	—	—
		Z_{e1}	- 4.302	—	-3.3	—
		Z_{e1g}	-4.930	—	—	-2.9
Static load (Ballast track Electric pole)	M_{d2} = 211.03	Z_{e2}'	5.055	41.8	—	—
		Z_{e2}	- 4.445	—	-47.5	—
		Z_{e2g}	- 5.065	—	—	-41.7
Dead load Total	ΣM_d = 463.86	—	—	99.7	-112.4	-98.7
Live load	$M\ell$ = 269.17	Z_{e2}'	5.055	53.3	—	—
		Z_{e2}	- 4.445	—	- 60.6	—
		Z_{e2g}	- 5.065	—	—	-53.1
Total	ΣM = 733.03	—	—	153.0	-173.0	-151.8

§3. Summary of stress calculations caused by pre-stressing at mid span

States	Items			Unit	Values
Immediate after the practice of pre-stressing	σ_{pt}			kg/mm^2	94
	A_p			mm^2	1185
	N				5
	A_0			$x10^3\ cm^2$	8.270
	e_{p0}			m	-0.999
	Section modulus		Z_0'	$x10^5\ cm^3$	4.359
			Z_0	"	-3.869
			Z_{0g}	"	-4.412
	P_t			$x10^3$ kg	556.95
	Stress	Top fibre	σ_{ct}'	kg/cm^2	-60.3
		Bottom fibre	σ_{ct}	"	211.1
		Grav. Center of cables	σ_{0pt}	"	193.5
Effective pre-stress	n				5.71
	ψ				2.6
	γ				0.05
	$\Sigma\sigma_{dg}$			kg/cm^2	-98.7
	E_p			$x10^5 kg/cm^2$	20
	ε_s			$x10^{-5}$	20
	$\Delta\sigma_{p\gamma}$			kg/mm^2	-4.70
	$\Delta\sigma_{p\psi}$			"	-13.09
	σ_{pe}			"	76.21
	η				0.811
	Stress	Top fibre	σ_{ce}'	kg/cm^2	-48.9
		Bottom fibre	σ_{ce}	"	171.2
		Grav. Center of cables	σ_{cpe}	"	156.8

§4. Summary of combined Bending stress at mid span

Loads		Stresses (kg/cm^2) Top fibre	Bottom fibre
(1) Own weight of Main girder		54.7	-61.6
(2) Concrete between girders		3.2	-3.3
(3) Static load		41.8	-47.5
(4) Dead load total ((1) + (2) + (3))		99.7	-112.4
(5) Live load		53.3	-60.6
(6) Total load ((4) + (5))		153.0	-173.0
(7) Immediate after the pre-stressing		-60.3	211.1
(8) Effective pre-stress		-48.9	171.2
Combined stress Immediate after the pre-stressing	(1) + (7)	-5.6	149.5
	Allowable value	> - 15.0	< 180.0
Total Dead loading	(4) + (8)	50.8	58.8
Design loading	(6) + (8)	104.1	-1.8
	Allowable value	< 140.0	> -10.0

NO. 7 P.C. GIRDERS

SUPER-STRUCTURE

DESIGN CALCULATION

B12 - PC 29 $L = 25^{m}$, $H = 2.35^{m}$

(Curve $R = 500^{m}$)

CONTENTS

Chapter 1. Design criteria

1. Basis for design and loading conditions

- Kind of bridge: Pre-stressed concrete railroad bridge.
- Type of Bridge/Girders: Bridge superstructure is a simple beam, consisted of 2 main girders aligned in parallel.
  Girder is made of post-tensioned concrete of I type section.
- Length of girder: 24.960 m
- Span of main girder: 24.200 m
- Live load : KS-16
- Impact coefficient : i = 0.357
- Crossing angle: { at younger change: 90° 00' 00"
  at elder change: 90° 00' 00"
- Railroad curve: R = 500 m

2. Strength of materials for design

2-1. Concrete

(1) Concrete used for main girder

- Standard strength for design (28 day value)
  : σ_{CK} = 400 kg/cm^2
- Allowable compressive strength for bending calculation
  : σ_{ca} = 140 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 180 kg/cm^2
- Allowable tensile strength for bending calculation applied for,
  - design loading : σ_{cat} = -10 kg/cm^2
  - dead load : $\sigma_{cat'}$ = 0 kg/cm^2
  - immediate after the pre-stressing : $\sigma_{cat''}$ = -15 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_c=3.5×10^5 kg/cm^2

(2) Concrete used for lateral connection

- Standard strength for design (28 day value)
  : σ_{ck} = 300 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 110 kg/cm^2
- Allowable tensile strength for bending calculation : $\sigma_{ca'}$ = -8 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 140 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_c=3.0x10^{5}kg/cm^2

(3) Cantilever part of bridge slab, edge coaming and handrail concrete

- Standard strength for design (28 day value) : σ_{ck} = 240 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 80 kg/cm^2

2-2. Steel materials used for P.C. concrete

(1) P.C. Cable (SWPR-7B) 12T 12.7 mm

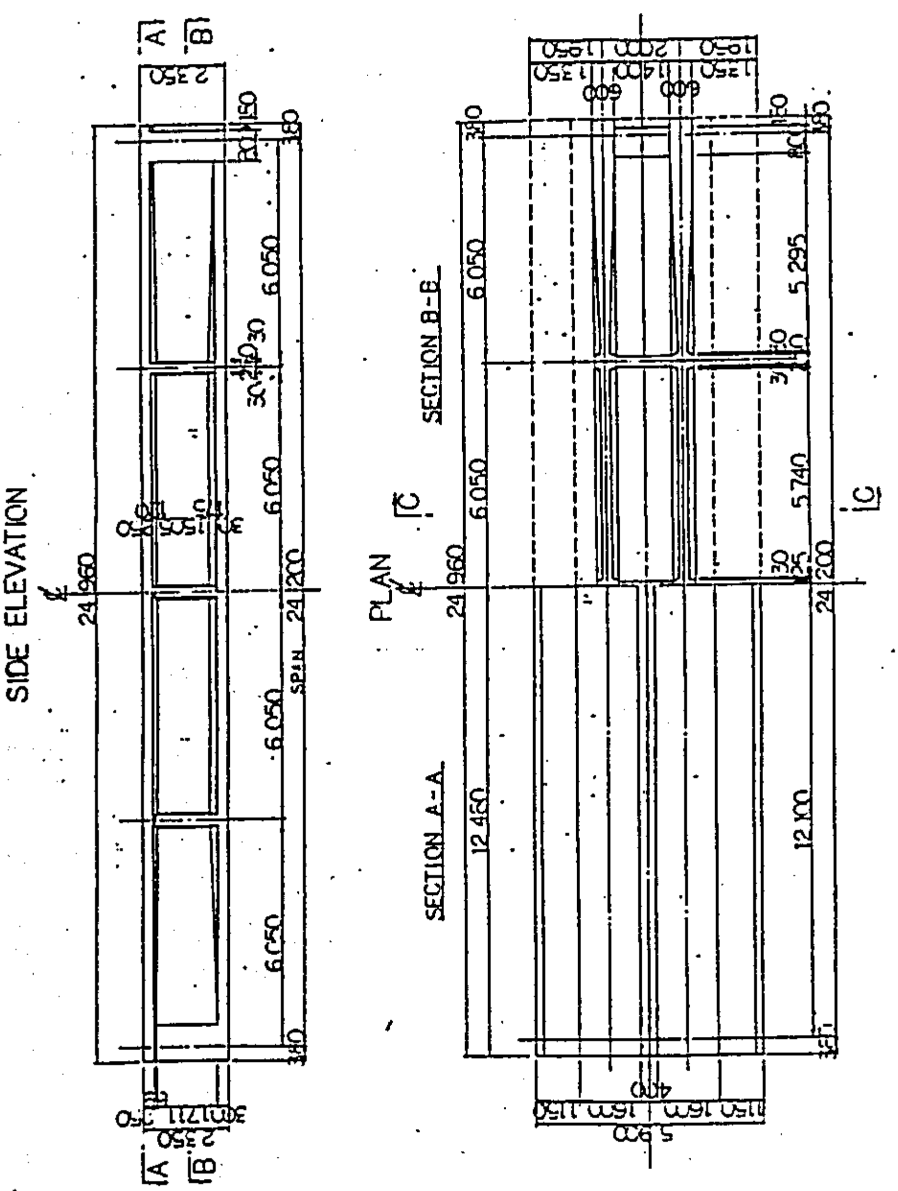
- Tensile strength : σ_{pu} = 190 kg/mm^2
- Yielding point : σ_{py} = 160 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 114 kg/mm^2
  - immediate after the pre-stressing: σ_{pat} = 133 kg/mm^2
  - during pre-stressing : σ_{pai} = 145 kg/mm^2
- Young's modulus of P.C. steel material : $E_p = 2.0 \times 10^6 kg/cm^2$

(2) P.C. steel bar (SBPR 95/110) ϕ 23 mm

- Tensile strength : σ_{pu} = 110 kg/mm^2
- Yielding point : σ_{py} = 95 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 66 kg/mm^2
  - immediate after the pre-stressing: σ_{pat} = 77 kg/mm^2
  - during pre-stressing : σ_{pai} = 85.5 kg/mm^2
- Young's modulus of P.C. steel material : $E_p = 2.0 \times 10^6 kg/mm^2$

2-3. Reinforcing Bar : SD 30

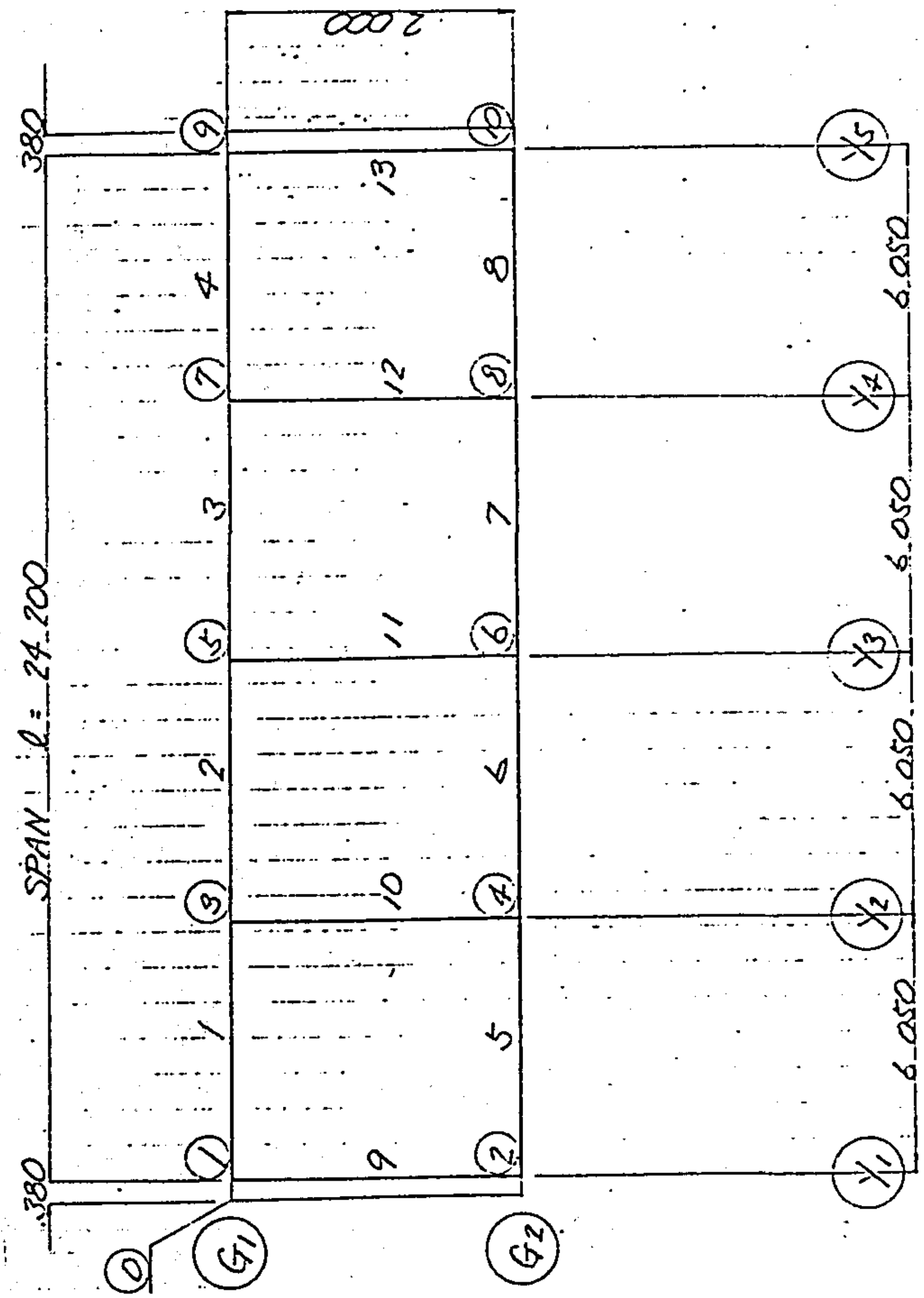
Chapter 2. Configuration and Dimensions of Bridge



Chapter 3. Input for Grid-system calculation

§1. Numbering & Coordinates of Skeleton Point

1. Member numbering & Skeleton point numbering



2. Coordinates calculations of Skeleton points

Assumed the Skeleton point (0) as fundamental point, coordinates of other skeleton points are calculated as listed below.

(Unit: m)

Skeleton point number	Skeleton point coordinates		Skeleton point number	Skeleton point coordinates	
	x	y		x	y
(1)	0.380	0	○		
(2)	〃	-2.000	○		
(3)	6.430	0	○		
(4)	〃	-2.000	○		
(5)	12.480	0	○		
(6)	〃	-2.000	○		
(7)	18.530	0	○		
(8)	〃	-2.000	○		
(9)	24.580	0	○		
(10)	〃	-2.000	○		
○			○		
○			○		
○			○		
○			○		

§2. Support conditions and Young's modulus of Concrete

1. Support conditions

Skeleton number	Rotation around		Z direction
	Y axis	X axis	
①	free	free	restricted
②	"	"	"
⑨	"	"	"
⑩	"	"	"
◯			
◯			
◯			
◯			

2. Young's modulus of concrete

(1) Young's modulus

Main girder : $E\ell = 3.50 \times 10^5\ kg/cm^2 = 35.0 \times 10^5\ t/m^2$

Cross beam : $Et = 3.00 \times 10^5\ kg/cm^2 = 30.0 \times 10^5\ t/m^2$

(2) Young's modulus corresponding to shearing

$G = 0.43E$

Main girder : $G\ell = 0.43 \times 35.0 \times 10^5 = 15.05 \times 10^5\ t/m^2$

Cross beam : $Gt = 0.43 \times 30.0 \times 10^5 = 12.90 \times 10^5\ t/m^2$

§3. Configuration and Dimensions of Main girder and Cross beam

1. Configuration and Dimensions of Main girder

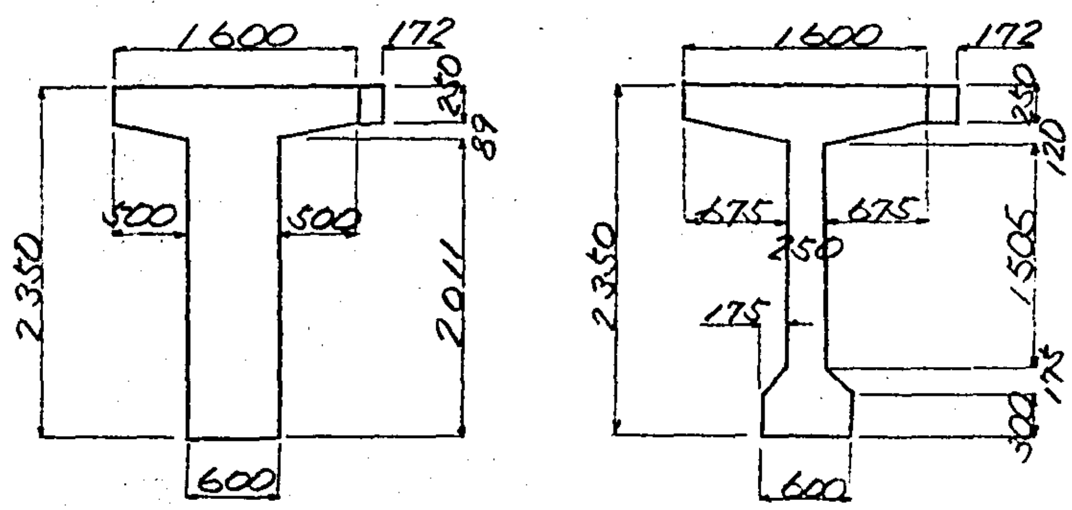
Dimension of concrete between Girders are as shown.

$$Et/E\ell = \frac{30.0 \times 10^5}{35.0 \times 10^5} = 0.857 \fallingdotseq 0.86$$

$$b = 0.400 \times 0.86 \times \frac{1}{2} = 0.172$$

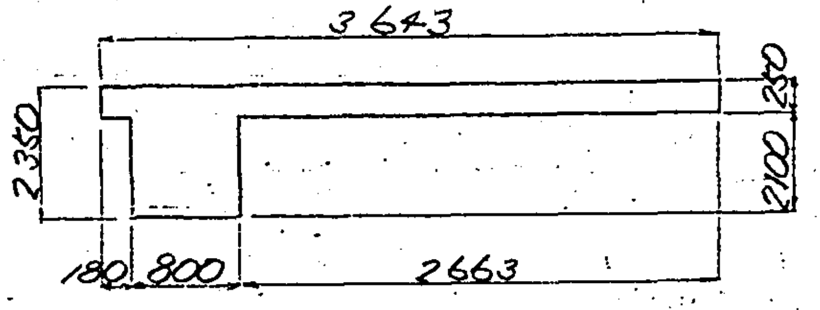
SECTION NUMBER ①: G1, G2 (Y1, Y5)

SECTION NUMBER ② G1, G2 (Y2 ~ Y4)

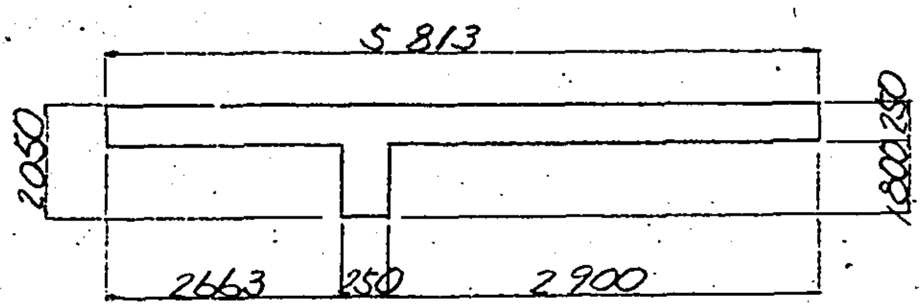


2. Configuration and Dimensions of Cross beam

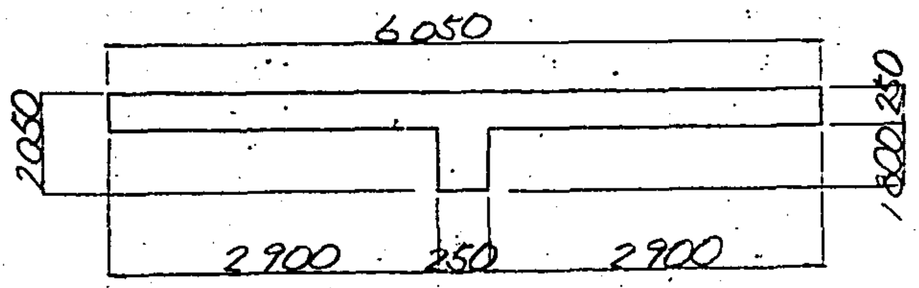
SECTION NUMBER ③ (Y1, Y5)



SECTION NUMBER ④ (Y2 Y4)



SECTION NUMBER ⑤ (Y3)



3. Applicable section number for various Girder, Beam/location

Girders		Location of number	Section number	Notes
Main girder	G_1, G_2	Location of Cross beam : y_1, y_5	①	
		〃 : $y_2 \sim y_4$	②	
			◯	
			◯	
Cross beam		y_1 , y_5	③	
		y_2 , y_4	④	
		y_3	⑤	

4. Moment of inertia of the section

(Unit: m^4)

Girders		Members	Moment of inertia (Average)
Main girder	G_1 G_2	1. 2 7 8	0.85073
		3. 4. 5. 6	0.76140
Cross beam		9. 13.	1.43756
		10 12.	0.52629
		11	0.53029

§4. Loads and Loading conditions

1. Application of loads for calculation

(1) Application of static load

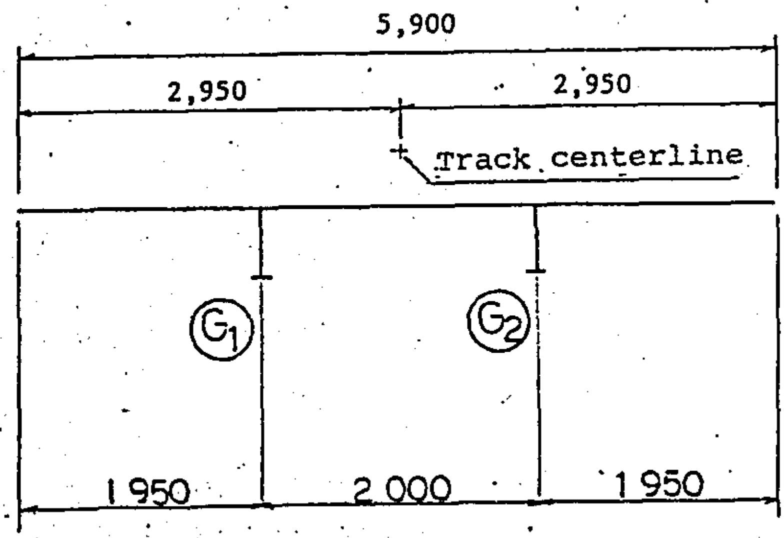
As the grid-system are carried out based on influence lines, the static load loading is applied in dual ways, one is a lined loading and the other is a uniformly distributed loading, to determine the loading length and width.

(2) Application of combined train loading

(a) Train load loading

Train load is assumed to be transmitted through sleepers downwards and distributed to the enlarged width within inclined lines with 53 deg. starting at both end points of sleeper bottom.

Distribution of loads through track is shown in the sketch drawing.



(b) Combined loading of train load

(i) Train load is supposed to distribute entire length of the span.

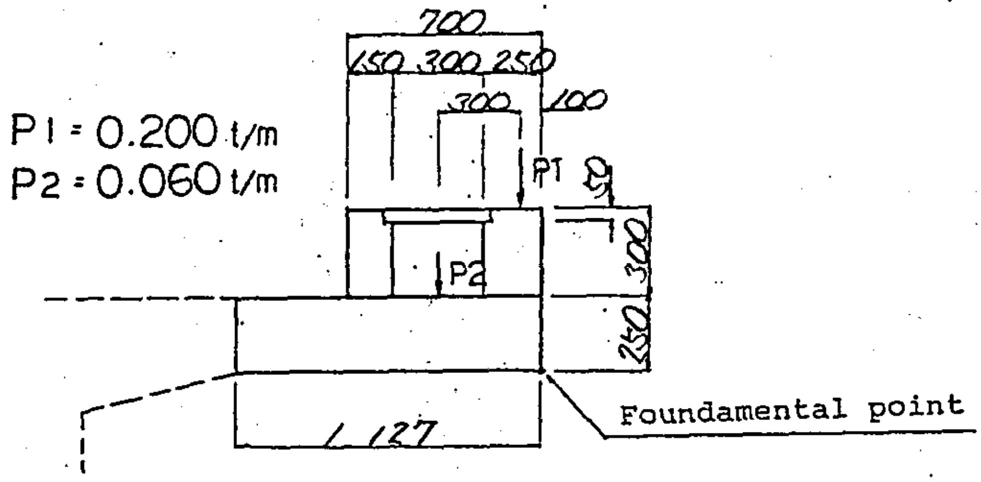
(ii) Train load is supposed to distribute limited to one side of span with 1/2 ℓ length.

Train load is applied combined the above (i) and (ii) loadings. Thus, further calculations are made for the sectional strength.

2. Dead load calculations of the own weight of structure

(1) Cantilever part of bridge slab, edge coaming and handrail concrete

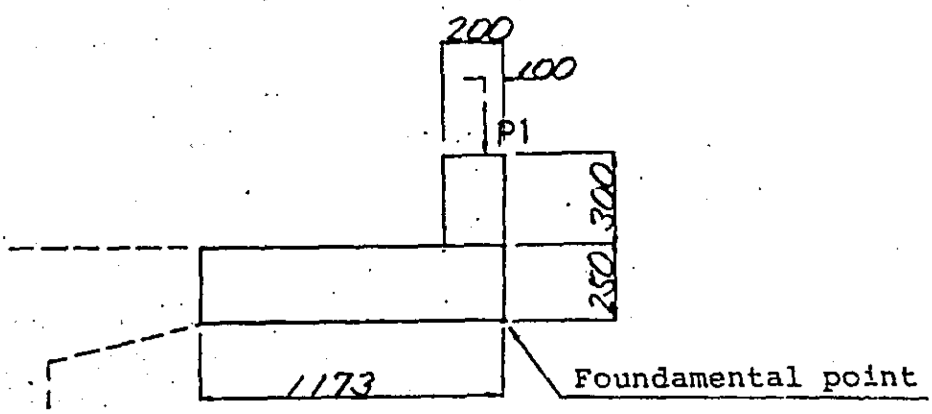
(a) G2 girder side



Load/Load acting point

Total dead load : ΣW(t/m) = 1.303
Total bending moment : $\Sigma W X$(t-m/m) = 0.551
Acting point of resultant force : $X = \Sigma W X / \Sigma W$(m) = 0.423

(b) G1 girder side

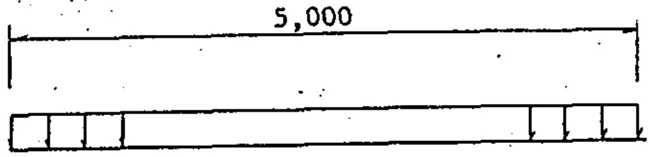


Load/Load acting point

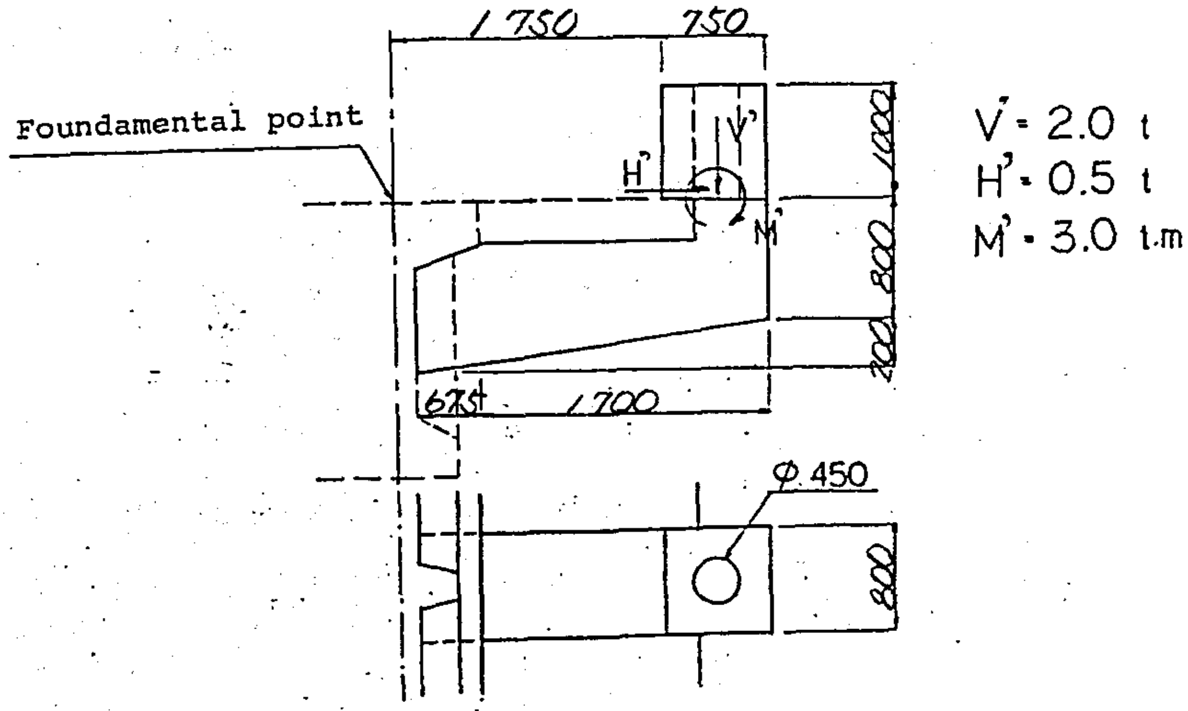
Total dead load : ΣW(t/m) = 1.083
Total bending moment : $\Sigma W X$(t-m/m) = 0.465
Acting point of resultant force : $X = \Sigma W X / \Sigma W$(m) = 0.429

(2) Graded Concrete

$Wp = 2.35 \times 0.07 = 0.165\ t/m^2$



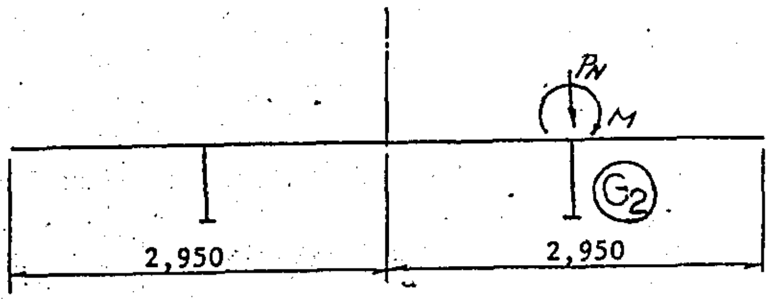
(3) Electric pole and its supporting beam



Load/Load acting point

Total dead load : ΣW (t/m) = 6.299 = P_N
Total bending moment : $\Sigma W\ X$ (t-m/m) = 11.203

$M = M' + \Sigma WX$ = 14.203



3. Dead load calculations of surcharge

(1) Surcharge load of ballast

Calculated as a uniformly distributed load.

$$W_B = 1.9 \text{ t/m}^3 \times (h_B - h_p) = 0.995 \text{ t/m}^2$$

(2) Surcharge load of track assembly

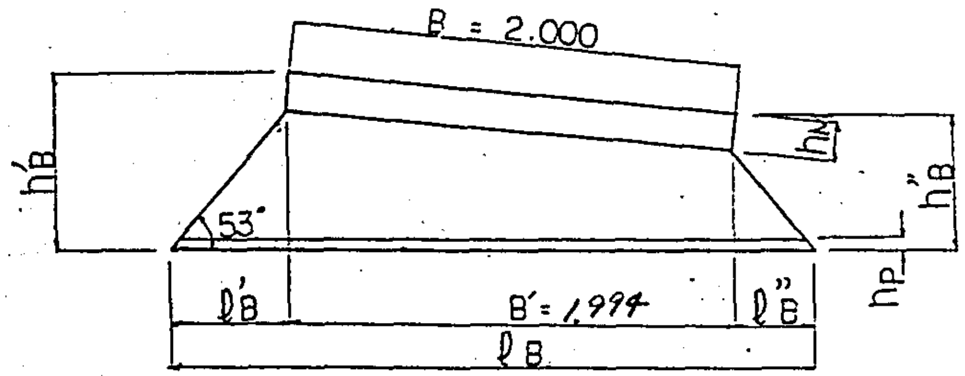
Load of track assembly is assumed to be distributed on the bridge slab with the width between two points on the slab, where lines drawn from the both ends of sleeper bottom with 53 deg. inclination towards outward-downward, crossing the slab surface.

- Load of track assembly : ΣW_R = 0.450 t/m
- Width of sleeper : B = 2.000 m
- Thickness of sleeper : h_M = 0.165 m
- Height between the girder top and the sleeper top : h_B = 0.660 m . 0.518 m
- Average thickness of graded concrete for drainage : h_p = 0.070 m

$$\ell_B' + \ell_B'' = (h_B - h_M) \cdot \text{Cot } 53° = 0.639 \text{ m}$$

- Load distribution width:

$$\ell_B = B' + \ell_B' + \ell_B'' = 2.633 \text{ m}$$



Uniformly distributed load:

$$W_R = \frac{\Sigma W_R}{\ell_B} = 0.171 \text{ t/m}^2$$

4. Live load calculations of train loading

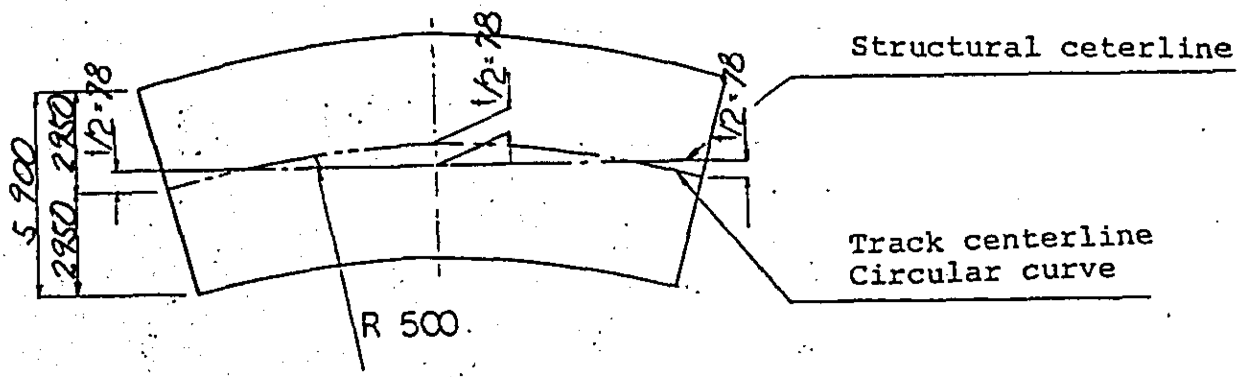
(1) Impact coefficient

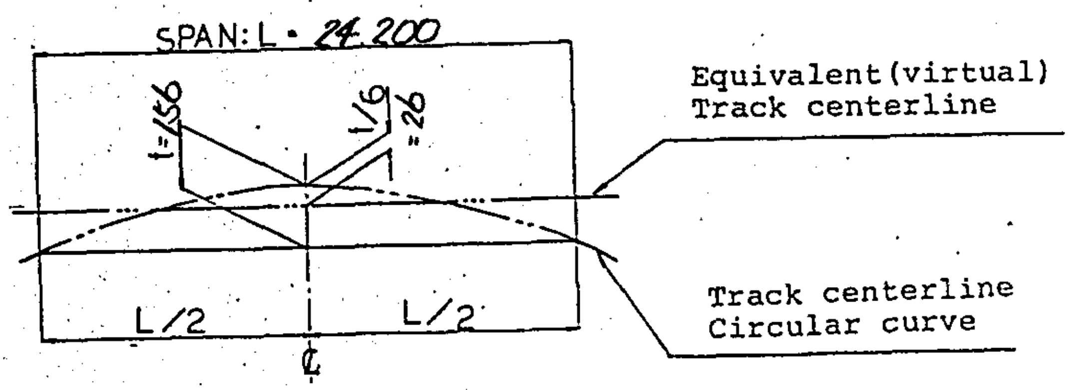
Span : ℓ = 24.200 m

Impact coefficient : i = 0.357

(2) Equivalent loading centerline of the track

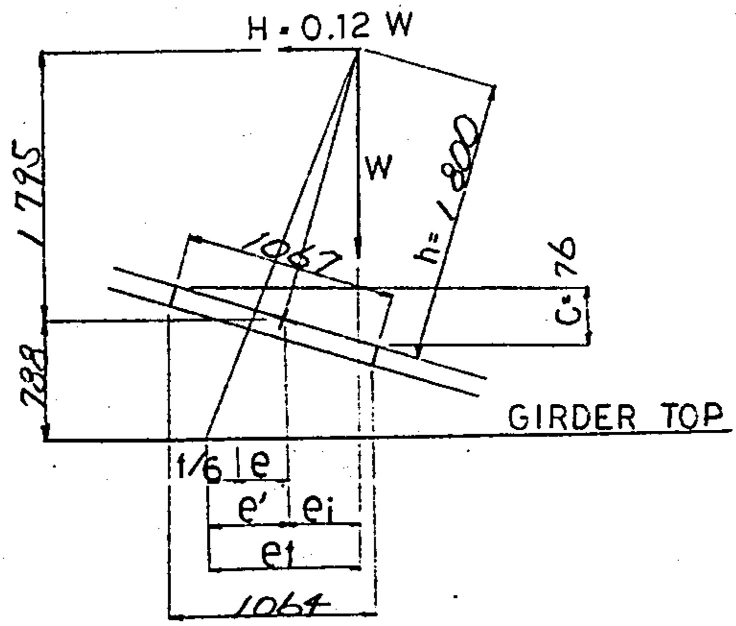
The bridge is located within a curve however, for the sake of practical design calculation, the loading centerline of track is assumed as a virtual track centerline drawn tangent at the mid span with f/6 shift.





(3) Acting point of resultant force, which is the combined force of the train load and the load caused by centrifugal force

The centrifugal force is assumed to have the magnitude equivalent to the value of train load times the coefficient of centrifugal load α = 0.12, acting horizontally at the point 1.80 m above the rail level in the section transversal to the track.



$e_i = 0.128$ m

$e_f = 0.310$ m

$e' = 0.182$ m

$e = 0.156$ m

(4) Uniformly distributed load, equivalent to the train loading

Bending moment calculation:

For the bending moment calculation, the equivalent uniformly distributed load at the 1/4 span point will be employed and confirmed as calculated below.

$$M\ell = \{M\ell_{min} + \frac{\ell - \ell_{min}}{\ell_{max} - \ell_{min}} \cdot (M\ell_{max} - M\ell_{min})\} \gamma \cdot \beta \times \frac{1}{18}$$

where, $\ell = 24.200$, $\ell_{max} = 24.500$, $\ell_{min} = 24.000$

$\gamma = 2$ $\beta = 16$

$M\ell(\ell/4)_{min} = 224.3$ t·m , $M\ell(\ell/4)_{max} = 233.5$ t·m

$M\ell(\ell/2)_{min} = 293.7$ t·m , $M\ell(\ell/2)_{max} = 304.7$ t·m

$$M\ell(\ell/4) = \{ 224.3 + \frac{0.20}{0.50} \times (233.5 - 224.3)\} 2 \times 16 \times \frac{1}{18}$$
$$= 405.298$$

$$M\ell(\ell/2) = \{ 293.7 + \frac{0.20}{0.50} \times (304.7 - 293.7)\} 2 \times 16 \times \frac{1}{18}$$
$$= 529.956$$

Equivalent uniformly distributed load at $\ell/4$ span point, which is Wm, will be

$$W_m = \frac{32}{3} \times \frac{M\ell(\ell/4)}{\ell^2} = 7.382 \text{ t/m}$$

Employed the above Wm value and applied for the bending moment calculation at $\ell/2$ point.

$$M'_{\ell/2} = W_m \cdot \frac{\ell^2}{8} = 540.399 \text{ t·m}$$
$$> M\ell_{(\ell/2)} = 529.956 \text{ t·m}$$

The result is larger than the value of $M_{\ell/2}$.

$$Wm = 7.382 \ t/m$$

Train loading for bending moment:

$$W\ell = Wm(1 + i) = 10.017 \ t/m$$

(5) Train loading for bending moment: calculation

Train loading is distributed expanded with 53 deg. inclination from the both ends of sleeper bottom.

Uniformly distributed load: $W\ell$

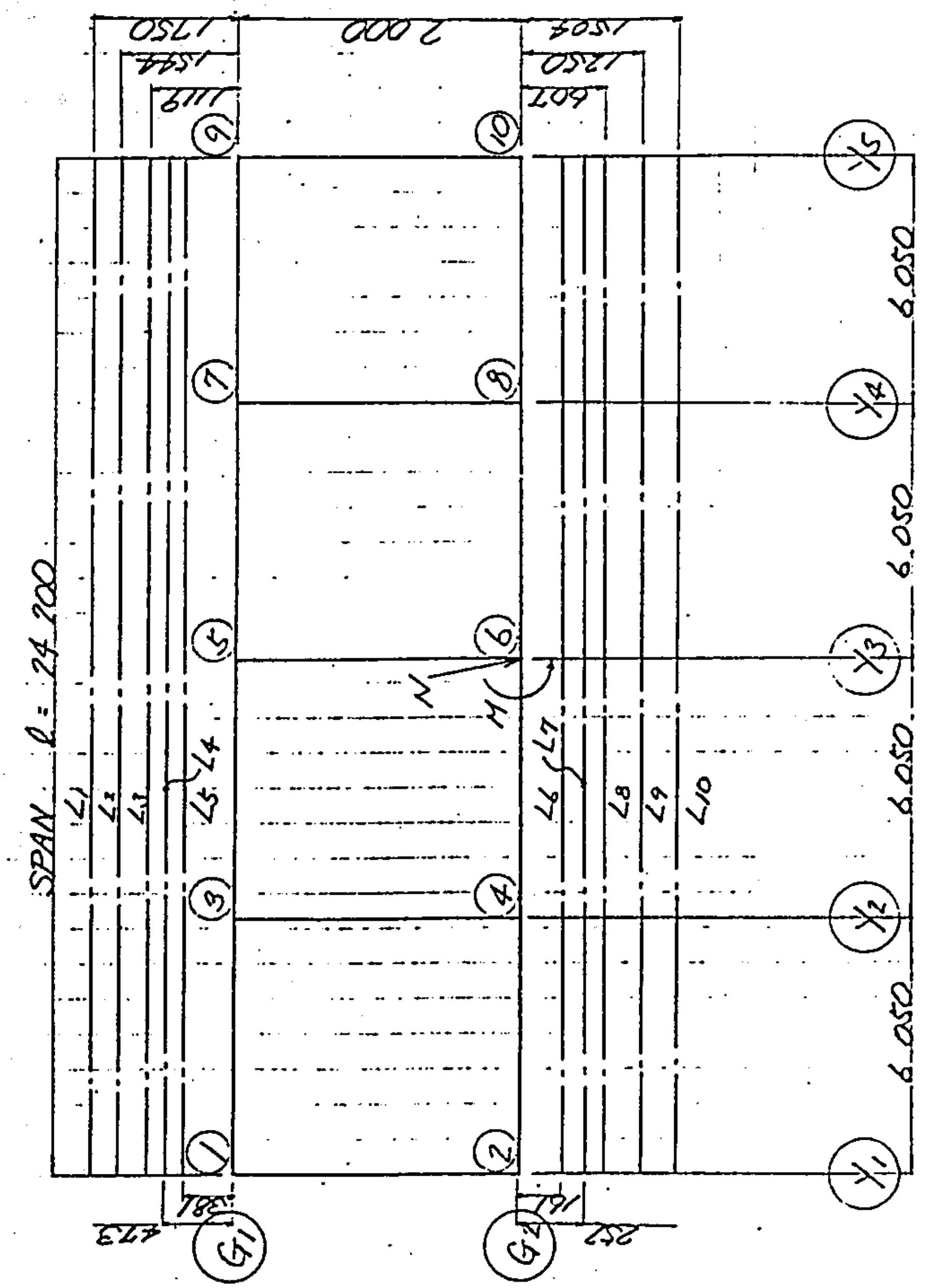
$$W\ell = \frac{Wm\ (1 + i)}{\ell_B} = 3.804 \ t/m^2$$

5. Load/Loading point of various loadings

(1) Summary of loads

Load	Cases	Title	Load distribution area: Width	Length	Intensity of load	Category of load
Dead load of surcharge and structure	Case 1	VANJO $-D_1$	L_{10}	$Y_1 \sim Y_5$	1.303 t/m	Canti. slab, handrail conc., etc.
			L_2	$Y_1 \sim Y_5$	1.083 "	
			$L_1 \sim L_9$	$Y_1 \sim Y_5$	0.165 t/m²	Graded conc.
			$L_3 \sim L_8$	$Y_1 \sim Y_5$	0.995 "	Ballast
			$L_5 \sim L_7$	$Y_1 \sim Y_5$	0.171 "	Track assembly
Electric pole, etc.	Case 2	DENCHU $-D_1$	G_2	Y_3	N = 6.299 t	Electric pole and its supporting beam
					M = 14.203 t·m	
Train load	Case 3	L_1	$L_4 \sim L_6$	$Y_1 \sim Y_5$	3.804 t/m²	Live load intensity applied for bending moment calculation
	Case 4	L_2	$L_4 \sim L_6$	$Y_1 \sim Y_3$	3.804 "	

(2) Loading conditions



6. Combined loading

(1) Case 1: Dead load of surcharge

(2) Case 2: Dead load of electric pole

(3) Case 3: Train load, loaded on full span

(4) Case 4: Train load, loaded on half span

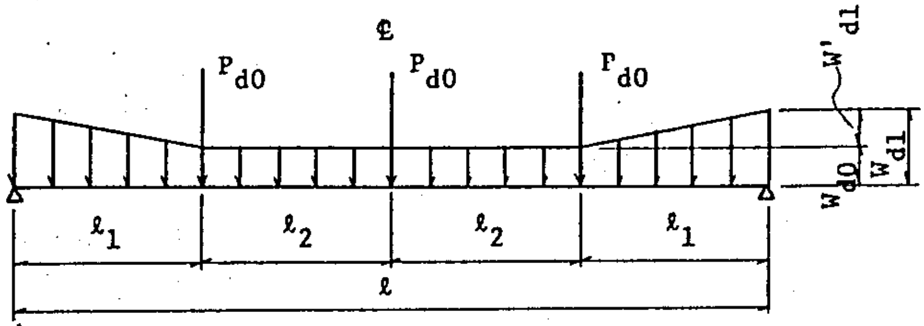
(5) Case 5: Case 1 + Case 2

(6) Case 6: Case 5 + Case 3

(7) Case 7: Case 5 + Case 4

Chapter 4. Design calculations of Main girder cross section

§1. Bending moment caused by own weight of Main girder



Bending moment (at center of span)

$$M_{d0} = \frac{1}{8}\cdot W_{d0}\cdot \ell^2 + \frac{1}{6}\cdot W_{d1}'\cdot \ell_1{}^2 + P_{d0}\cdot\{\frac{n}{2}(\ell_1 + \ell_2) - \ell_2\}$$

W_{d0} : Per meter weight of the section at the center (t/m) = 2.854

W_{di} : Per meter weight of the section at the point of support (t/m) = 4.261

$W_{d1}' = W_{d1} - W_{d0}$ = 1.407

P_{d0} : Weight of intermediate diaphragm (t) = 0.394

ℓ : Span (m) = 24.200

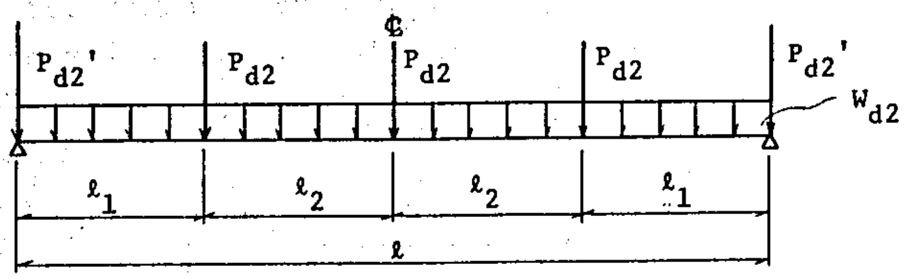
ℓ_1 : Length of the widened part of web (m) = 6.050

ℓ_2 : Location of diaphragm (m) = 6.050

n : Number of intermediate diaphragms

M_{d0} = 222.278 t·m

§2. Stress calculations of Cross beam cross section



- Bending moment (at center of span)

$$M_{d0} = \frac{1}{8} \cdot W_{d2} \cdot \ell^2 + P_{d2} \cdot \{ \frac{n}{2} \cdot (\ell_1 + \ell_2) - \ell_2 \}$$

where,

W_{d2} : Own weight of bridge slab between girders (t/m)
= 0.125

P_{d2} : Own weight of intermediate Cross beam (t)
= 0.866

P_{d2}' : Own weight of end Cross beam (t)
= 2.900

ℓ : Span (m) = 24.200

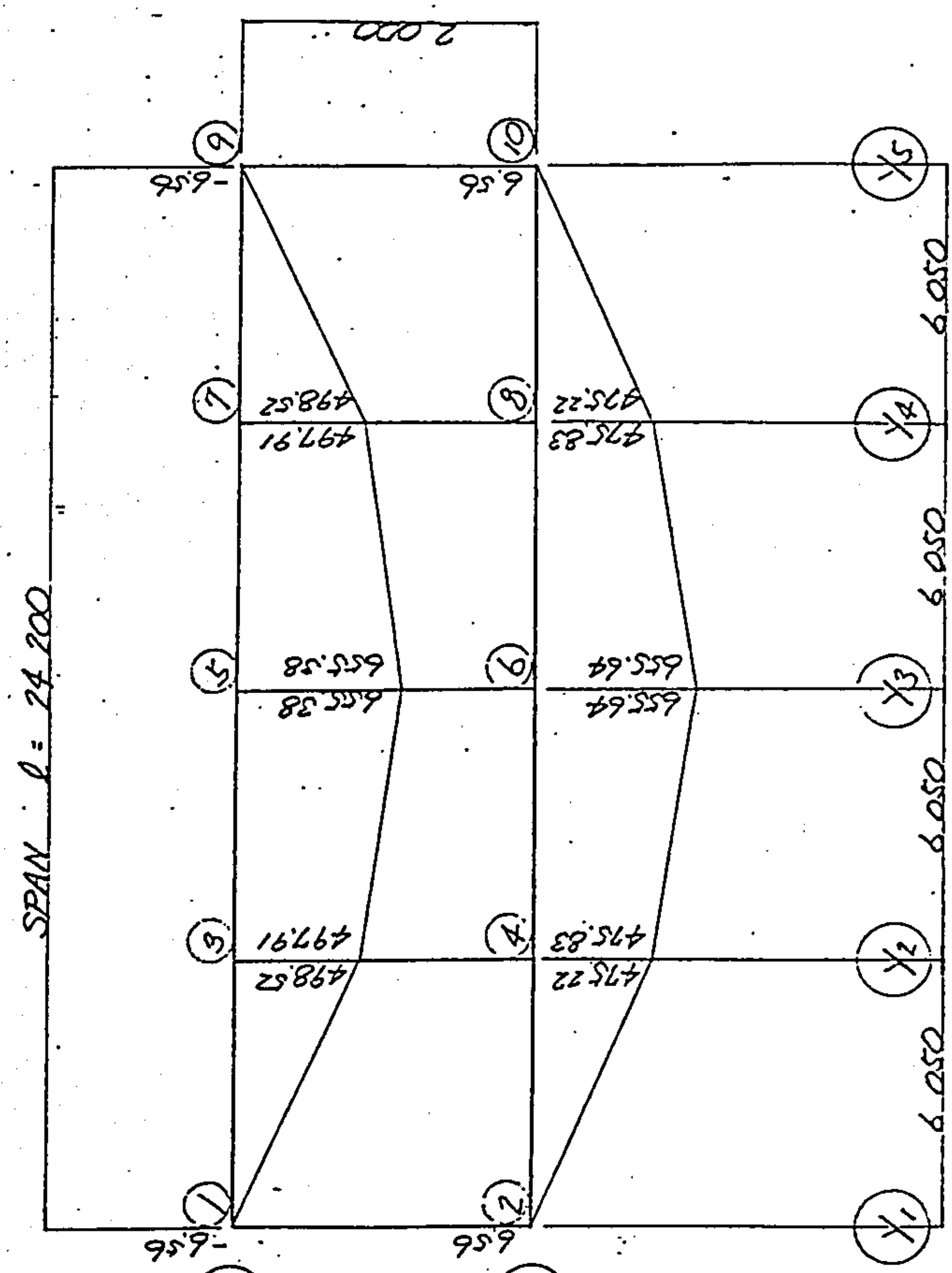
ℓ_1, ℓ_2 : Location of Cross beam (m) { $\ell_1 = 6.050$, $\ell_2 = 6.050$

n : Number of intermediate Cross beam = 3

M_{d0} = 19.629 t-m

§3. Stress caused by Static and Live load acting at the top of bridge slab

(Computer calculation with grid-system)
Bending moment diagram (Unit: t·m)



§4. Summary of bending moment calculations (at section of mid-span)

(Unit: t m)

Load / Main girder	Own Wt. (1) M.girder	(2) Concrete betw. girders	(3) Ballast Track	(4) Electric pole	(5)=Σ(1)~(4) D. load total	Live load		Total ((5) + (6))
						Mℓ (6)	Case	
G_1	222.28	19.63	278.01	-8.56	511.36	385.92	6	897.28
G_2	"	"	261.41	46.67	549.99	347.57	6	897.56

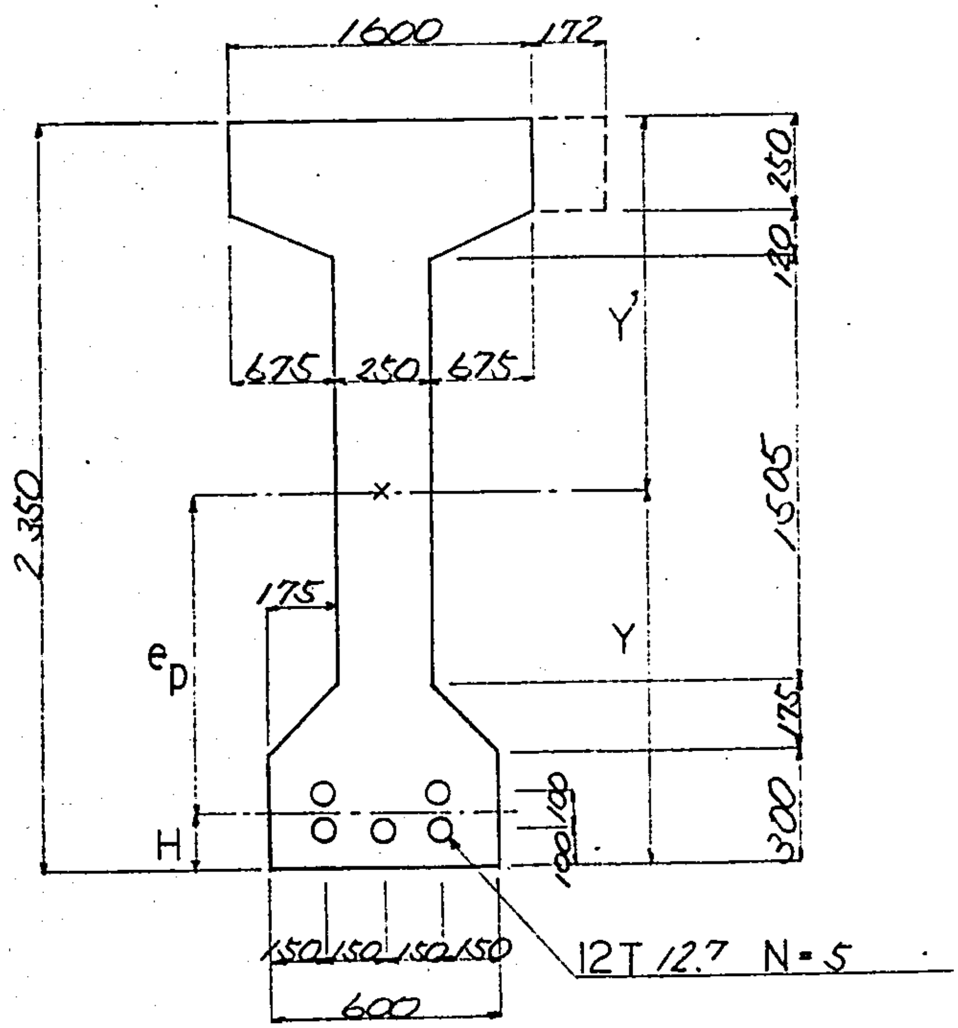
Developed the calculations in the preceding paragraphs, it became known that Maximum bending moment is exerted on Main girder.

Hence, further design calculations for Main girders will be represented by G2 girder.

Chapter 5. Main girder design

§1. Basis for the design calculations

1. Configuration and Dimensions of the girder section of mid span



A : Cross sectional area (cm^2)

I : Moment of inertia (cm^4)

Z : Section modulus (cm^3)

r : Radius of gyration (cm)

ep: Location of cables (cm)

N : Number of cables

6pt: Tensile stress immediate after the practice of pre-stressing (kg/mm^2)

Pt: total tensile stressimmediate after the practice of pre-stressing

n : Ratio of Young's modulus between Modulus of P.C. cables and that of concrete

ψ : Coefficient of creep

ε_s: Drying contraction rate of conerete

η : Effective factor

2. Summary of sectional values (mid span)

(1) Gross cross section

- A_c = 11416.25 cm^2
- I_c = 76.3896 x 10^6 cm^4
- Y_c = 143.2 cm
- Y_c' = 91.8 cm
- $Z_c = I_c/Y_c$ = 5.334 x 10^5 cm^3
- $Z_c' = I_c/Y_c'$ = 8.322 x 10^5 cm^3
- $\gamma_c^2 = I_c/A_c$ = 6.691 x 10^3 cm^2
- $e_{pc} = Y_c - H$ = 129.2 cm

(2) Net cross section

- A_0 = 11250.33 cm^2
- I_0 = 73.5791 x 10^6 cm^4
- Y_0 = 145.11 cm
- Y_0' = 89.89 cm
- $Z_0 = I_0/Y_0$ = 5.071 x 10^5 cm^3
- $Z_0' = I_0/Y_0'$ = 8.185 x 10^5 cm^3
- $\gamma_0^2 = I_0/A_0$ = 6.540 x 10^3 cm^2
- $e_{p0} = Y_0 - H$ = 131.11 cm
- $Z_{0g} = I_0/e_{p0}$ = 5.612 x 10^5 cm^3

(3) Equivalent cross section

- $n = E_p/E_c = \frac{2.0 \times 10^6}{3.5 \times 10^5} = 5.71$
- $n \cdot A_{p1} = 5.71 \times 11.85 = 67.664$ cm^2
- $A_{e1} = 11588.^{51}$ cm^2
- $I_{\ell 1} = 79.2224 \times 10^6$ cm^4
- $Y_{\ell 1} = \Sigma A_{e1} \cdot Y / \Sigma A_{e1} = 141.^{28}$ cm
- $Y_{e1}' = h - Y_{e1} = 93.^{72}$ cm
- $Z_{e1} = I_{e1}/Y_{e1} = 5.607 \times 10^5$ cm^3
- $Z_{e1}' = I_{e1}/Y_{e1}' = 8.453 \times 10^5$ cm^3
- $\gamma_{e1}^2 = I_{e1}/A_{e1} = 6.836 \times 10^3$ cm^2
- $e_{pe1} = Y_{e1} - H = 127.^{28}$ cm
- $Z_{e1g} = I_{e1}/e_{pe1} = 6.224 \times 10^5$ cm^3

(4) Equivalent cross section (including concrete between Girders)

- $A_{ez} = 12017.^{01}$ cm^2
- $I_{e2} = 81.9705 \times 10^6$ cm^4
- $Y_{e2} = \Sigma A_{e2} \cdot Y / \Sigma A_{e2} = 144.^{18}$ cm
- $Y_{e2}' = h - Y_{e2} = 90.^{82}$ cm
- $Z_{e2} = I_{e2}/Y_{e2} = 5.685 \times 10^5$ cm^3
- $Z_{e2}' = I_{e2}/Y_{e2}' = 9.025 \times 10^5$ cm^3
- $\gamma_{e2}^2 = I_{e2}/A_{e2} = 6.821 \times 10^3$ cm^2
- $e_{pe2} = Y_{e2} - H = 130.^{18}$ cm
- $Z_{e2g} = I_{e2}/e_{pe2} = 6.297 \times 10^5$ cm^3

§2. Summary of Bending stress calculations at mid span

Loads	Bending moment (x 10^5 kg·cm)	Section modulus (x 10^5 cm^3)		Bending stress (kg/cm^2) At top fibre	At bottom fibre	At the gravity center of cables
Own weight of Main girder	M_{d0} = 222.28	Z_0'	8.185	27.2	—	—
		Z_0	-5.071	—	-43.8	—
		Z_{0g}	-5.612	—	—	-39.6
Concrete between girders	M_{d1} = 19.63	Z_{e1}'	8.453	2.3	—	—
		Z_{e1}	-5.607	—	-3.5	—
		Z_{e1g}	-6.224	—	—	-3.2
Static load (Ballast track Electric pole)	M_{d2} = 308.08	Z_{e2}'	9.025	34.1	—	—
		Z_{e2}	-5.685	—	-54.2	—
		Z_{e2g}	-6.297	—	—	-48.9
Dead load Total	ΣM_d = 549.99	—	—	63.6	-101.5	-91.7
Live load	$M\ell$ = 347.57	Z_{e2}'	9.025	38.5	—	—
		Z_{e2}	-5.685	—	-61.1	—
		Z_{e2g}	-6.297	—	—	-55.2
Total	ΣM = 897.56	—	—	102.1	-162.6	-146.9

§3. Summary of stress calculations caused by pre-stressing at mid span

States	Items			Unit	Values
Immediate after the practice of pre-stressing	σ_{pt}			kg/mm^2	98
	A_p			mm^2	1185
	N				5
	A_0			$x10^3\ cm^2$	11.250
	e_{p0}			m	-1.311
	Section modulus	Z_0'		$x10^5\ cm^3$	8.185
		Z_0		"	-5.071
		Z_{0g}		"	-5.612
	P_t			$x10^3$ kg	580.65
	Stress	Top fibre	σ_{ct}'	kg/cm^2	41.4
		Bottom fibre	σ_{ct}	"	-201.7
		Grav.Center of cables	σ_{0pt}	"	-187.3
Effective pre-stress	n				5.71
	ψ				2.6
	γ				0.05
	$\Sigma\sigma_{dg}$			kg/cm^2	-91.7
	E_p			$x10^5 kg/cm^2$	20
	ε_s			$x10^{-5}$	20
	$\Delta\sigma_{p\gamma}$			kg/mm^2	-4.90
	$\Delta\sigma_{p\psi}$			"	-13.43
	σ_{pe}			"	79.67
	η				0.813
	Stress	Top fibre	σ_{ce}'	kg/cm^2	-33.7
		Bottom fibre	σ_{ce}	"	164.0
		Grav.Center of cables	σ_{cpe}	"	152.3

§4. Summary of combined Bending stress at mid span

Loads			Stresses (kg/cm²) Top fibre	Stresses (kg/cm²) Bottom fibre
(1)	Own weight of Main girder		27.2	-43.8
(2)	Concrete between girders		2.3	-3.5
(3)	Static load		34.1	54.2
(4)	Dead load total ((1) + (2) + (3))		63.6	-101.5
(5)	Live load		38.5	-61.1
(6)	Total load ((4) + (5))		102.1	-162.6
(7)	Immediate after the pre-stressing		-41.4	201.7
(8)	Effective pre-stress		-33.7	164.0
Combined stress Immediate after the pre-stressing		(1) + (7)	-14.2	157.9
		Allowable value	> - 15.0	< 180.0
Total Dead loading		(4) + (8)	27.3	75.4
Design loading		(6) + (8)	68.4	1.4
		Allowable value	< 140.0	> -10.0

NO. 8 P.C. GIRDERS

SUPER-STRUCTURE

DESIGN CALCULATION

B14 - PC40 $L = 33^{m}$, $H = 2.15^{m}$

(Right 59°34′41″)

(Right 70°08′11″)

CONTENTS

Chapter 1. Design criteria

1. Basis for design and loading conditions

- Kind of bridge: Pre-stressed concrete railroad bridge.
- Type of Bridge/Girders: Bridge superstructure is a simple beam, consisted of 4 main girders aligned in parallel.
  Girder is made of post-tensioned concrete of I type section.
- Length of girder: 32.621m ~ 33.299m
- Span of main girder: 31.621 m ~ 32.299 m
- Live load : KS-16
- Impact coefficient : i = 0.335
- Crossing angle: { at younger change: 59° 34' 41" RIGHT
  at elder change: 70° 08' 11" RIGHT
- Railroad curve: TRANSITION CURVE

2. Strength of materials for design

2-1. Concrete

(1) Concrete used for main girder

- Standard strength for design (28 day value).
  : $\sigma_{CK} = 400$ kg/cm^2
- Allowable compressive strength for bending calculation
  : $\sigma_{ca} = 140$ kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : $\sigma_{ci} = 180$ kg/cm^2
- Allowable tensile strength for bending calculation applied for,
  - design loading : $\sigma_{cat} = -10$ kg/cm^2
  - dead load : $\sigma_{cat'} = 0$ kg/cm^2
  - immediate after the pre-stressing: $\sigma_{cat''} = -15$ kg/cm^2
- Young's modulus corresponding to the standard strength for design : $E_c = 3.5\times10^5$ kg/cm^2

(2) Concrete used for lateral connection

- Standard strength for design (28 day value)
  : $\sigma_{ck} = 300$ kg/cm^2
- Allowable compressive strength for bending calculation : $\sigma_{ca} = 110$ kg/cm^2
- Allowable tensile strength for bending calculation : $\sigma_{ca'} = -8$ kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : $\sigma_{ci} = 140$ kg/cm^2
- Young's modulus corresponding to the standard strength for design : $E_c = 3.0\times10^5$ kg/cm^2

(3) Cantilever part of bridge slab, edge coaming and handrail concrete

- Standard strength for design (28 day value) : σ_{ck} = 240 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 80 kg/cm^2

2-2. Steel materials used for P.C. concrete

(1) P.C. Cable (SWPR-7B) 12T 12.7 mm

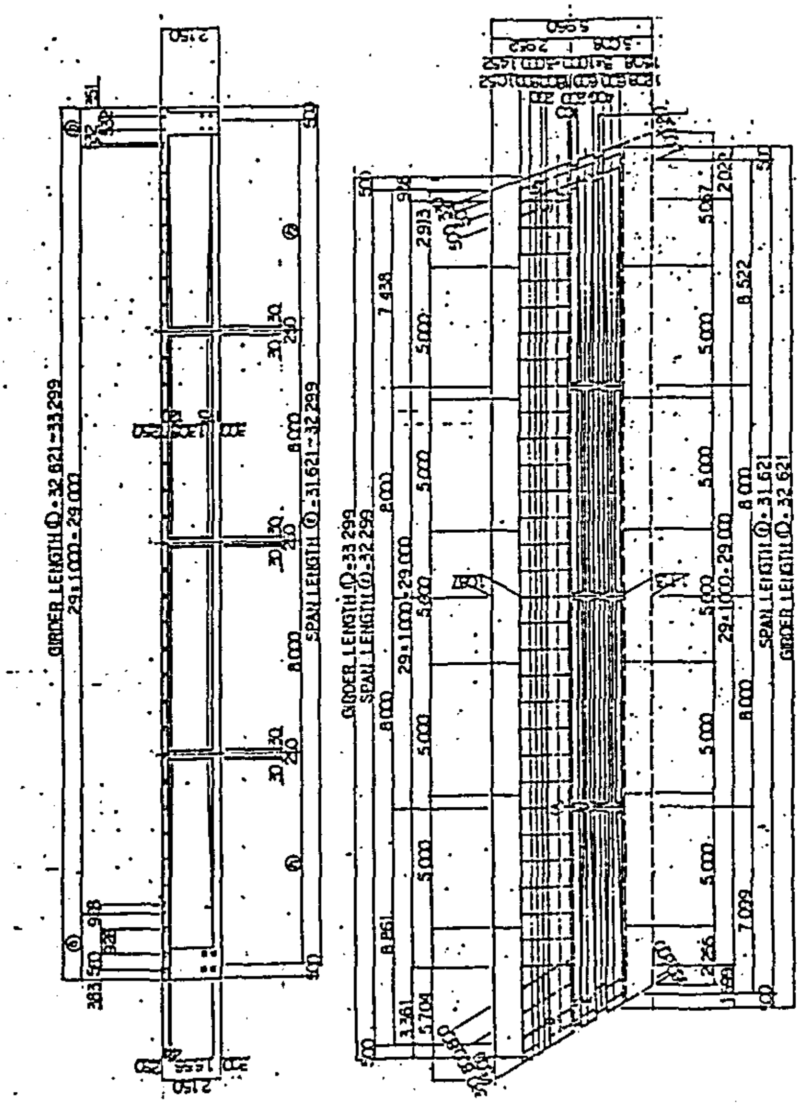
- Tensile strength : σ_{pu} =190 kg/mm^2
- Yielding point : σ_{py} =160 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} =114 kg/mm^2
  - immediate after the pre-stressing: σ_{pat}=133 kg/mm^2
  - during pre-stressing : σ_{pai}=145 kg/mm^2
- Young's modulus of P.C. steel material : $E_p=2.0\times10^6$kg/cm^2

(2) P.C. steel bar (SBPR 95/110) ϕ 23 mm

- Tensile strength : σ_{pu} = 110 kg/mm^2
- Yielding point : σ_{py} = 95 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 66 kg/mm^2
  - immediate after the pre-stressing: σ_{pat}= 77 kg/mm^2
  - during pre-stressing : σ_{pai}=85.5 kg/mm^2
- Young's modulus of P.C. steel material : $E_p=2.0\times10^6$kg/mm^2

2-3. Reinforcing Bar : SD 30

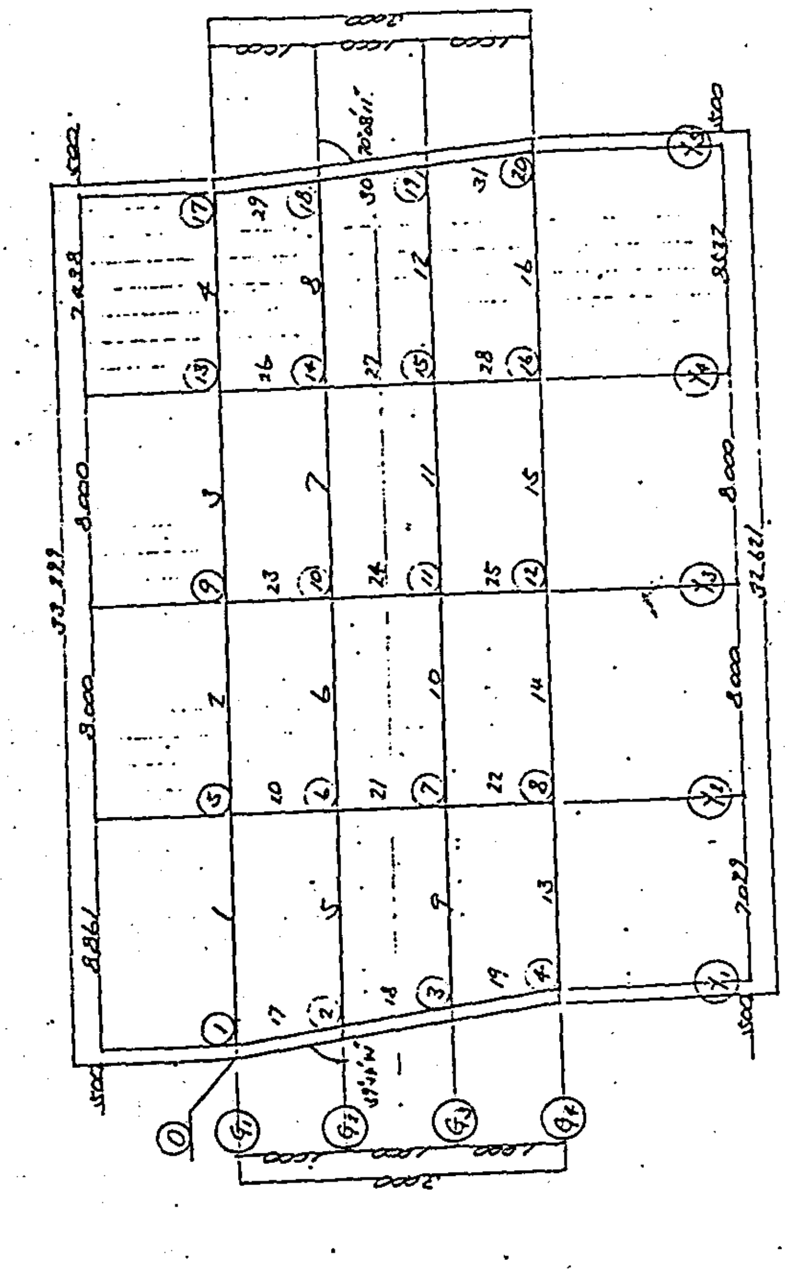
Chapter 2. Configuration and Dimensions of Bridge



Chapter 3. Input for Grid-system calculation

§1. Numbering & Coordinates of Skeleton Point

1. Member numbering & Skeleton point numbering



2. Coordinates calculations of Skeleton points

Assumed the Skeleton point (0) as fundamental point, coordinates of other skeleton points are calculated as listed below.

(Unit: m)

Skeleton point number	Skeleton point coordinates x	Skeleton point coordinates y	Skeleton point number	Skeleton point coordinates x	Skeleton point coordinates y
(1)	0.500	0	(15)	25.361	-2.000
(2)	1.087	-1.000	(16)	"	-3.000
(3)	1.674	-2.000	(17)	32.799	0
(4)	2.262	-3.000	(18)	33.160	-1.000
(5)	9.361	0	(19)	33.522	-2.000
(6)	"	-1.000	(20)	33.833	-3.000
(7)	"	-2.000	( )		
(8)	"	-3.000	( )		
(9)	17.361	0	( )		
(10)	"	-1.000	( )		
(11)	"	-2.000	( )		
(12)	"	-3.000	( )		
(13)	25.361	0	( )		
(14)	"	-1.000	( )		

§2. Support conditions and Young's modulus of Concrete

1. Support conditions

Skeleton number	Rotation around		Z direction
	Y axis	X axis	
①	free	free	restricted
②	"	"	"
③	"	"	"
④	"	"	"
⑰	"	"	"
⑱	"	"	"
⑲	"	"	"
⑳	"	"	"

2. Young's modulus of concrete

(1) Young's modulus

Main girder : $E\ell = 3.50 \times 10^5$ kg/cm^2 = 35.0×10^5 t/m^2

Cross beam : $Et = 3.00 \times 10^5$ kg/cm^2 = 30.0×10^5 t/m^2

(2) Young's modulus corresponding to shearing

$G = 0.43E$

Main girder : $G\ell = 0.43 \times 35.0 \times 10^5 = 15.05 \times 10^5$ t/m^2

Cross beam : $Gt = 0.43 \times 30.0 \times 10^5 = 12.90 \times 10^5$ t/m^2

§3. Configuration and Dimensions of Main girder and Cross beam

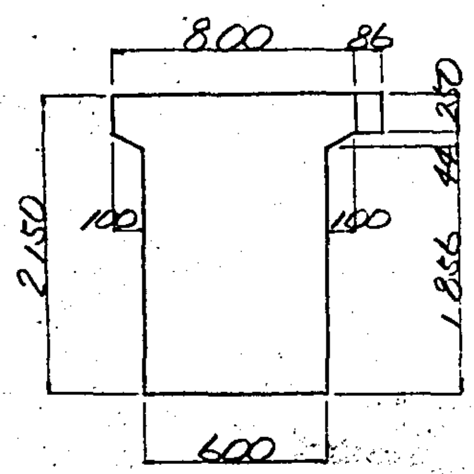
1. Configuration and Dimensions of Main girder

Dimension of concrete between Girders are as shown.

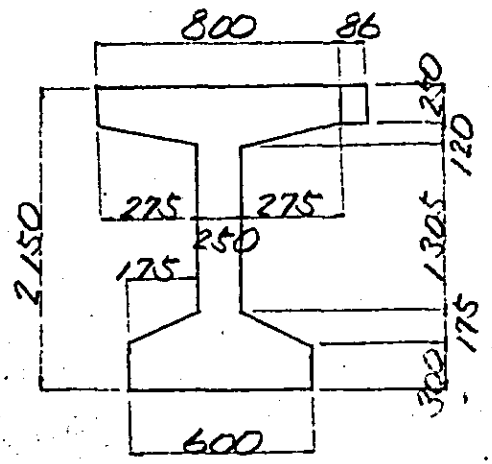
$$Et/E\ell = \frac{30.0 \times 10^5}{35.0 \times 10^5} = 0.857 \fallingdotseq 0.86$$

$$b = 0.200 \times 0.86 \times \frac{1}{2} = 0.086$$

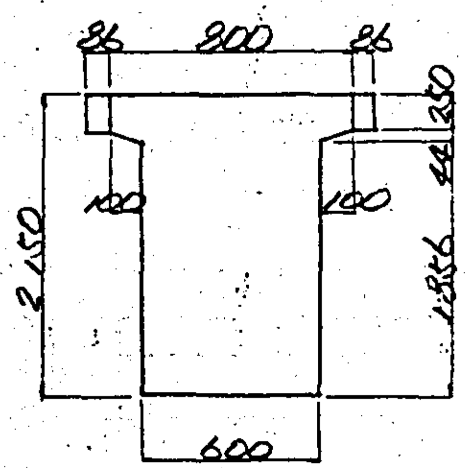
SECTION NUMBER ①: G1, G4 (Y1, Y5)



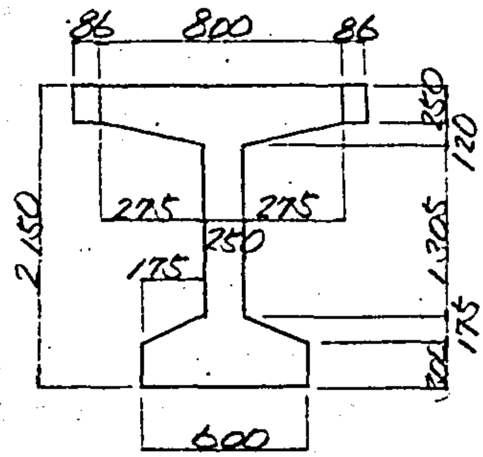
SECTION NUMBER ②: G1, G4 (Y2 ~ Y4)



SECTION NUMBER ③: G2 G3 (Y1, Y5)

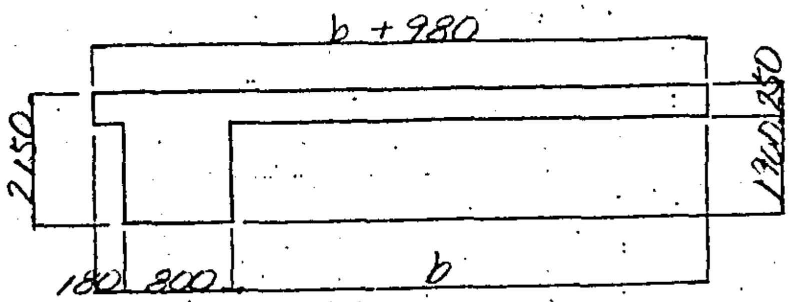


SECTION NUMBER ④: G2 G3 (Y2 ~ Y4)



2. Configuration and Dimensions of Cross beam

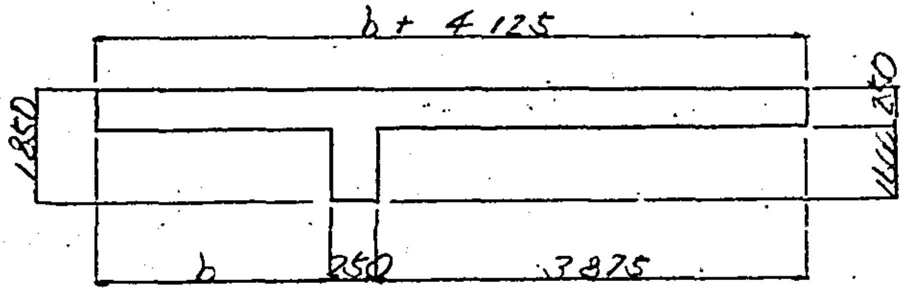
SECTION NUMBER ⑤ (Y1)



	G1	G2	G3	G4
b	4.128	3.835	3.541	3.247

(m)

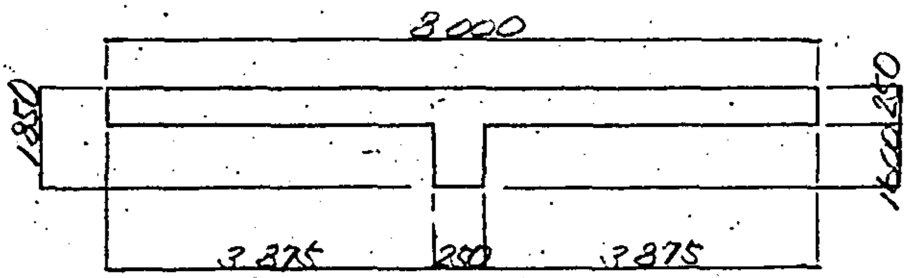
SECTION NUMBER ⑥ (Y2)



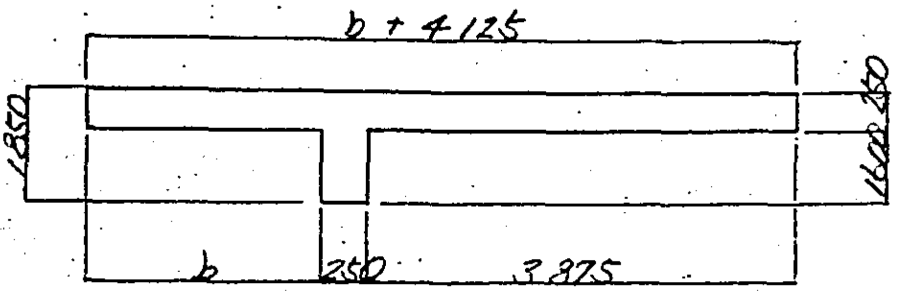
	G1	G2	G3	G4
b	4.128	3.835	3.541	3.247

(m)

SECTION NUMBER ⑦ (Y3)



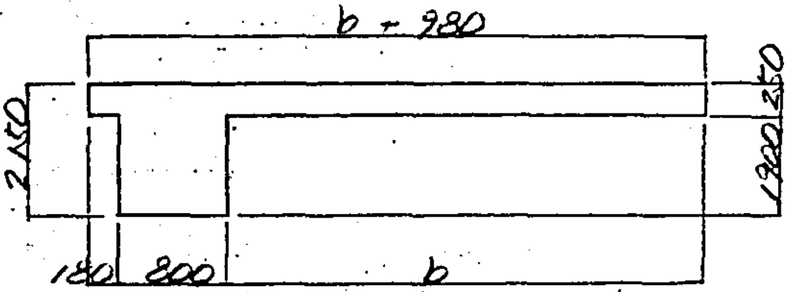
SECTION NUMBER ⑧ (y_4)



	G_1	G_2	G_3	G_4
b	3.417	3.597	3.778	3.959

(m)

SECTION NUMBER ⑨ (y_5)



	G_1	G_2	G_3	G_4
b	3.417	3.597	3.778	3.959

(m)

3. Applicable section number for various Girder, Beam/location

Girders		Location of number	Section number	Notes
Main girder	G_1, G_4	Location of Cross beam : y_1 , y_5	①	
		〃 : $y_2 \sim y_4$	②	
	G_2, G_3	〃 : y_1 , y_5	③	
		〃 : $y_2 \sim y_4$	④	
Cross beam		y_1	⑤	
		y_2	⑥	
		y_3	⑦	
		y_4	⑧	
		y_5	⑨	

4. Moment of inertia of the section

(Unit: m^4)

Girders		Members	Moment of inertia (Average)
Main girder	G_1 G_4	1, 4, 13, 16	0.51762
		2, 3, 14, 15	0.47427
	G_2 G_3	5, 8, 9, 12	0.53445
		6, 7, 10, 11	0.49076
Cross beam		17	1.25286
		18	1.22605
		19	1.19771
		20	0.38171
		21	0.37957
		22	0.37731
		23 24 25	0.38096
		26	0.37820
		27	0.37957
		28	0.38091
		29	1.20891
		30	1.22613
		31	1.24282

§4. Loads and Loading conditions

1. Application of loads for calculation

(1) Application of static load

As the grid-system are carried out based on influence lines, the static load loading is applied in dual ways, one is a lined loading and the other is a uniformly distributed loading, to determine the loading length and width.

(2) Application of combined train loading

(a) Train load loading

Train load is assumed to be transmitted through sleepers downwards and distributed to the enlarged width within inclined lines with 53 deg. starting at both end points of sleeper bottom.

(b) Combined loading of train load

(i) Train load is supposed to distribute entire length of the span.

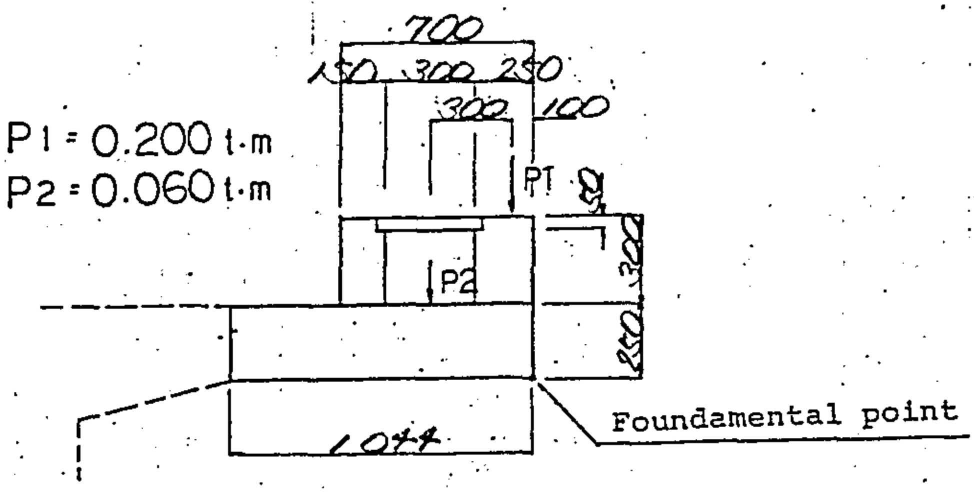
(ii) Train load is supposed to distribute limited to one side of span with 1/2 ℓ length.

Train load is applied combined the above (i) and (ii) loadings. Thus, further calculations are made for the sectional strength.

2. Dead load calculations of the own weight of structure

(1) Cantilever part of bridge slab, edge coaming and handrail concrete

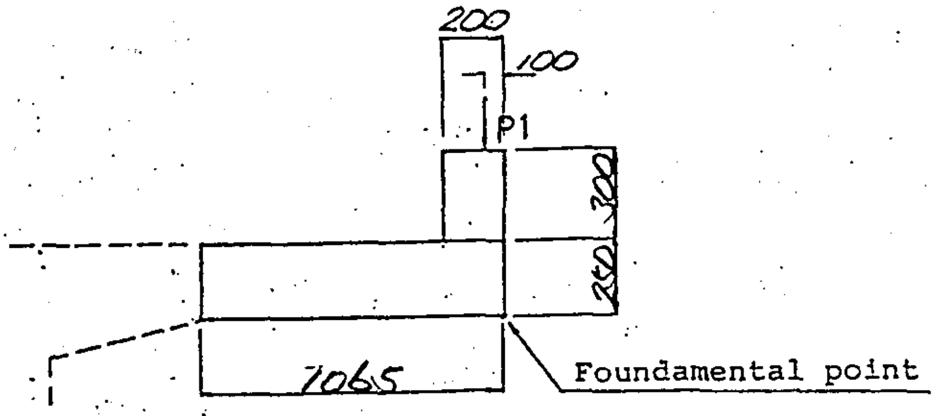
(a) G4 girder side



Load/Load acting point

Total dead load : ΣW(t/m) = 1.252
Total bending moment : $\Sigma W X$(t-m/m) = 0.495
Acting point of resultant force : $X = \Sigma W X / \Sigma W$(m) = 0.395

(b) G1 girder side



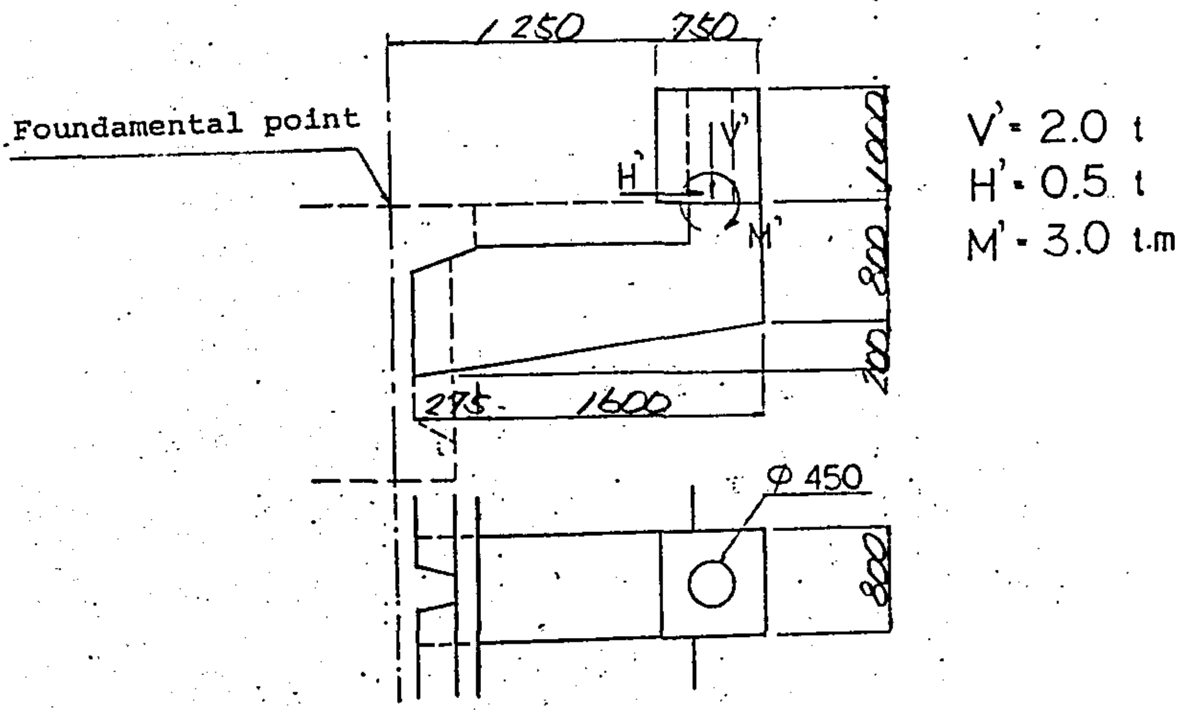
Load/Load acting point

Total dead load : ΣW(t/m) = 1.016
Total bending moment : $\Sigma W X$(t-m/m) = 0.390
Acting point of resultant force : $X = \Sigma W X / \Sigma W$(m) = 0.384

(2) Graded Concrete

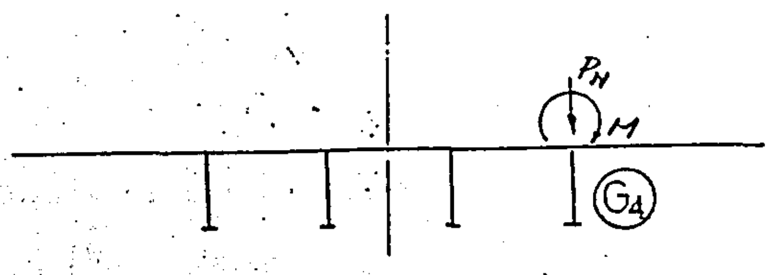
$W_p = 2.35 \times 0.07 = 0.165\ t/m^2$

(3) Electric pole and its supporting beam



Load/Load acting point

Total dead load : ΣW (t/m) = 5.716 = P_N
Total bending moment : $\Sigma W X$ (t-m/m) = 7.990
$M = M' + \Sigma WX$ = 10.990



3. Dead load calculations of surcharge

(1) Surcharge load of ballast

Calculated as a uniformly distributed load.

$$W_B = 1.9\ t/m^3 \times (h_B - h_p) = 0.914\ t/m^2$$

(2) Surcharge load of track assembly

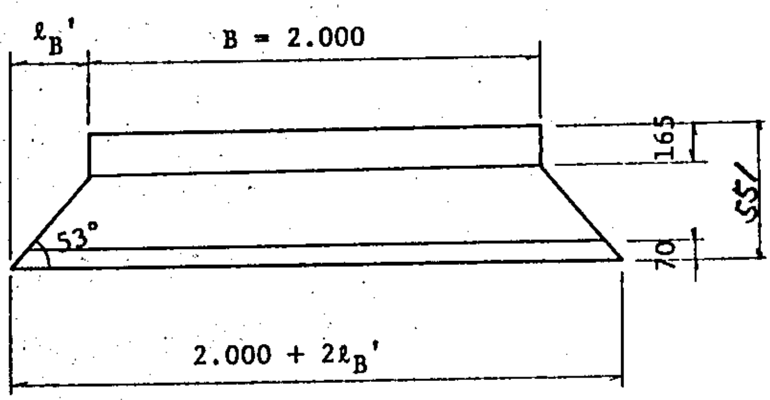
Load of track assembly is assumed to be distributed on the bridge slab with the width between two points on the slab, where lines drawn from the both ends of sleeper bottom with 53 deg. inclination towards outward-downward, crossing the slab surface.

- Load of track assembly : $\Sigma W_R = 0.450$ t/m
- Width of sleeper : $B = 2.000$ m
- Thickness of sleeper : $h_M = 0.165$ m
- Height between the girder top and the sleeper top : $h_B = 0.551$ m
- Average thickness of graded concrete for drainage : $h_p = 0.070$ m

$$2\ell_B' = 2(h_B - h_M) \cdot \text{Cot } 53° = 0.582\ m$$

- Load distribution width:

$$\ell_B = B + 2\ell_B' = 2.582\ m$$



Uniformly distributed load:

$$W_R = \frac{\Sigma W_R}{\ell_B} = 0.174\ t/m^2$$

4. Uniformly distributed load, equivalent to the train loading

Bending moment calculation:

For the bending moment calculation, the equivalent uniformly distributed load at the 1/4 span point will be employed and confirmed as calculated below.

$$M\ell = \{M\ell_{min} + \frac{\ell - \ell_{min}}{\ell_{max} - \ell_{min}} \cdot (M\ell_{max} - M\ell_{min})\}\ \gamma \cdot \beta \times \frac{1}{18}$$

where, $\ell = 32.299$, $\ell_{max} = 33.000$, $\ell_{min} = 32.000$

$\gamma = 2$ $\beta = 16$

$M\ell(\ell/4)_{min} = 389.3$, $M\ell(\ell/4)_{max} = 412.3$

$M\ell(\ell/2)_{min} = 480.3$, $M\ell(\ell/2)_{max} = 509.6$

$$M\ell(\ell/4) = \{389.3 + \frac{0.299}{1.000} \times (412.3 - 389.3)\}\ 2 \times 16 \times \frac{1}{18}$$
$$= 704.315$$

$$M\ell(\ell/2) = \{480.3 + \frac{0.299}{1.000} \times (509.6 - 480.3)\}\ 2 \times 16 \times \frac{1}{18}$$
$$= 869.441$$

Equivalent uniformly distributed load at $\ell/4$ span point, which is Wm, will be

$$W_m = \frac{32}{3} \times \frac{M\ell(\ell/4)}{\ell^2} = 7.201$$

Employed the above Wm value and applied for the bending moment calculation at $\ell/2$ point.

$$M'_{\ell/2} = W_m \cdot \frac{\ell^2}{8} = 939.033\ t.m$$
$$> M\ell_{(\ell/2)} = 869.441\ t \cdot m$$

The result is larger than the value of $M'_{\ell/2}$.

$W_m = 7.201$ t/m

Train loading for bending moment:

$W_\ell = W_m(1 + i) = 9.613$ t/m

Train loading for bending moment: calculation

Train loading is distributed expanded with 53 deg. inclination from the both ends of sleeper bottom.

Uniformly distributed load: W_ℓ

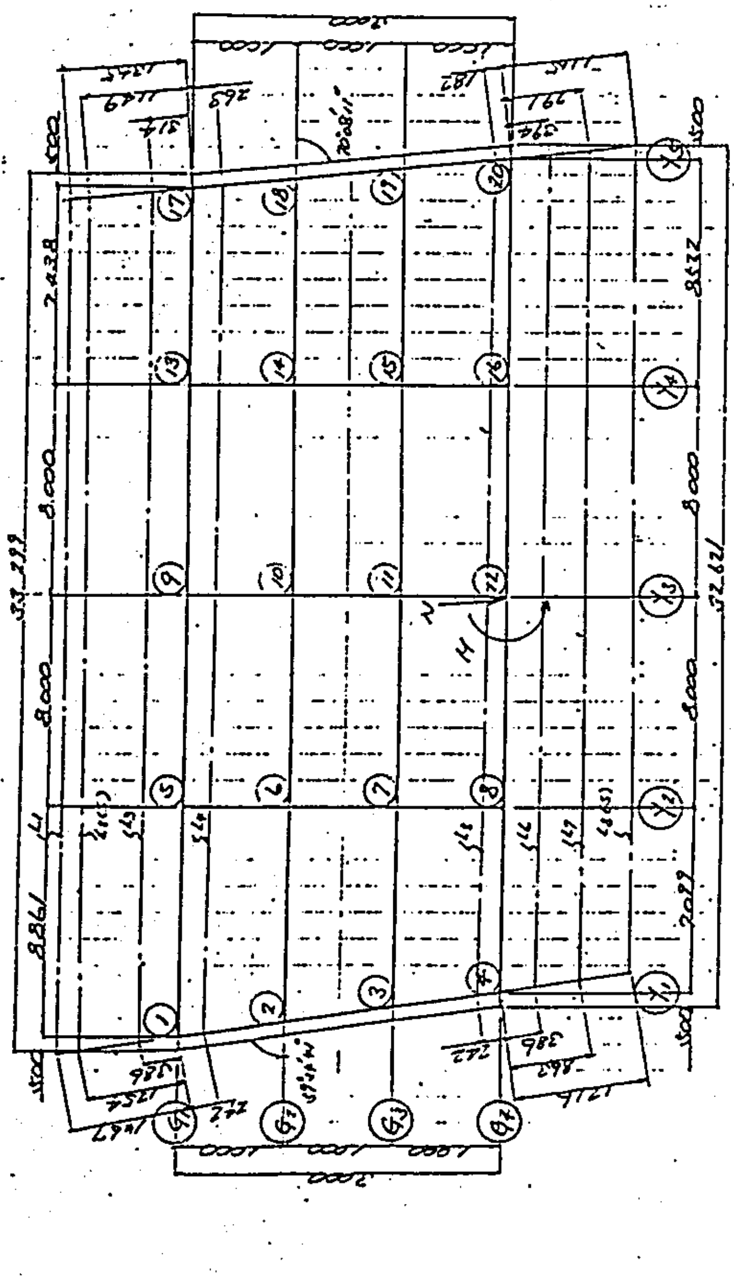
$$W_\ell = \frac{W_m\ (1 + i)}{\ell_B} = 3.723\ t/m^2$$

5. Load/Loading point of various loadings

(1) Summary of loads

Load	Cases	Title	Load distribution area: Width	Load distribution area: Length	Intensity of load	Category of load
Dead load of surcharge and structure	Case 1	VANJO $-D_1$	L_8	$Y_1 \sim Y_5$	1.252 t/m	Canti. slab, handrail conc., etc.
			L_2	$Y_1 \sim Y_5$	1.016 〃	
			$L_1 \sim L_7$	$Y_1 \sim Y_5$	0.165 t/m²	Graded conc.
			$L_3 \sim L_6$	$Y_1 \sim Y_5$	0.914 〃	Ballast
			$L_4 \sim L_5$	$Y_1 \sim Y_5$	0.174 〃	Track assembly
Electric pole, etc.	Case 2	DENCHU $-D_1$	G_4	Y_3	N = 5.716 t M = 10.990 t·m	Electric pole and its supporting beam
Train load	Case 3	L_1	$L_4 \sim L_5$	$Y_1 \sim Y_5$	3.723 t/m²	Live load intensity applied for bending moment calculation
	Case 4	L_2	$L_4 \sim L_5$	$Y_1 \sim Y_3$	3.723 〃	
	Case 5	L3	$L_4 \sim L_5$	$Y_3 \sim Y_5$	3.723 〃	

(2) Loading conditions

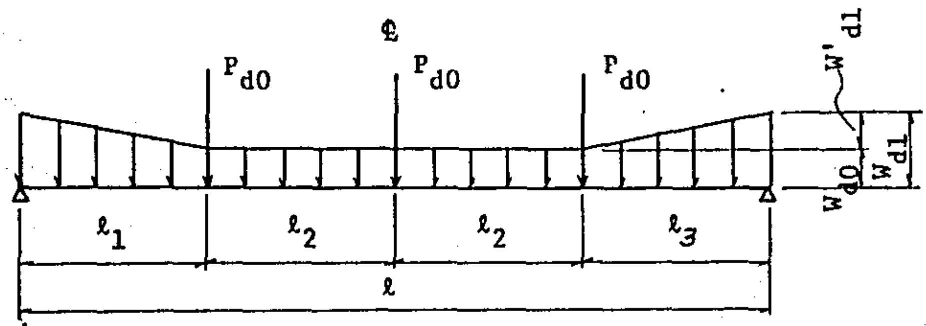


6. Combined loading

(1) Case 1: Dead load of surcharge
(2) Case 2: Dead load of electric pole
(3) Case 3: Train load, loaded on full span
(4) Case 4: Train load, loaded on half span
(5) Case 5: Train load, loaded on half span
(6) Case 6: Case 1 + Case 2
(7) Case 7: Case 6 + Case 3
(8) Case 8: Case 6 + Case 4
(9) Case 9: Case 6 + Case 5

Chapter 4. Design calculations of Main girder cross section

§1. Bending moment caused by own weight of Main girder



Bending moment (at center of span)

M_{d0}

W_{d0} : Per meter weight of the section at the center (t/m) = 2.109

W_{d1} : Per meter weight of the section at the point of support (t/m) = 3.361

$W_{d1}' = W_{d1} - W_{d0}$ = 1.252

P_{d0} : Weight of intermediate diaphragm (t) = 0.351

ℓ : Span (m)

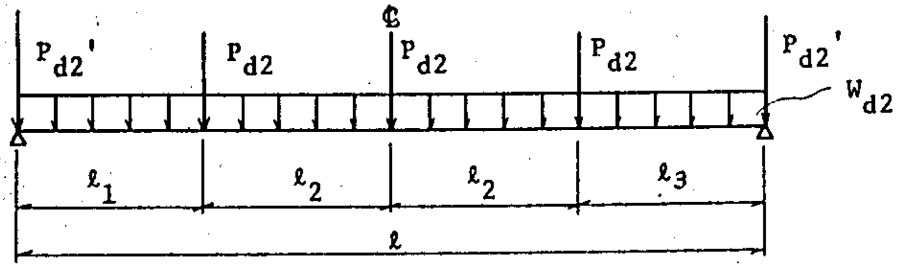
ℓ_1 : Length of the widened part of web (m)

ℓ_2, ℓ_3 : Location of diaphragm (m)

n : Number of intermediate diaphragms

	ℓ	ℓ1	ℓ2	ℓ3	Mdo (t·m)
G 1	32.299	8.861	8.000	7.438	294.021
G 2	32.073	8.274	〃	7.799	290.236
G 3	31.848	7.687	〃	8.161	286.010
G 4	31.621	7.099	〃	8.522	281.291

§2. Stress calculations of Cross beam cross section



- Bending moment (at center of span)

M_{d0}

where,

W_{d2} : Own weight of bridge slab between girders (t/m)
= 0.094

P_{d2} : Own weight of intermediate Cross beam (t)
= 0.298

P_{d2}' : Own weight of end Cross beam (t)
= 1.314 , 1.204

ℓ : Span (m)

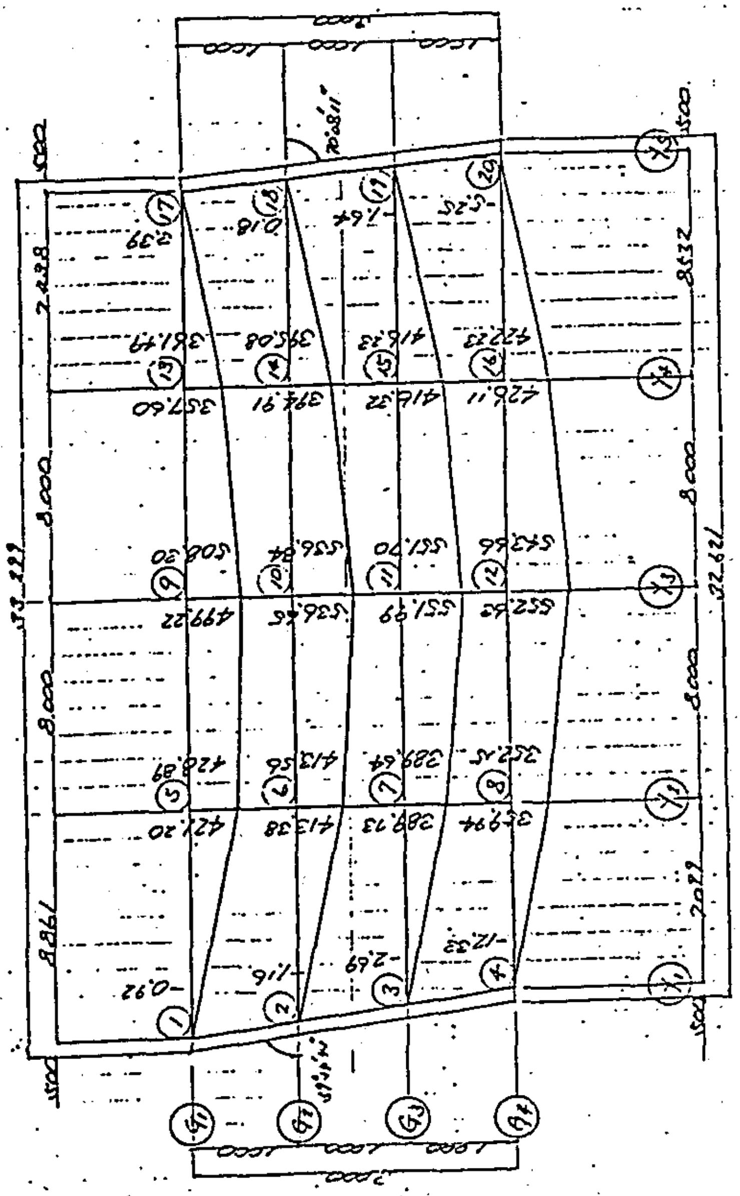
ℓ_1, ℓ_2 (ℓ_3) : Location of Cross beam (m)

n : Number of intermediate Cross beam

	ℓ	ℓ1	ℓ2	ℓ3	Mdo (t-m)
G 1	32.299	8.861	8.000	7.438	17.055
G 2	32.073	8.274	"	7.799	16.867
G 3	31.848	7.687	"	8.161	16.647
G 4	31.621	7.099	"	8.522	16.394

§3. Stress caused by Static and Live load acting at the top of bridge slab

(Computer calculation with grid-system)
Bending moment diagram (Unit: t·m)



§4. Summary of bending moment calculations (at section of mid-span)

(Unit: t m)

Load / Main girder	Own Wt. (1) M.girder	(2) Concrete betw. girders	(3) Ballast Track	(4) Electric pole	(5)=Σ(1)~(4) D. load total	Live load		Total ((5) + (6))
						Mℓ (6)	Case	
G_1	294.02	17.06	213.41	-6.03	518.46	300.91	7	819.37
G_2	290.24	16.87	221.78	5.11	534.00	309.95	7	843.95
G_3	286.01	16.65	224.22	16.90	543.78	310.88	7	854.66
G_4	281.29	16.39	220.44	28.52	546.64	303.67	7	850.31

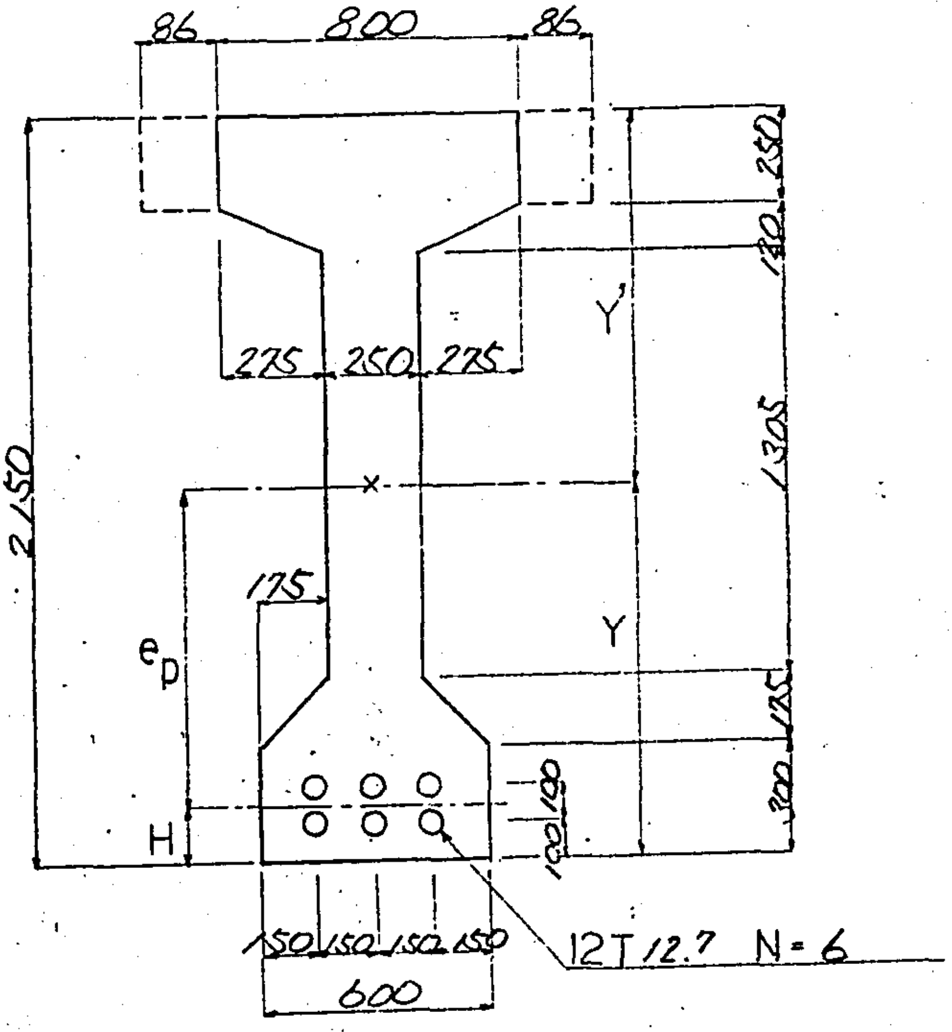
Developed the calculations in the preceding paragraphs, it became known that Maximum bending moment is exerted on Main girder.

Hence, further design calculations for Main girders will be represented by G_3 girder.

Chapter 5. Main girder design

§1. Basis for the design calculations

1. Configuration and Dimensions of the girder section of mid span



A :	Cross sectional area	(cm^2)
I :	Moment of inertia	(cm^4)
Z :	Section modulus	(cm^3)
r :	Radius of gyration	(cm)
ep:	Location of cables	(cm)
N :	Number of cables	
6pt:	Tensile stress immediate after the practice of pre-stressing (kg/mm^2)	
Pt:	total tensile stressimmediate after the practice of pre-stressing	
n :	Ratio of Young's modulus between Modulus of P.C. cables and that of concrete	
ψ :	Coefficient of creep	
ε_s:	Drying contraction rate of conerete	
η :	Effective factor	

2. Summary of sectional values (mid span)

(1) Gross cross section

- A_c = 8.436.3 cm^2
- I_c = 45.696 x 10^6 cm^4
- Y_c = 111.9 cm
- Y_c' = 103.1 cm
- $Z_c = I_c/Y_c$ = 4.083 x 10^5 cm^3
- $Z_c' = I_c/Y_c'$ = 4.432 x 10^5 cm^3
- $\gamma_c^2 = I_c/A_c$ = 5.417 x 10^3 cm^2
- $e_{pc} = Y_c - H$ = 97.9 cm

(2) Net cross section

- A_0 = 8.237.2 cm^2
- I_0 = 43.777 x 10^6 cm^4
- Y_0 = 114.2 cm
- Y_0' = 100.8 cm
- $Z_0 = I_0/Y_0$ = 3.832 x 10^5 cm^3
- $Z_0' = I_0/Y_0'$ = 4.345 x 10^5 cm^3
- $\gamma_0^2 = I_0/A_0$ = 5.315 x 10^3 cm^2
- $e_{p0} = Y_0 - H$ = 99.2 cm
- $Z_{0g} = I_0/e_{p0}$ = 4.411 x 10^5 cm^3

(3) Equivalent cross section

- $n = E_p/E_c = \frac{2.0 \times 10^6}{3.5 \times 10^5} = 5.71$
- $n \cdot A_{p1} = 5.71 \times 11.85 = 67.664$ cm²
- $A_{e1} = 8643.2$ cm²
- $I_{\ell 1} = 47.597 \times 10^6$ cm⁴
- $Y_{\ell 1} = \Sigma A_{e1} \cdot Y / \Sigma A_{e1} = 109.6$ cm
- $Y_{e1}' = h - Y_{e1} = 105.4$ cm
- $Z_{e1} = I_{e1}/Y_{e1} = 4.344 \times 10^5$ cm³
- $Z_{e1}' = I_{e1}/Y_{e1}' = 4.515 \times 10^5$ cm³
- $\gamma_{e1}^2 = I_{e1}/A_{e1} = 5.507 \times 10^3$ cm²
- $e_{pe1} = Y_{e1} - H = 94.6$ cm
- $Z_{e1g} = I_{e1}/e_{pe1} = 5.033 \times 10^5$ cm³

(4) Equivalent cross section (including concrete between Girders)

- $A_{ez} = 9073.2$ cm²
- $I_{e2} = 51.155 \times 10^6$ cm⁴
- $Y_{e2} = \Sigma A_{e2} \cdot Y / \Sigma A_{e2} = 114.0$ cm
- $Y_{e2}' = h - Y_{e2} = 101.0$ cm
- $Z_{e2} = I_{e2}/Y_{e2} = 4.487 \times 10^5$ cm³
- $Z_{e2}' = I_{e2}/Y_{e2}' = 5.065 \times 10^5$ cm³
- $\gamma_{e2}^2 = I_{e2}/A_{e2} = 5.638 \times 10^3$ cm²
- $e_{pe2} = Y_{e2} - H = 99.0$ cm
- $Z_{e2g} = I_{e2}/e_{pe2} = 5.167 \times 10^5$ cm³

§2. Summary of Bending stress calculations at mid span

Loads	Bending moment ($\times 10^5$ kg·cm)	Section modulus ($\times 10^5$ cm^3)		Bending stress (kg/cm^2) At top fibre	At bottom fibre	At the gravity center of cables
Own weight of Main girder	M_{d0} = 286.01	Z_0'	4.345	65.8	—	—
		Z_0	-3.832	—	-74.6	—
		Z_{0g}	-4.411	—	—	-64.8
Concrete between girders	M_{d1} = 16.65	Z_{e1}'	4.515	3.7	—	—
		Z_{e1}	-4.344	—	-3.8	—
		Z_{e1g}	-5.033	—	—	-3.3
Static load (Ballast track Electric pole)	M_{d2} = 241.12	Z_{e2}'	5.065	47.6	—	—
		Z_{e2}	-4.487	—	-53.7	—
		Z_{e2g}	-5.167	—	—	-46.7
Dead load Total	ΣM_d = 543.78	—	—	117.1	-132.1	-114.8
Live load	$M\ell$ = 310.88	Z_{e2}'	5.065	61.4	—	—
		Z_{e2}	-4.487	—	-69.3	—
		Z_{e2g}	-5.167	—	—	-60.2
Total	ΣM = 854.66	—	—	178.5	-201.4	-175.0

§3. Summary of stress calculations caused by pre-stressing at mid span

States	Items			Unit	Values
Immediate after the practice of pre-stressing	σ_{pt}			kg/mm^2	94
	A_p			mm^2	1185
	N				6
	A_0			x10^3 cm^2	8.237
	e_{p0}			m	-0.992
	Section modulus	Z_0'		x10^5 cm^3	4.345
		Z_0		"	-3.832
		Z_{0g}		"	-4.411
	P_t			x10^3 kg	668.34
	Stress	Top fibre	σ_{ct}'	kg/cm^2	-71.5
		Bottom fibre	σ_{ct}	"	254.2
		Grav.Center of cables	σ_{0pt}	"	231.4
Effective pre-stress	n				5.71
	ψ				2.6
	γ				0.05
	$\Sigma\sigma_{dg}$			kg/cm^2	-114.8
	E_p			x10^{5}kg/cm^2	20
	ε_s			x10^{-5}	20
	$\Delta\sigma_{p\gamma}$			kg/mm^2	-4.7
	$\Delta\sigma_{p\psi}$			"	-14.8
	σ_{pe}			"	74.5
	η				0.792
	Stress	Top fibre	σ_{ce}'	kg/cm^2	-56.6
		Bottom fibre	σ_{ce}	"	201.4
		Grav.Center of cables	σ_{cpe}	"	183.4

§4. Summary of combined Bending stress at mid span

Loads		Stresses (kg/cm^2) Top fibre	Stresses (kg/cm^2) Bottom fibre
(1) Own weight of Main girder		65.8	-74.6
(2) Concrete between girders		3.7	-3.8
(3) Static load		47.6	-53.7
(4) Dead load total ((1) + (2) + (3))		117.1	-132.1
(5) Live load		61.4	-69.3
(6) Total load ((4) + (5))		178.5	-201.4
(7) Immediate after the pre-stressing		-71.5	254.2
(8) Effective pre-stress		-56.6	201.4
Combined stress Immediate after the pre-stressing	(1) + (7)	-5.7	179.6
	Allowable value	> - 15.0	< 180.0
Total Dead loading	(4) + (8)	60.5	69.3
Design loading	(6) + (8)	121.9	0
	Allowable value	< 140.0	> -10.0

NO. 9 P.C. GIRDERS

SUPER-STRUCTURE

DESIGN CALCULATION

B 14 – PC42 L = 26^{m} , H = 2.35^{m}

(Right 70°00′00″)

CONTENTS

Chapter 1. Design criteria

1. Basis for design and loading conditions

- Kind of bridge: Pre-stressed concrete railroad bridge.
- Type of Bridge/Girders: Bridge superstructure is a simple beam, consisted of 4 main girders aligned in parallel.
  Girder is made of post-tensioned concrete of I type section.
- Length of girder: 24.605 m ~ 26.743 m
- Span of main girder: 23.712 m ~ 25.863 m
- Live load : KS-16
- Impact coefficient : i = 0.352
- Crossing angle: { at younger change: 70° 00' 00" RIGHT
  at elder change: 90° 00' 00"
- Railroad curve: STRAIGHT
  STRAIGHT + R = 300 m

2. Strength of materials for design

2-1. Concrete

(1) Concrete used for main girder

- Standard strength for design (28 day value)
  : σ_{CK} = 400 kg/cm^2
- Allowable compressive strength for bending calculation
  : σ_{ca} = 140 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 180 kg/cm^2
- Allowable tensile strength for bending calculation applied for,
  - design loading : σ_{cat} = -10 kg/cm^2
  - dead load : $\sigma_{cat'}$ = 0 kg/cm^2
  - immediate after the pre-stressing: $\sigma_{cat''}$ = -15 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_C=3.5×10^5 kg/cm^2

(2) Concrete used for lateral connection

- Standard strength for design (28 day value)
  : σ_{ck} = 300 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 110 kg/cm^2
- Allowable tensile strength for bending calculation : $\sigma_{ca'}$ = -8 kg/cm^2
- Compressive strength immediate after the practice of pre-stressing : σ_{ci} = 140 kg/cm^2
- Young's modulus corresponding to the standard strength for design : E_C=3.0x10^{5}kg/cm^2

(3) Cantilever part of bridge slab, edge coaming and handrail concrete

- Standard strength for design (28 day value)
  : σ_{ck} = 240 kg/cm^2
- Allowable compressive strength for bending calculation : σ_{ca} = 80 kg/cm^2

2-2. Steel materials used for P.C. concrete

(1) P.C. Cable (SWPR-7B) 12T 12.7 mm

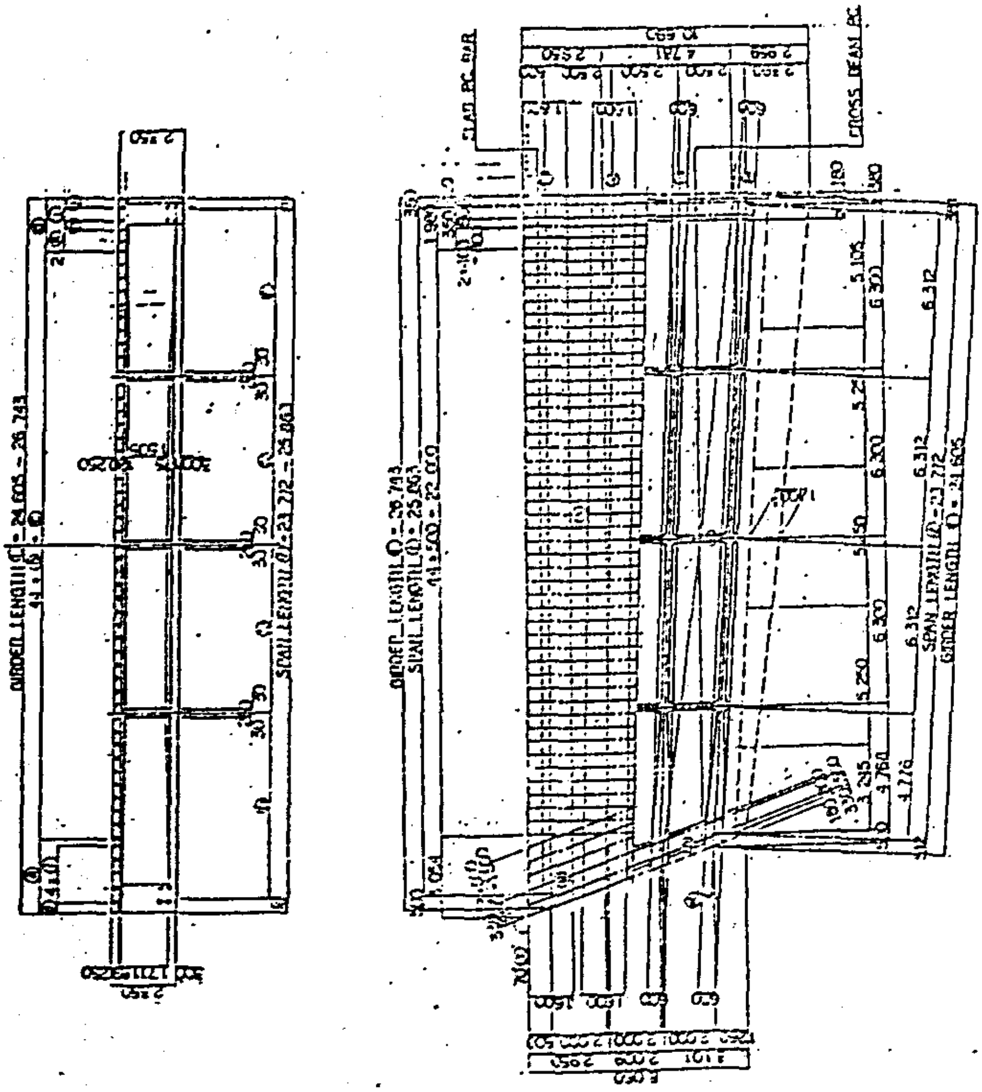
- Tensile strength : σ_{pu} = 190 kg/mm^2
- Yielding point : σ_{py} = 160 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 114 kg/mm^2
  - immediate after the pre-stressing: σ_{pat} = 133 kg/mm^2
  - during pre-stressing : σ_{pai} = 145 kg/mm^2
- Young's modulus of P.C. steel material
  : $E_p = 2.0\times10^6$ kg/cm^2

(2) P.C. steel bar (SBPR 95/110) ϕ 23 mm

- Tensile strength : σ_{pu} = 110 kg/mm^2
- Yielding point : σ_{py} = 95 kg/mm^2
- Allowable tensile strength applied for,
  - design loading : σ_{pa} = 66 kg/mm^2
  - immediate after the pre-stressing: σ_{pat} = 77 kg/mm^2
  - during pre-stressing : σ_{pai} = 85.5 kg/mm^2
- Young's modulus of P.C. steel material
  : $E_p = 2.0\times10^6$ kg/mm^2

2-3. Reinforcing Bar : SD 30

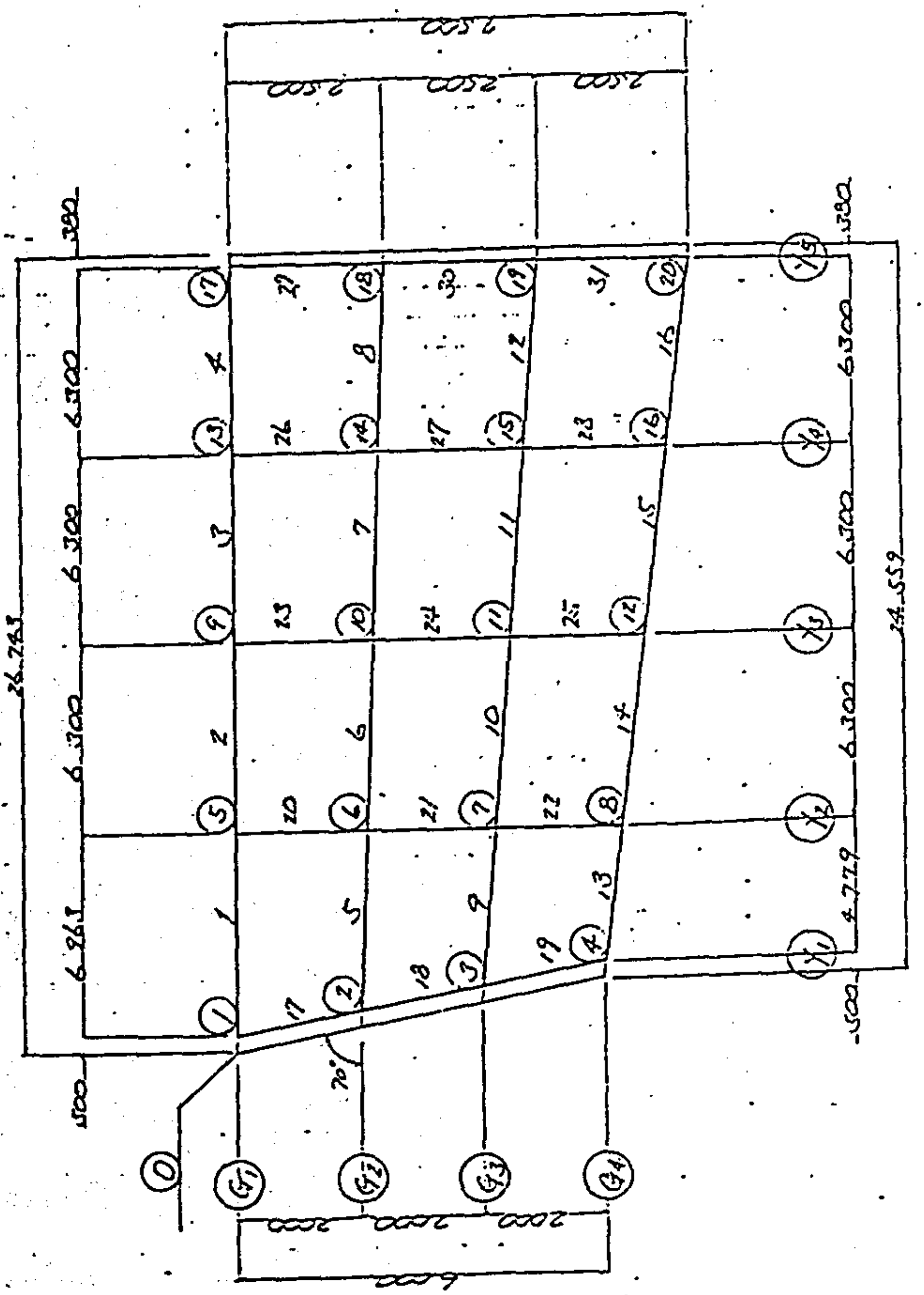
Chapter 2. Configuration and Dimensions of Bridge



Chapter 3. Input for Grid-system calculation

§1. Numbering & Coordinates of Skeleton Point

1. Member numbering & Skeleton point numbering



2. Coordinates calculations of Skeleton points

Assumed the Skeleton point (0) as fundamental point, coordinates of other skeleton points are calculated as listed below.

(Unit: m)

Skeleton point number	Skeleton point coordinates x	Skeleton point coordinates y	Skeleton point number	Skeleton point coordinates x	Skeleton point coordinates y
(1)	0.500	0	(15)	20.063	-4.736
(2)	1.228	-2.010	(16)	〃	-7.092
(3)	1.956	-4.020	(17)	26.363	0
(4)	2.684	-6.031	(18)	〃	-2.493
(5)	7.463	0	(19)	〃	-4.985
(6)	〃	-2.129	(20)	〃	-7.477
(7)	〃	-4.238	( )		
(8)	〃	-6.323	( )		
(9)	13.763	0	( )		
(10)	〃	-2.251	( )		
(11)	〃	-4.487	( )		
(12)	〃	-6.707	( )		
(13)	20.063	0	( )		
(14)	〃	-2.372	( )		

§2. Support conditions and Young's modulus of Concrete

1. Support conditions

Skeleton number	Rotation around		Z direction
	Y axis	X axis	
①	free	free	restricted
②	"	"	"
③	"	"	"
④	"	"	"
⑰	"	"	"
⑱	"	"	"
⑲	"	"	"
⑳	"	"	"

2. Young's modulus of concrete

(1) Young's modulus

Main girder : $E\ell = 3.50 \times 10^5\ kg/cm^2 = 35.0 \times 10^5\ t/m^2$

Cross beam : $Et = 3.00 \times 10^5\ kg/cm^2 = 30.0 \times 10^5\ t/m^2$

(2) Young's modulus corresponding to shearing

$G = 0.43E$

Main girder : $G\ell = 0.43 \times 35.0 \times 10^5 = 15.05 \times 10^5\ t/m^2$

Cross beam : $Gt = 0.43 \times 30.0 \times 10^5 = 12.90 \times 10^5\ t/m^2$

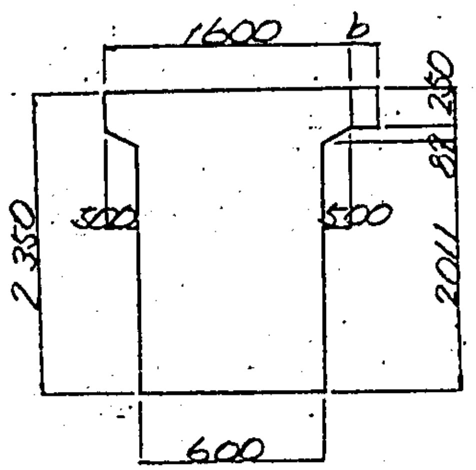
§3. Configuration and Dimensions of Main girder and Cross beam

1. Configuration and Dimensions of Main girder

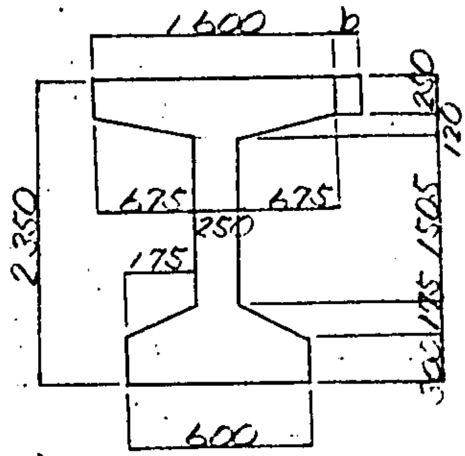
Dimension of concrete between Girders are as shown.

$$Et/E\ell = \frac{30.0 \times 10^5}{35.0 \times 10^5} = 0.857 \fallingdotseq 0.86$$

SECTION NUMBER ①: G1.G4 (Y1, Y5)

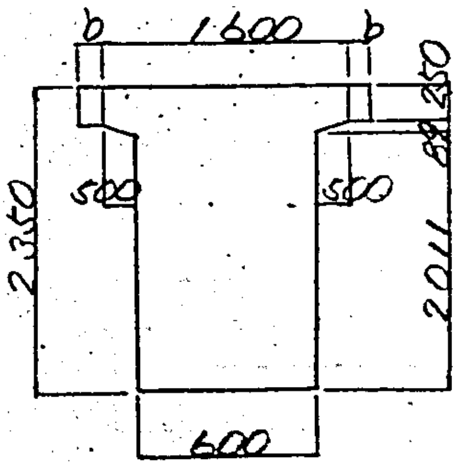


SECTION NUMBER ②: G1,G4 (Y2 ~ Y4)

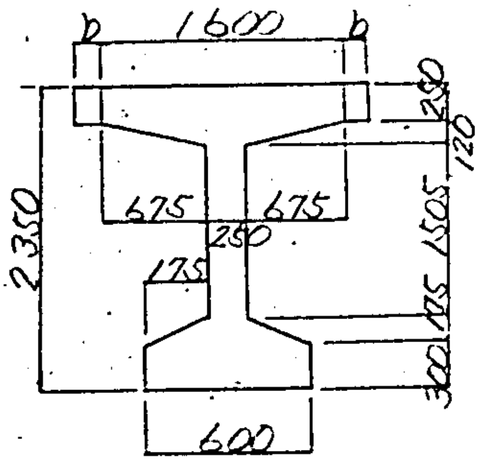


	Y1	Y2	Y3	Y4	Y5	
b	0.176	0.218	0.273	0.328	0.333	(m)

SECTION NUMBER ③: G2 G3 (Y1, Y5)



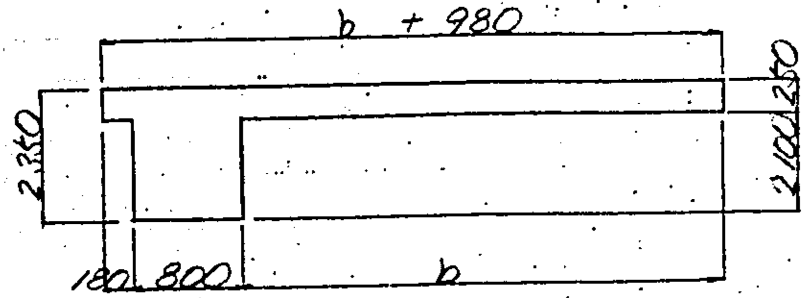
SECTION NUMBER ④: G2 G3 (Y2 ~ Y4)



	Y1	Y2	Y3	Y4	Y5	
b	0.176	0.218	0.273	0.328	0.383	(m)

2. Configuration and Dimensions of Cross beam

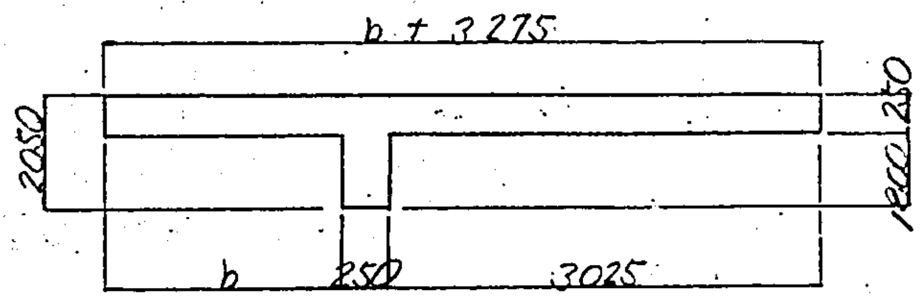
SECTION NUMBER ⑤ (y_1)



	G_1	G_2	G_3	G_4
b	3.179	2.815	2.451	2.087

(m)

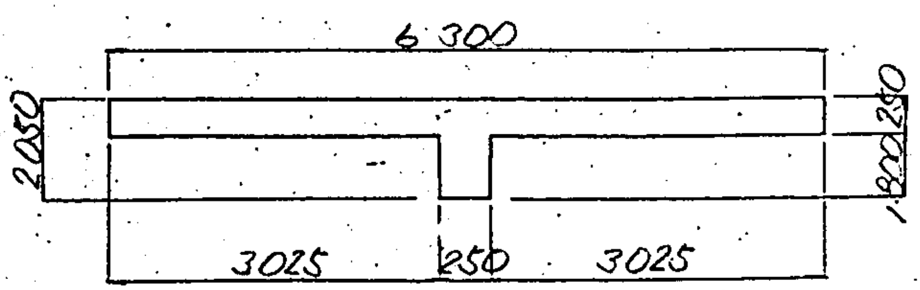
SECTION NUMBER ⑥ (y_2)



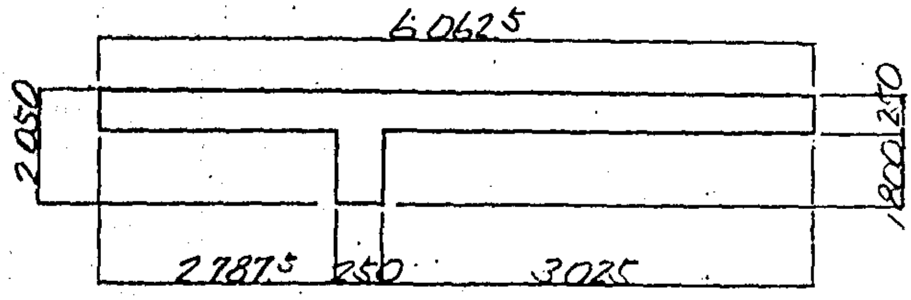
	G_1	G_2	G_3	G_4
b	3.179	2.815	2.451	2.087

(m)

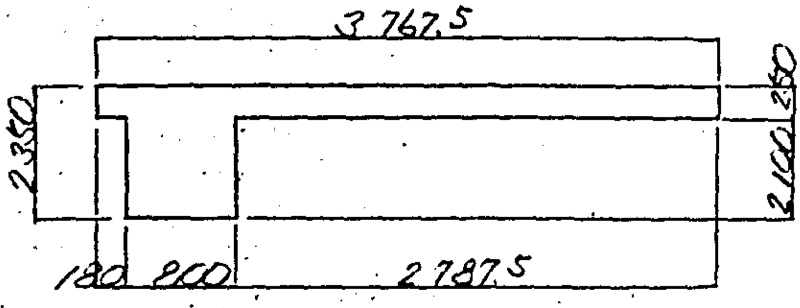
SECTION NUMBER ⑦ (y_3)



SECTION NUMBER ⑧ (Y4)



SECTION NUMBER ⑨ (Y5)



3. Applicable section number for various Girder, Beam/location

Girders		Location of number	Section number	Notes
Main girder	G_1, G_4	Location of Cross beam : y_1 , y_5	①	
		〃 : $y_2 \sim y_4$	②	
	G_2, G_3	〃 : y_1 , y_5	③	
		〃 : $y_2 \sim y_4$	④	
Cross beam		y_1	⑤	
		y_2	⑥	
		y_3	⑦	
		y_4	⑧	
		y_5	⑨	

4. Moment of inertia of the section

(Unit: m^4)

Girders		Members	Moment of inertia (Average)
Main girder	G_1 G_4	1 13	0.86883
		2 14	0.80082
		3 15	0.81235
		4 16	0.89869
	G_2 G_3	5 9	0.89955
		6 10	0.83416
		7 11	0.84810
		8 12	0.94745
Cross beam		17	1.48450
		18	1.43265
		19	1.37704
		20	0.49697
		21	0.49151
		22	0.48555
		23 24 25	0.49742
		26 27 28	0.49395
		29 30 31	1.45561

§4. Loads and Loading conditions

1. Application of loads for calculation

(1) Application of static load

As the grid-system are carried out based on influence lines, the static load loading is applied in dual ways, one is a lined loading and the other is a uniformly distributed loading, to determine the loading length and width.

(2) Application of combined train loading

(a) Train load loading

Train load is assumed to be transmitted through sleepers downwards and distributed to the enlarged width within inclined lines with 53 deg. starting at both end points of sleeper bottom.

(b) Combined loading of train load

(i) Train load is supposed to distribute entire length of the span.

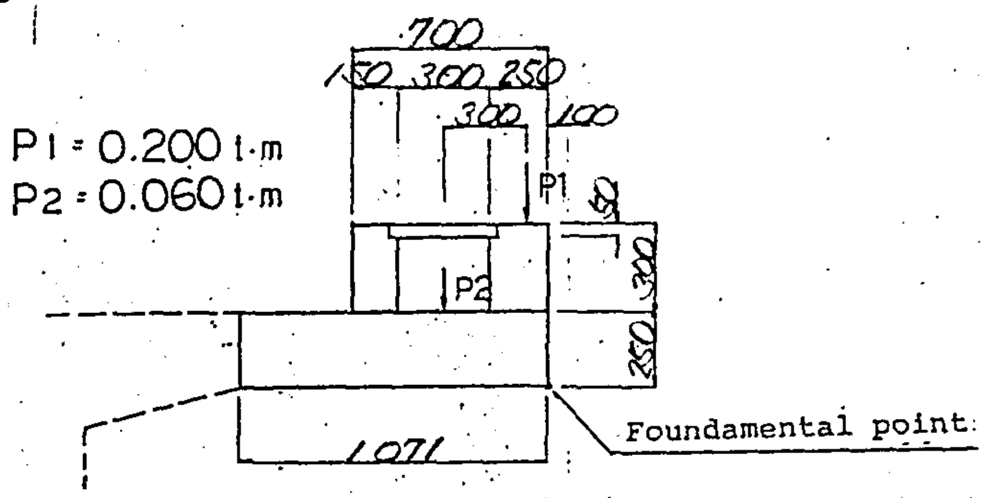
(ii) Train load is supposed to distribute limited to one side of span with 1/2 ℓ length.

Train load is applied combined the above (i) and (ii) loadings. Thus, further calculations are made for the sectional strength.

2. Dead load calculations of the own weight of structure

(1) Cantilever part of bridge slab, edge coaming and handrail concrete

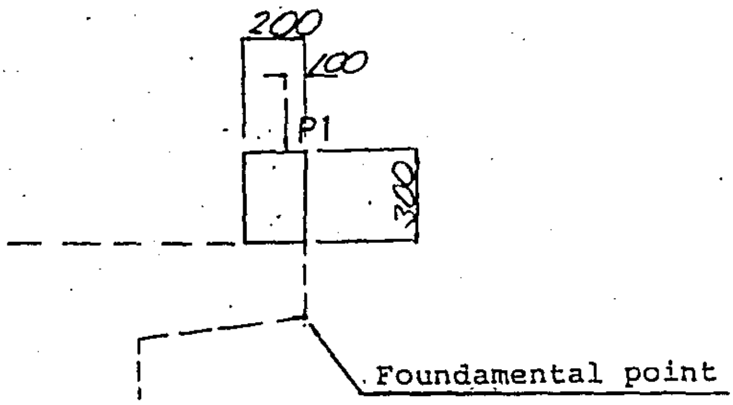
(a) G4 girder side



Load/Load acting point

Total dead load : ΣW (t/m) = 1.268
Total bending moment : $\Sigma W X$ (t-m/m) = 0.513
Acting point of resultant force : $X = \Sigma W X / \Sigma W$ (m) = 0.405

(b) G1 girder side



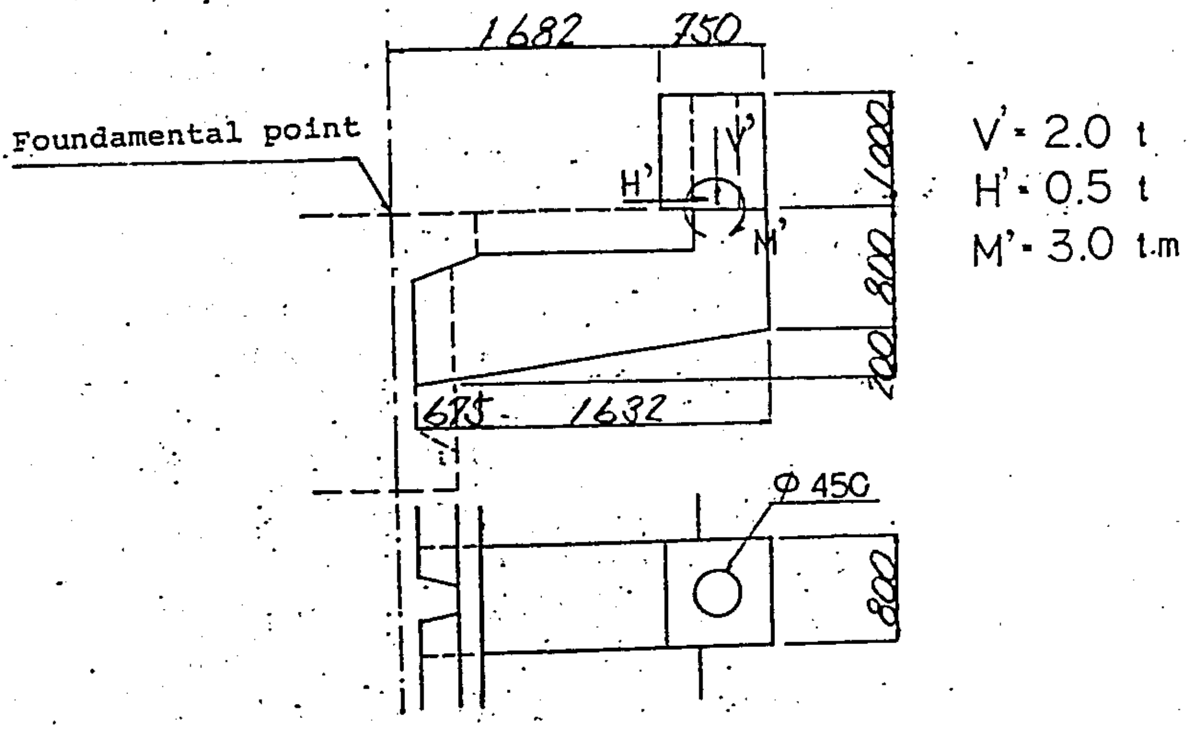
Load/Load acting point

Total dead load : ΣW (t/m) = 0.350
Total bending moment : $\Sigma W \cdot X$ (t-m/m) = 0.035
Acting point of resultant force : $X = \Sigma W X / \Sigma W$ (m) = 0.100

(2) Graded Concrete

$Wp = 2.35 \times 0.07 = 0.165\ t/m^2$

(3) Electric pole and its supporting beam

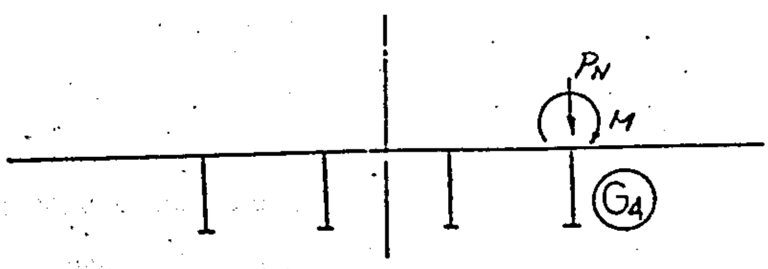


Load/Load acting point

Total dead load : $\Sigma W (t/m)$ = 6.200 → P_N

Total bending moment : $\Sigma W X (t\text{-}m/m)$ = 10.566

$M = M' + \Sigma WX$ = 13.566



3. Dead load calculations of surcharge

(1) Surcharge load of ballast

Calculated as a uniformly distributed load.

$$W_B = 1.9\ t/m^3 \times (h_B - h_p) = 0.914\ t/m^2$$

(2) Surcharge load of track assembly

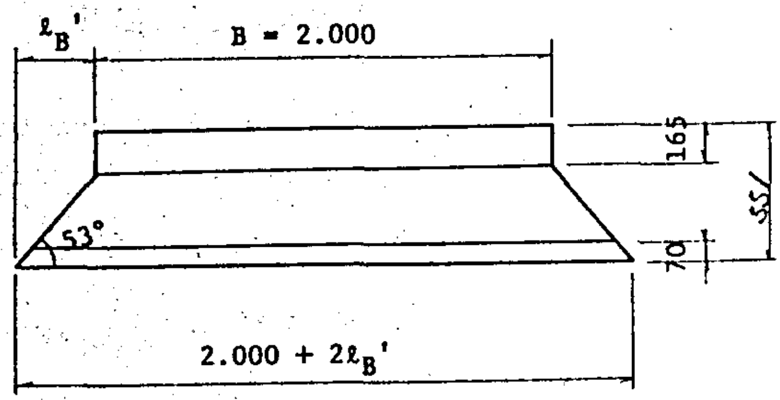
Load of track assembly is assumed to be distributed on the bridge slab with the width between two points on the slab, where lines drawn from the both ends of sleeper bottom with 53 deg. inclination towards outward-downward, crossing the slab surface.

- Load of track assembly : $\Sigma W_R = 0.450$ t/m
- Width of sleeper : $B = 2.000$ m
- Thickness of sleeper : $h_M = 0.165$ m
- Height between the girder top and the sleeper top : $h_B = 0.551$ m
- Average thickness of graded concrete for drainage : $h_p = 0.070$ m

$$2\ell_B' = 2(h_B - h_M) \cdot \text{Cot } 53° = 0.582\ m$$

- Load distribution width:

$$\ell_B = B + 2\ell_B' = 2.582\ m$$



Uniformly distributed load:

$$W_R = \frac{\Sigma W_R}{\ell_B} = 0.174\ t/m^2$$

4. Uniformly distributed load, equivalent to the train loading

Bending moment calculation:

For the bending moment calculation, the equivalent uniformly distributed load at the 1/4 span point will be employed and confirmed as calculated below.

$$M\ell = \{M\ell_{min} + \frac{\ell - \ell_{min}}{\ell_{max} - \ell_{min}} \cdot (M\ell_{max} - M\ell_{min})\} \gamma \cdot \beta \times \frac{1}{18}$$

where, $\ell = 25.863$, $\ell_{max} = 26.000$, $\ell_{min} = 25.500$

$\gamma = 2$ $\beta = 16$

$M\ell(\ell/4)_{min} = 253.2$, $M\ell(\ell/4)_{max} = 263.0$

$M\ell(\ell/2)_{min} = 327.7$, $M\ell(\ell/2)_{max} = 339.5$

$$M\ell(\ell/4) = \{253.2 + \frac{0.363}{0.500} \times (263.0 - 253.2)\} \; 2 \times 16 \times \frac{1}{18}$$
$$= 462.782$$

$$M\ell(\ell/2) = \{327.7 + \frac{0.363}{0.500} \times (339.5 - 327.7)\} \; 2 \times 16 \times \frac{1}{18}$$
$$= 597.808$$

Equivalent uniformly distributed load at $\ell/4$ span point, which is Wm, will be

$$W_m = \frac{32}{3} \times \frac{M\ell(\ell/4)}{\ell^2} = 7.380$$

Employed the above Wm value and applied for the bending moment calculation at $\ell/2$ point.

$$M'_{\ell/2} = W_m \cdot \frac{\ell^2}{8} = 617.055 \; t \cdot m$$
$$> M\ell_{(\ell/2)} = 597.808 \; t \cdot m$$

The result is larger than the value of $M'_{\ell/2}$.

$W_m = 7.380$ t/m

Train loading for bending moment:

$W_\ell = W_m(1 + i) = 9.978$ t/m

Train loading for bending moment: calculation

Train loading is distributed expanded with 53 deg. inclination from the both ends of sleeper bottom.

Uniformly distributed load: W_ℓ

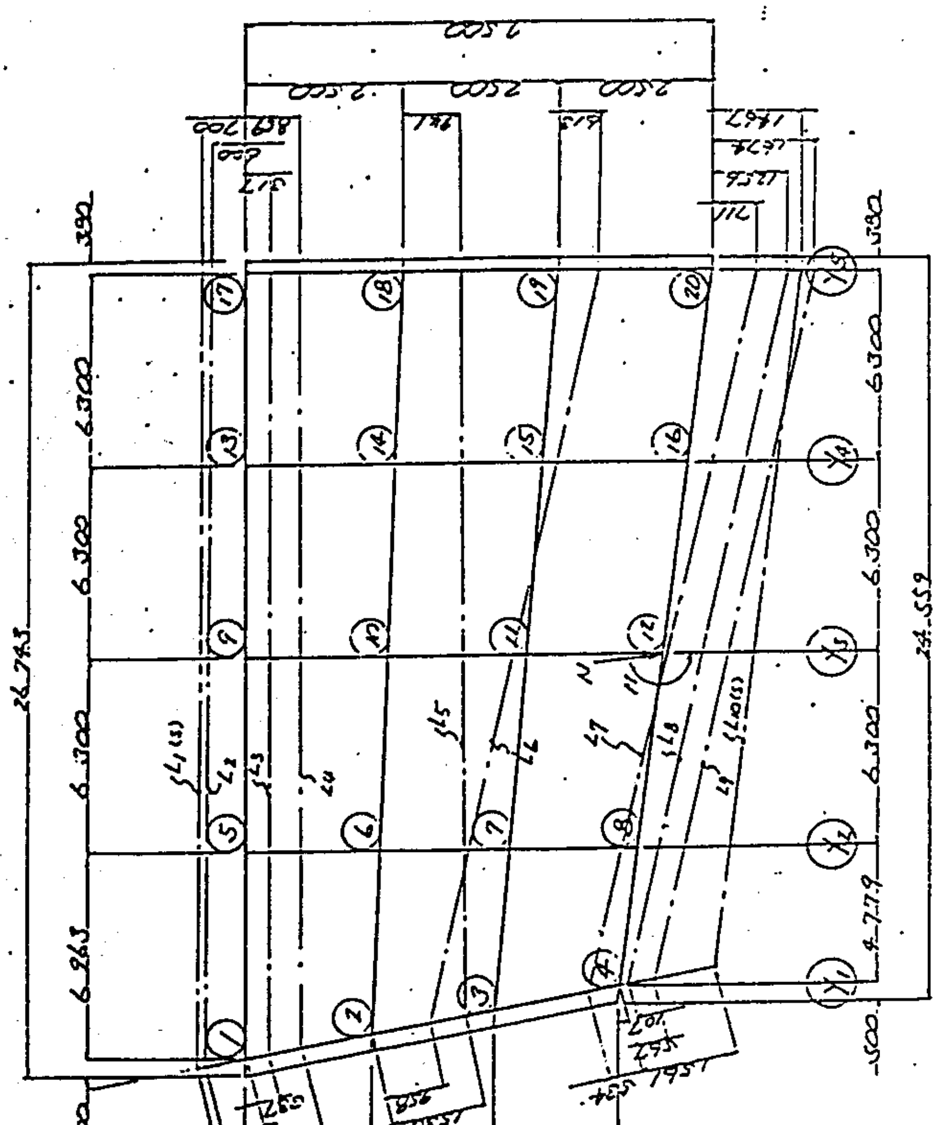
$$W_\ell = \frac{W_m\ (1 + i)}{\ell_B} = 3.864\ t/m^2$$

5. Load/Loading point of various loadings

(1) Summary of loads

Load	Cases	Title	Load distribution area: Width	Load distribution area: Length	Intensity of load	Category of load
Dead load of surcharge and structure	Case 1	VANJO $-D_1$	L_{10}	$Y_1 \sim Y_5$	1.268 t/m	Canti. slab, handrail conc., etc.
			L_1	$Y_1 \sim Y_5$	0.350 〃	
			$L_2 \sim L_9$	$Y_1 \sim Y_5$	0.165 t/m^2	Graded conc.
			$L_3 \sim L_8$	$Y_1 \sim Y_5$	0.914 〃	Ballast
			$L_4 \sim L_5$	$Y_1 \sim Y_5$	0.174 〃	Track assembly
			$L_6 \sim L_7$	$Y_1 \sim Y_5$	0.174 〃	〃
Electric pole, etc.	Case 2	DENCHU $-D_1$	G_4	Y_3	N = 6.200 t M = 13.566 t·m	Electric pole and its supporting beam
Train load	Case 3	L_1	$L_4 \sim L_5$	$Y_1 \sim Y_5$	3.864 t/m^2	Live load intensity applied for bending moment calculation
	Case 4	L_2	$L_4 \sim L_5$	$Y_1 \sim Y_3$	3.864 〃	
	Case 5	L3	$L_4 \sim L_5$	$Y_3 \sim Y_5$	3.864 〃	
	Case 6	L4	$L_6 \sim L_7$	$Y_1 \sim Y_5$	3.864 〃	
	Case 7	L5	$L_6 \sim L_7$	$Y_1 \sim Y_3$	3.864 〃	
	Case 8	L6	$L_6 \sim L_7$	$Y_3 \sim Y_5$	3.864 〃	

(2) Loading conditions



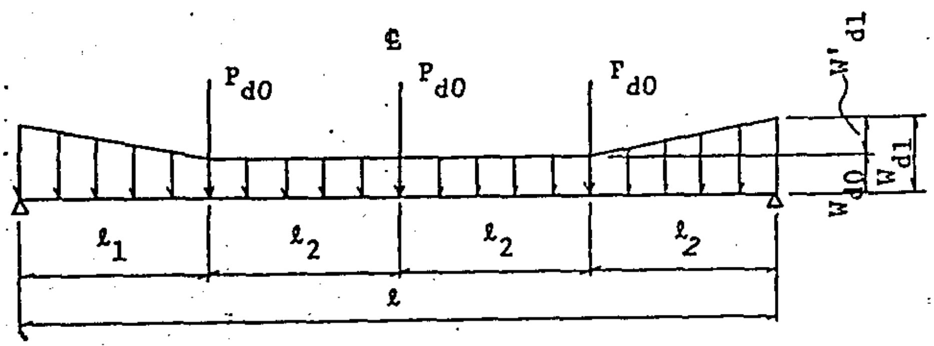
6. Combined loading

(1) Case 1: Dead load of surcharge
(2) Case 2: Dead load of electric pole
(3) Case 3: Train load, loaded on full span
(4) Case 4: Train load, loaded on half span
(5) Case 5: Train load, loaded on half span
(6) Case 6: Train load, loaded on full span
(7) Case 7: Train load, loaded on half span
(8) Case 8: Train load, loaded on half span

(9) Case 9: Case 1 + Case 2
(10) Case 10: Case 9 + Case 3
(11) Case 11: Case 9 + Case 4
(12) Case 12: Case 9 + Case 5
(13) Case 13: Case 9 + Case 6
(14) Case 14: Case 9 + Case 7
(15) Case 15: Case 9 + Case 8

Chapter 4. Design calculations of Main girder cross section

§1. Bending moment caused by own weight of Main girder



Bending moment (at center of span)

M_{d0}

W_{d0} : Per meter weight of the section at the center (t/m) = 2.854

W_{d1} : Per meter weight of the section at the point of support (t/m) = 4.261

$W_{d1}' = W_{d1} - W_{d0} = 1.407$

P_{d0} : Weight of intermediate diaphragm (t) = 0.394

ℓ : Span (m)

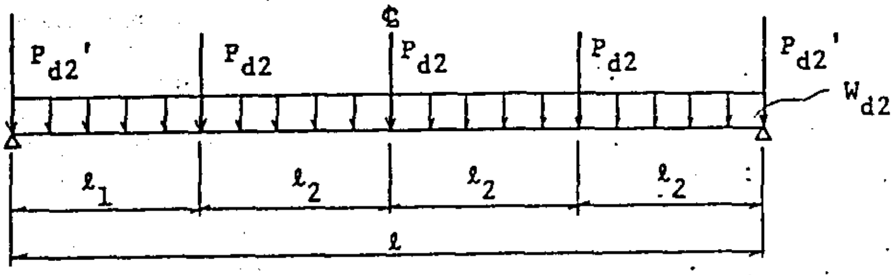
ℓ_1 : Length of the widened part of web (m)

ℓ_2 : Location of diaphragm (m)

n : Number of intermediate diaphragms

	ℓ	ℓ_1	ℓ_2	Mdo (t·m)
G1	25.863	6.963	6.300	253.938
G2	25.140	6.236	6.301	239.631
G3	24.426	5.511	6.305	225.536
G4	23.723	4.788	6.312	211.672

§2. Stress calculations of Cross beam cross section



• Bending moment (at center of span)

M_{d0}

where,

W_{d2} : Own weight of bridge slab between girders (t/m)
= 0.304

P_{d2} : Own weight of intermediate Cross beam (t)
= 1.370

P_{d2}': Own weight of end Cross beam (t)
= 5.128

ℓ : Span (m)

ℓ_1, ℓ_2: Location of Cross beam (m)

n : Number of intermediate Cross beam

	ℓ	ℓ_1	ℓ_2	Mdo (t·m)
G 1	25.863	6.963	6.300	43.327
G 2	25.140	6.236	6.301	41.214
G 3	24.426	5.511	6.305	39.081
G 4	23.723	4.788	6.312	36.927

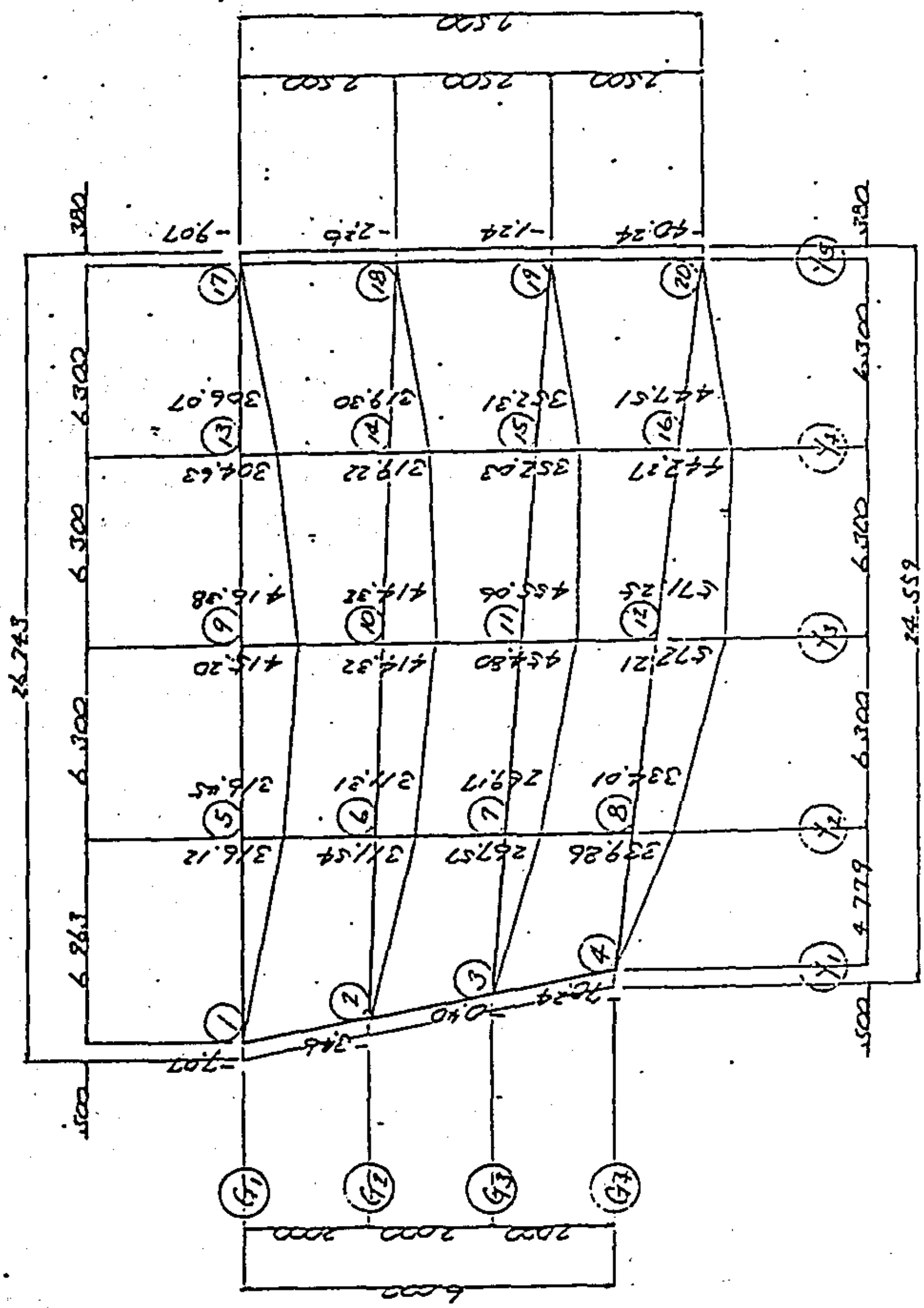
§3. Stress caused by Static and Live load acting at the top of bridge slab

(Computer calculation with grid-system)

Bending moment diagram (Unit: t·m)

G_1, G_2 : Caso 10

G_3, G_4 : Caso 13



§4. Summary of bending moment calculations (at section of mid-span)

(Unit: t m)

Load / Main girder	(1) Own Wt. M.girder	(2) Concrete betw. girders	(3) Ballast Track	(4) Electric pole	(5)=Σ(1)~(4) D. load total	Live load: Mℓ (6)	Live load: Case	Total ((5) + (6))
G_1	253.94	43.33	144.88	-8.68	433.47	280.19	10	713.66
G_2	239.63	41.21	181.92	0.19	462.95	232.21	10	695.16
G3	225.54	39.08	214.10	12.39	491.11	228.57	13	719.68
G4	211.67	36.93	235.69	31.36	515.65	305.16	13	820.81

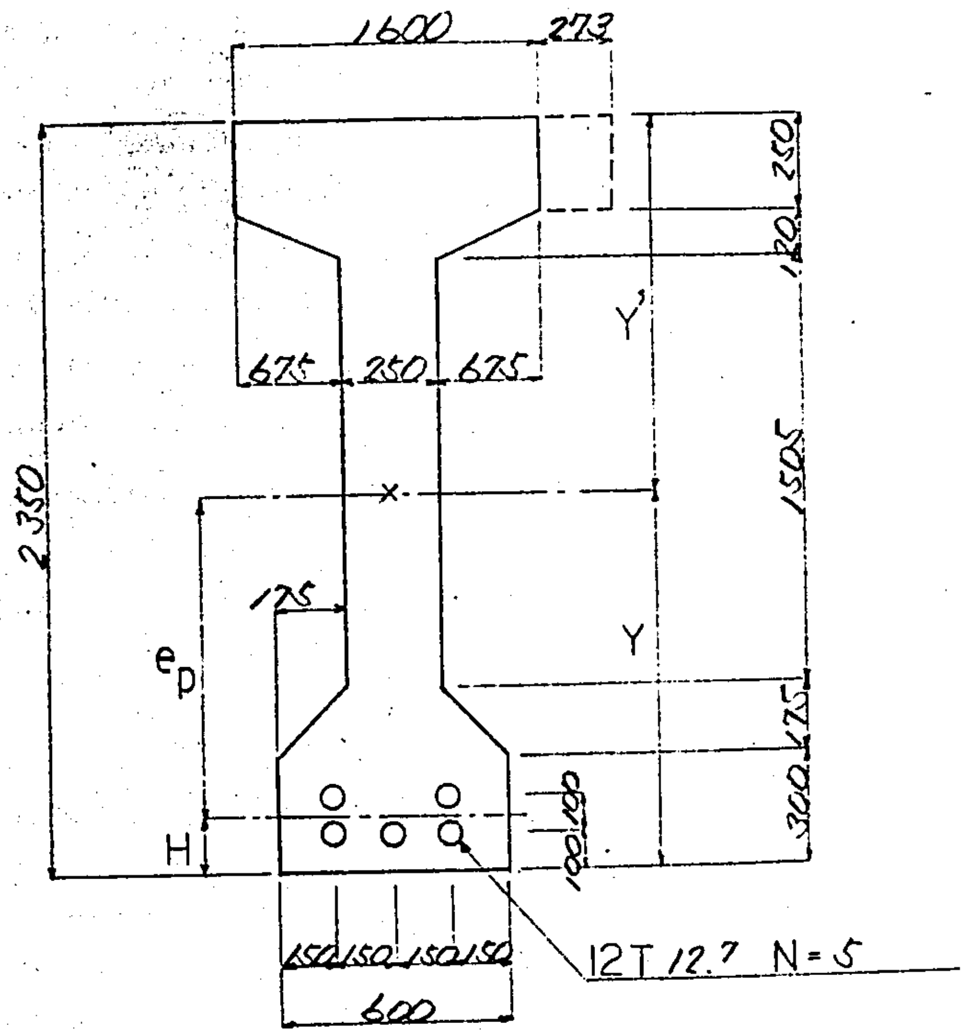
Developed the calculations in the preceding paragraphs, it became known that Maximum bending moment is exerted on Main girder.

Hence, further design calculations for Main girders will be represented by G4 girder.

Chapter 5. Main girder design

§1. Basis for the design calculations

1. Configuration and Dimensions of the girder section of mid span



A :	Cross sectional area	(cm^2)
I :	Moment of inertia	(cm^4)
Z :	Section modulus	(cm^3)
r :	Radius of gyration	(cm)
ep:	Location of cables	(cm)
N :	Number of cables	
6pt:	Tensile stress immediate after the practice of pre-stressing (kg/mm^2)	
Pt:	total tensile stressimmediate after the practice of pre-stressing	
n :	Ratio of Young's modulus between Modulus of P.C. cables and that of concrete	
ψ :	Coefficient of creep	
ε_s:	Drying contraction rate of conerete	
η :	Effective factor	

2. Summary of sectional values (mid span)

(1) Gross cross section

- A_c = 11416.3 cm^2
- I_c = 76.388 x 10^6 cm^4
- Y_c = 143.2 cm
- Y_c' = 91.8 cm
- $Z_c = I_c/Y_c$ = 5.335 x 10^5 cm^3
- $Z_c' = I_c/Y_c'$ = 8.320 x 10^5 cm^3
- $\gamma_c^2 = I_c/A_c$ = 6.691 x 10^3 cm^2
- $e_{pc} = Y_c - H$ = 128.2 cm

(2) Net cross section

- A_0 = 11250.4 cm^2
- I_0 = 73.574 x 10^6 cm^4
- Y_0 = 145.1 cm
- Y_0' = 89.9 cm
- $Z_0 = I_0/Y_0$ = 5.070 x 10^5 cm^3
- $Z_0' = I_0/Y_0'$ = 8.184 x 10^5 cm^3
- $\gamma_0^2 = I_0/A_0$ = 6.540 x 10^3 cm^2
- $e_{p0} = Y_0 - H$ = 131.1 cm
- $Z_{0g} = I_0/e_{p0}$ = 5.612 x 10^5 cm^3

(3) Equivalent cross section

- $n = E_p/E_c = \frac{2.0 \times 10^6}{3.5 \times 10^5} = 5.71$
- $n \cdot A_{pl} = 5.71 \times 11.85 = 67.664$ cm^2
- $A_{el} = 11588.7$ cm^2
- $I_{\ell 1} = 79.228 \times 10^6$ cm^4
- $Y_{\ell 1} = \Sigma A_{el} \cdot Y / \Sigma A_{el} = 141.3$ cm
- $Y_{el}' = h - Y_{el} = 93.7$ cm
- $Z_{el} = I_{el}/Y_{el} = 5.608 \times 10^5$ cm^3
- $Z_{el}' = I_{el}/Y_{el}' = 8.453 \times 10^5$ cm^3
- $\gamma_{el}^2 = I_{el}/A_{el} = 6.837 \times 10^3$ cm^2
- $e_{pel} = Y_{el} - H = 127.3$ cm
- $Z_{elg} = I_{el}/e_{pel} = 6.225 \times 10^5$ cm^3

(4) Equivalent cross section (including concrete between Girders)

- $A_{ez} = 12271.2$ cm^2
- $I_{e2} = 83.477 \times 10^6$ cm^4
- $Y_{e2} = \Sigma A_{e2} \cdot Y / \Sigma A_{e2} = 145.8$ cm
- $Y_{e2}' = h - Y_{e2} = 89.2$ cm
- $Z_{e2} = I_{e2}/Y_{e2} = 5.725 \times 10^5$ cm^3
- $Z_{e2}' = I_{e2}/Y_{e2}' = 9.360 \times 10^5$ cm^3
- $\gamma_{e2}^2 = I_{e2}/A_{e2} = 6.803 \times 10^3$ cm^2
- $e_{pe2} = Y_{e2} - H = 131.8$ cm
- $Z_{e2g} = I_{e2}/e_{pe2} = 6.333 \times 10^5$ cm^3

§2. Summary of Bending stress calculations at mid span

Loads	Bending moment (x 10^5 kg·cm)	Section modulus (x 10^5 cm^3)		Bending stress (kg/cm^2) At top fibre	At bottom fibre	At the gravity center of cables
Own weight of Main girder	M_{d0} = 211.67	Z_0'	8.184	25.9	—	—
		Z_0	-5.070	—	-41.7	—
		Z_{0g}	-5.612	—	—	-37.7
Concrete between girders	M_{d1} = 36.93	Z_{e1}'	8.453	4.4	—	—
		Z_{e1}	-5.608	—	-6.6	—
		Z_{e1g}	-6.225	—	—	-5.9
Static load (Ballast track Electric pole)	M_{d2} = 267.05	Z_{e2}'	9.360	28.5	—	—
		Z_{e2}	-5.725	—	-46.6	—
		Z_{e2g}	-6.333	—	—	-42.2
Dead load Total	ΣM_d = 515.65	—	—	58.8	-94.9	-85.8
Live load	$M\ell$ = 305.16	Z_{e2}'	9.360	32.6	—	—
		Z_{e2}	-5.725	—	-53.3	—
		Z_{e2g}	-6.333	—	—	-48.2
Total	ΣM = 820.81	—	—	91.4	-148.2	-134.0

§3. Summary of stress calculations caused by pre-stressing at mid span

States	Items			Unit	Values
Immediate after the practice of pre-stressing	σ_{pt}			kg/mm^2	90
	A_p			mm^2	1185
	N				5
	A_0			$x10^3\ cm^2$	11.250
	e_{p0}			m	-1.311
	Section modulus	Z_0'		$x10^5\ cm^3$	8.184
		Z_0		"	-5.070
		Z_{0g}		"	-5.612
	P_t			$x10^3$ kg	533.25
	Stress	Top fibre	σ_{ct}'	kg/cm^2	-38.0
		Bottom fibre	σ_{ct}	"	185.3
		Grav. Center of cables	σ_{0pt}	"	172.0
Effective pre-stress	n				5.71
	ψ				2.6
	γ				0.05
	$\Sigma\sigma_{dg}$			kg/cm^2	-85.8
	E_p			$x10^5 kg/cm^2$	20
	ϵ_s			$x10^{-5}$	20
	$\Delta\sigma_{p\gamma}$			kg/mm^2	-4.50
	$\Delta\sigma_{p\psi}$			"	-12.40
	σ_{pe}			"	73.10
	η				0.812
	Stress	Top fibre	σ_{ce}'	kg/cm^2	-30.9
		Bottom fibre	σ_{ce}	"	150.5
		Grav. Center of cables	σ_{cpe}	"	139.7

§4. Summary of combined Bending stress at mid span

Loads		Stresses (kg/cm²) Top fibre	Bottom fibre
(1) Own weight of Main girder		25.9	-41.7
(2) Concrete between girders		4.4	-6.6
(3) Static load		28.5	-46.6
(4) Dead load total ((1) + (2) + (3))		58.8	-94.9
(5) Live load		32.6	-53.3
(6) Total load ((4) + (5))		91.4	-148.2
(7) Immediate after the pre-stressing		-38.0	185.3
(8) Effective pre-stress		-30.9	150.5
Combined stress Immediate after the pre-stressing	(1) + (7)	-12.1	143.6
	Allowable value	> - 15.0	< 180.0
Total Dead loading	(4) + (8)	27.9	55.6
Design loading	(6) + (8)	60.5	2.3
	Allowable value	< 140.0	> -10.0

§§2. R.C. GIRDERS

CONTENTS

§1 Design criteria

1-1. Type of girder

Upper deck simple beam girder made of R.C.

1-2. Construction of track

Ballast type track

1-3. Shoe.

Rubber shoe and steel rod stopper are combined

1-4. Design load

(1). Dead load (Unit weight)

Track assembly weight	0.45	t/m
Ballast	1.9	t/m³
Reinforced concrete	2.5	〃
Plain concrete	2.35	〃
Steel materials	7.85	〃
Handrail	0.2	t/m

Material will be used actual unit weight of relevant.

(2). Train load

Train load will be equivalent to KS-16

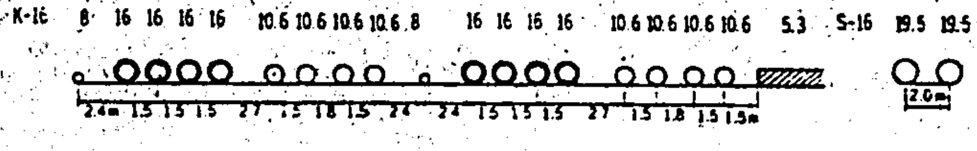
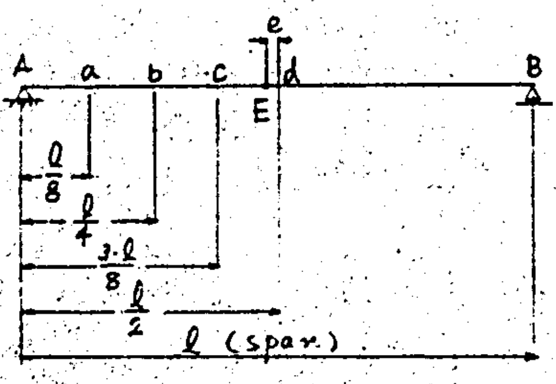


Table illustrating shearing force, pier reaction bending moment : Live load KS-16 (one rail)



(E is the point of max bending moment)

l(m)	Shearing force (t)					Bending moment (t·m)					e (m)
	S_A	S_a	S_b	S_c	S_d	M_a	M_b	M_c	M_d	M_E	
9.0	25.24	20.44	16.00	11.60	7.61	22.99	37.40	46.84	49.20	49.25	0.117
9.5	26.16	21.05	16.52	11.94	7.71	25.00	40.90	51.06	53.70	53.75	〃
10.0	26.99	21.65	17.04	12.26	7.82	27.07	44.80	55.27	58.20	58.25	〃
14.0	33.58	26.90	20.49	14.65	9.55	47.07	78.80	96.53	102.13	102.13	0.077
14.5	34.34	27.57	20.99	15.01	9.72	49.98	83.80	102.13	108.00	108.00	0.454
15.0	35.08	28.21	21.46	15.35	9.95	52.90	88.80	108.27	113.78	114.49	〃
15.5	35.82	28.81	21.89	15.67	10.16	55.81	93.78	115.02	120.27	120.98	〃
16.0	36.55	29.39	22.30	15.96	10.36	58.77	99.11	121.69	127.38	127.47	〃

(3). Impact load

The impact of train load shall be the train load multipied by the following impact coefficient.

Impact coefficient (KS-Loading)

Span l (m)	0	5	10	20
Impact coefficient i_0	0.60	0.48	0.48	0.37

For structure subjected double track loading, impact coefficient is reduced according to the equation.

$$i = i_0 \times \left(1 - \frac{l}{200}\right)$$

l: Span length (m)

(4). Centrifugal load

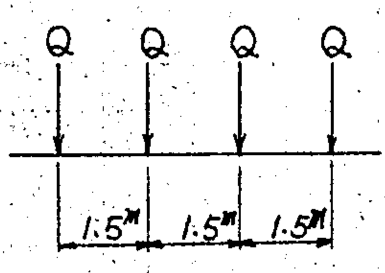
The magnitude of centrifugal load shall be the train load multiplied by the following coefficient as shown below. The working height of load is 1.8 m above the rail level. The acting direction of load is horizontal and right angle to the track.

Curve Radius R (m)	Centritugal coefficient α
R ≦ 700	0.12
700 < R ≦ 1000	0.10
1000 < R ≦ 1800	0.08
1800 < R	0

(5) Train lateral load.

Train lateral load under KS loading scheme shall be Q, loading diagram as shown the figure which is 15% of a driving axle load per track under K-loading scheme warking horizontally on the track at rail level indriection of right angle to the track.

In the case of structure supporting the line with two or more tracks. Train lateral load is assumed as the load of only one track.



(6) Seismic effect.

Seismic effect of eartquake is assumed as dead load and surcharge load multiplied by seismic coefficient plus seismic earth pressure.

K_h = 0.10 …… in horizontal direction.

K_v = 0 …… in vertical direction.

1-5. Concrete minimum cover

slab 25 mm (net thickness)

beam 30 mm (net thickness)

1-6. Material and its allowable stress.

(1). Material

1). Concrete $\sigma_{ck} = 240\ kg/cm^2$

2). Reinforcing bar SD30

3). Max size of coarse aggregate 25 mm

(2). Allowable stress

1). Reinforced concrete

			Design stress
Allowable compressive stress			90 kg/cm²
Allowable shearing stress	Diagonal tension member	Bonding shear τ_{a1}	3.9 "
		Punching shear τ_{ap}	5.4 "
		τ_{a2}	17 "
Allowable bonding stress		Deformed reinforcing bar	18 "

2). Reinforcing bar

Type of reinforced bar	SD30
Allowable tensile slress determined by yielding point.	1800 kg/cm²

Allowable stress for analysis, against cracking.

Surrounding condition	Allowable value corresponding to dead load	
	slab	beam
Alternate dry and wet condition	σ_{sa1} = 800 kg/cm²	σ_{sa1} = 1000 kg/cm²
	σ_{sa2} = 1000 "	σ_{sa2} = 1200 "

$\sigma_{sa1}: \alpha = \dfrac{\sigma_{\ell+i}}{\sigma_d + \sigma_{\ell+i}} \geqq 0.25$, $\sigma_{sa2}: \alpha = \dfrac{\sigma_{\ell+i}}{\sigma_d + \sigma_{\ell+i}} < 0.25$

σ_d : Tensile stress of re-bar subjected dead load.

$\sigma_{\ell+i}$: Tensile stress of re-bar subjected train load and impact load.

1-7. Allowable stress, subjected combined stress

	Given extra
D + T + I	1.00
D + T + I + C	1.00
D + T + I + C + TL	1.15

D : Dead load.

T : Train load.

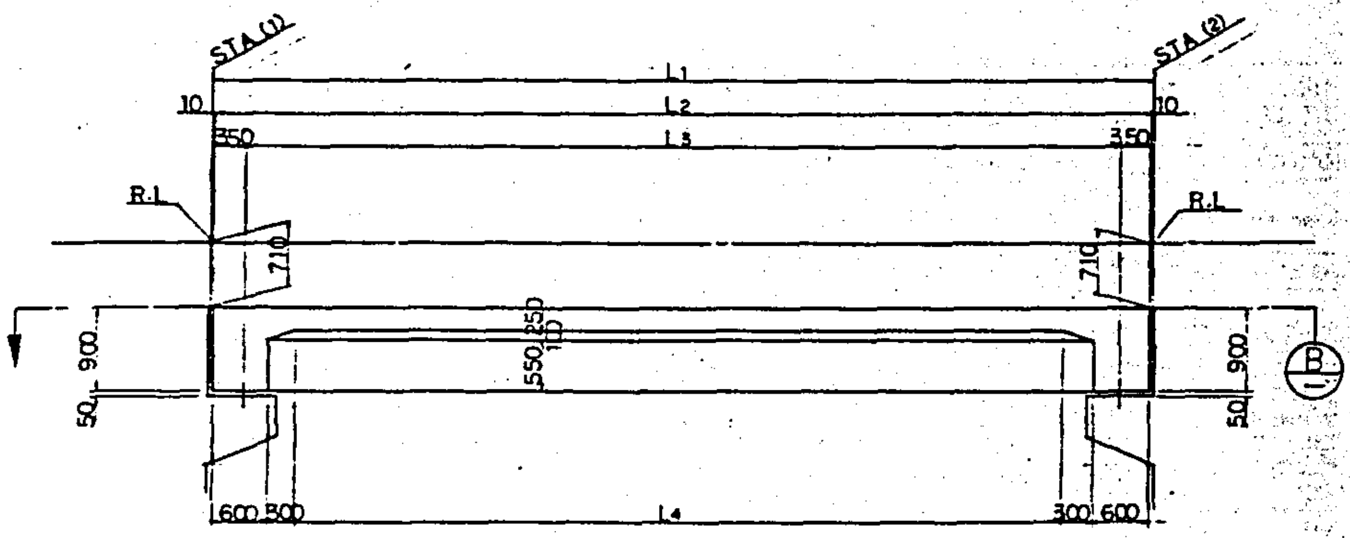
I : Impact load.

C : Centrifugal load.

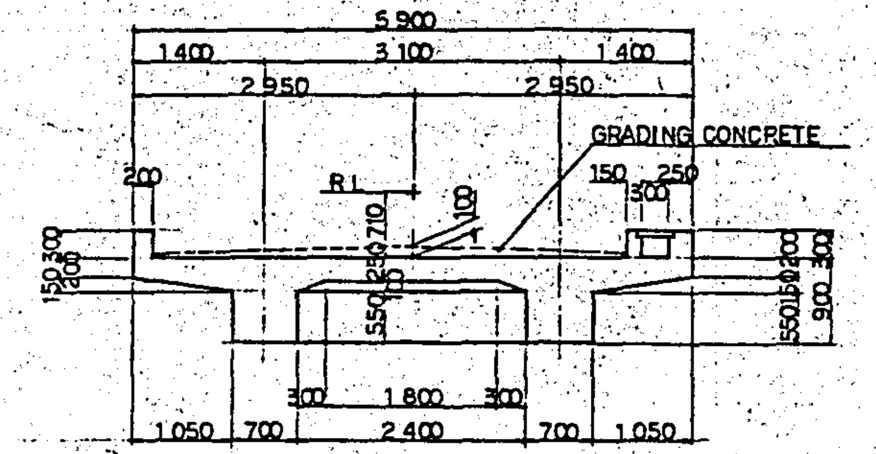
TL : Train lateral load.

§ 2. R.C. Girder RC01

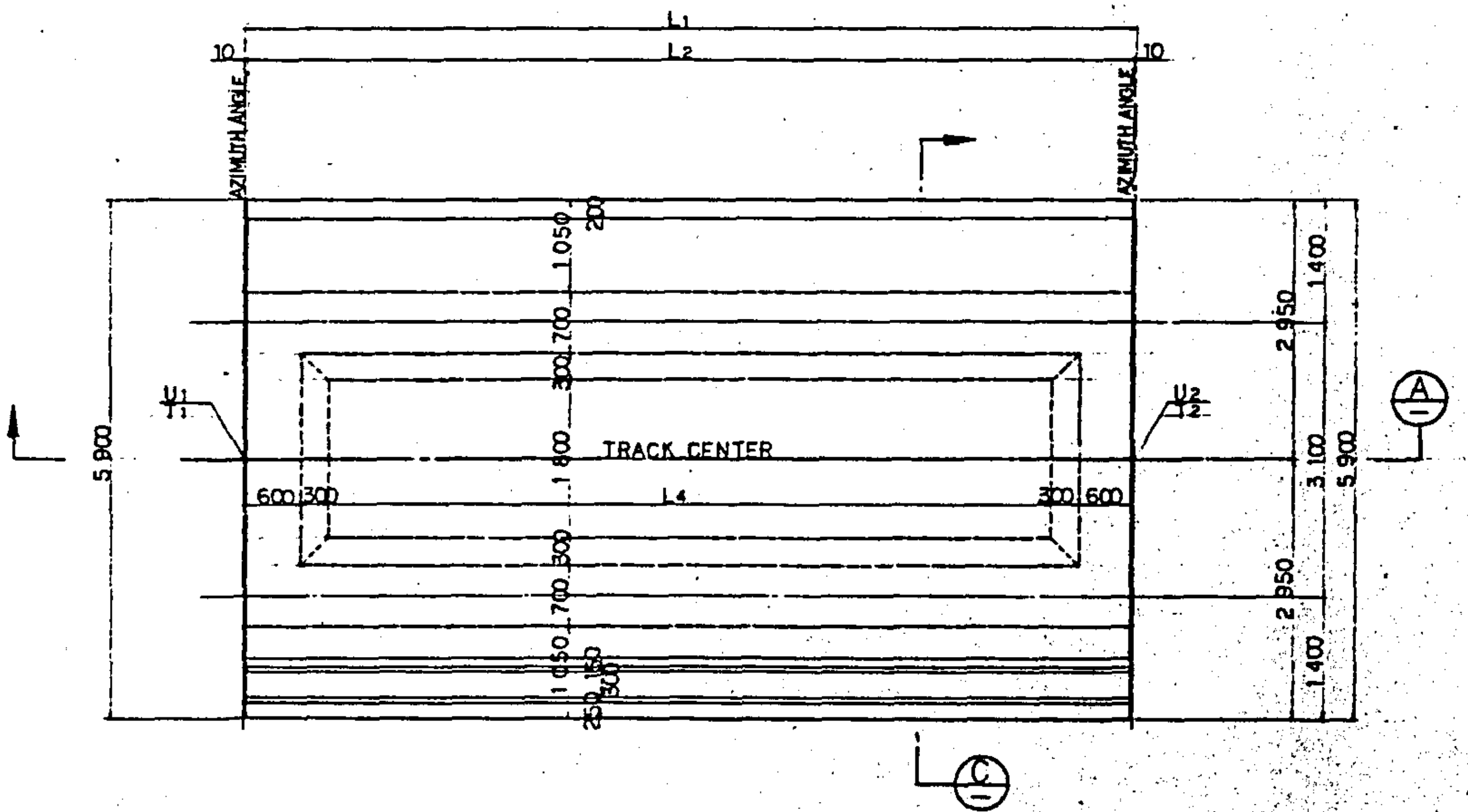
1. GENERAL VIEW



SECTION (A)



SECTION (C)



SECTION (B)

NOTES ;

1. ALL DIMENSIONS ARE SHOWN IN MILLIMETERS UNLESS OTHERWISE INDICATED
2. REFERENCE DRAWING FOR BAR ARRANGEMENT ; CS-187~189
3. GRADING CONCRETE SHALL BE SIMULTANEOUSLY PLACED WITH SLAB CONCRETE

DIMENSION SCHEDULE

	RC001	RC002	RC003	RC004	RC008	RC009
STA (1)	13K399M000	13K645M000	13K680M000	13K765M000	14K202M000	14K416M000
STA (2)	13K409M000	13K655M000	13K689M000	13K774M000	14K211M000	14K424M000
R.L (1)						
R.L (2)						
AZIMUTH ANGLE (θ1)	350° 39' 55"58	350° 39' 55"58	350° 39' 55"58	350° 39' 55"58	2° 29' 30"68	2° 29' 30"68
DO (θ2)	,	,	,	,	,	2° 43' 34"56
U1	12K035M540	12K075M441	12K081M118	12K094M904	12K119M106	12K109M802
T1	-2K768M578	-2K525M836	-2K491M299	-2K407M425	-1K972M658	-1K758M861
U2	12K037M162	12K077M063	12K082M577	12K094M364	12K118M715	12K109M454
T2	-2K758M711	-2K515M968	-2K482M419	-2K398M544	-1K963M667	-1K750M868
L1	10000	10000	9000	9000	9000	8000
L2	9980	9980	8980	8980	8980	7980
L3	9280	9280	8280	8280	8280	7280
L4	8180	8180	7180	7180	7180	6180
θ1	90° 00' 00"00	90° 00' 00"00	90° 00' 00"00	90° 00' 00"00	90° 00' 00"00	90° 00' 00"00
θ2	,	,	"	,	,	89° 46' 04"58

	RC010	RC011	RC012	RC013	RC015		RC027	RC028
STA (1)	14K766M000	14K843M000	15K569M000	15K639M000	17K041M000		17K625M000	17K749M000
STA (2)	14K775M000	14K853M000	15K579M000	15K649M000	17K048M000		17K635M000	17K759M000
R.L (1)								
R.L (2)								
AZIMUTH ANGLE (θ1)	9° 43' 08"64	9° 43' 08"64	1° 06' 02"00	1° 06' 02"00	345° 30' 45"40		345° 30' 45"40	345° 30' 45"40
DO (θ2)	344° 43' 08"64	,	,	,	,		,	,
U1	12K063M088	12K050M089	12K000M168	11K998M823	12K064M127		12K210M225	12K241M245
T1	-1K412M375	-1K336M481	-613M716	-545M729	848M914		1K414M345	1K534M402
U2	12K061M569	12K048M401	11K999M976	11K998M631	12K065M878		12K212M726	12K243M747
T2	-1K403M505	-1K326M624	-603M718	-533M731	855M692		1K424M027	1K544M084
L1	9000	10000	10000	10000	7000		10000	10000
L2	8980	9980	9980	9980	6980		9980	9980
L3	8280	9280	9280	9280	6280		9280	9280
L4	7180	8180	8180	8180	5180		8180	8180
θ1	90° 00' 00"00	90° 00' 00"00	90° 00' 00"00	90° 00' 00"00	90° 00' 00"00		90° 00' 00"00	90° 00' 00"00
θ2	115° 00' 00"00	,	,	,	,		,	,

	RC029	RC033	RC034	RC121
STA (1)	17K784M000	19K117M000	19K232M000	19K428M254
STA (2)	17K794M000	19K126M000	19K242M000	19K438M254
R L (1)				
R L (2)				
AZIMUTH ANGLE (θ1)	345° 30' 45"40	75° 05' 10"71	75° 05' 10"71	75° 05' 10"71
DO (θ2)	,	,	,	,
U1	12K250M001	11K647M999	11K536M872	11K346M008
T1	1K565M289	2K606M935	2K636M532	2K681M467
U2	12K252M508	11K639M302	11K527M209	11K336M345
T2	1K577M971	2K609M251	2K639M105	2K684M041
L1	10000	9000	10000	10000
L2	9980	8980	9980	9980
L3	9280	8280	9280	9280
L4	8180	7180	8180	8180
θ1	90° 00' 00"00	90° 00' 00"00	90° 00' 00"00	90° 00' 00"00
θ2	,	,	,	,

NOTES:

1. ALL DIMENSIONS ARE SHOWN IN MILLIMETERS UNLESS OTHERWISE INDICATED
2. REFERENCE DRAWING FOR GENERAL VIEW : CS-185

2. Calculation of slab

(Note)

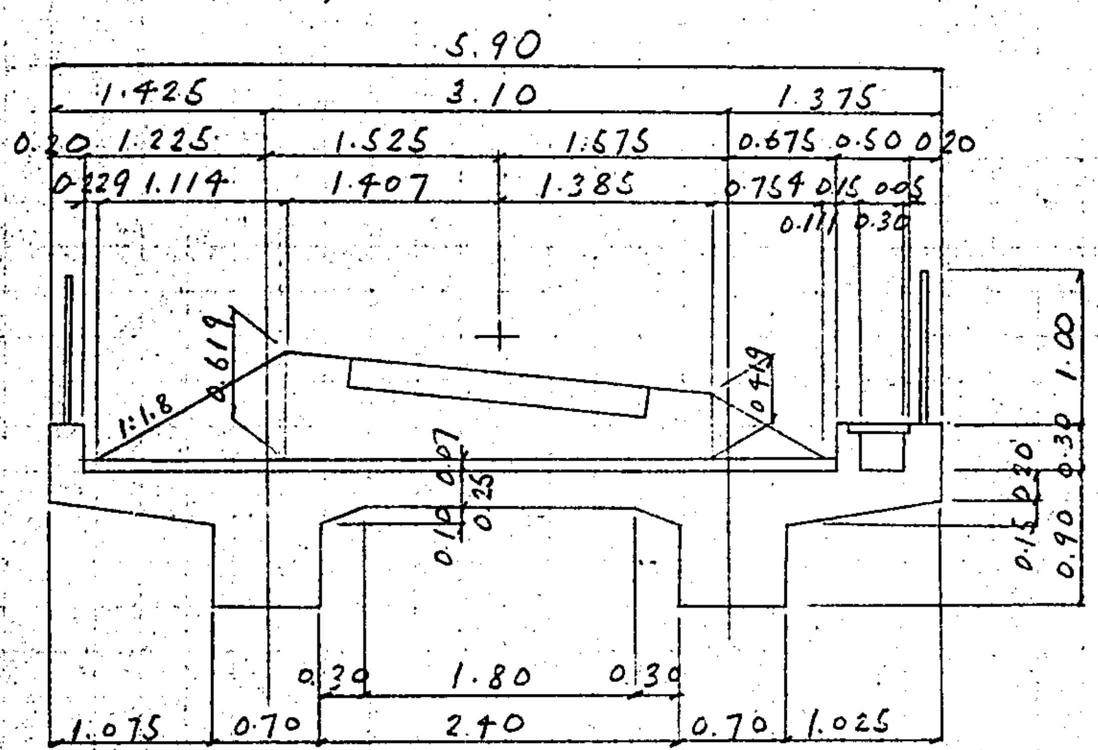
Referred to the Rahmen viduct.

3. Calculation of main beam

$L = 9.98^m$ $l = 9.30^m$

Cross beam $U_0 = 0.60^m$

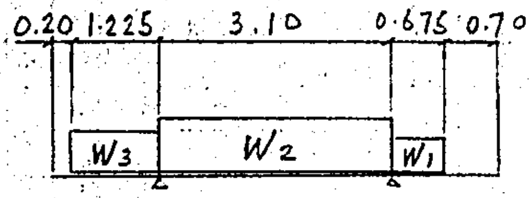
3-1. Weight of elments on the slab



(1) Concentrated loads ---

Curb and Handrail (left)	$2.50^{t/m^3} \times 0.20 \times 0.30 + 0.20$	$= 0.35^{t/m}$
Curb (right)	$2.50 \times 0.25 \times 0.30$	$= 0.19$
Handrail (right)		$= 0.20$
Ballast stopper (right)	$2.50 \times 0.15 \times 0.30$	$= 0.11$
Duct cover (right)	$2.50 \times 0.05 \times 0.30$	$= 0.04$
Cable (right)		$= 0.06$

(2) Weight of elements on the slab except track weight



$$W_1 = 1.90^{t/m^3} \times 0.419 \times 0.754 \times 1/2 \times 1/0.754 + 2.35 \times 0.07 = 0.56^{t/m}$$

$$W_2 = 1.90 \times (0.619 + 0.419) \times 1/2 + 2.35 \times 0.07 = 1.15''$$

$$W_3 = 1.90 \times 0.619 \times 1.114 \times 1/2 \times 1/1.114 + 2.35 \times 0.07 = 0.75''$$

(3) Various dead loads loaded on slab, with their acting eccentricity

	Calculation	N (t/m)	x (m)	N·x (t·m/m)
Track weight	—	0.450	—	—
Ballast	1.90 t/m³ × 0.20 × 2.792 × 1/2	0.530	0.476	0.525
do	1.90 × 0.419 × 2.792	2.223	-0.011	-0.024
do	1.90 × 0.619 × 1.114 × 1/2	0.655	-1.778	-0.165
do	1.90 × 0.419 × 0.754 × 1/2	0.300	1.636	0.491
Grading Concrete	2.35 t/m³ × 0.07 × 5.00	0.823	-0.250	-0.206
Hand rail (left)	—	0.200	-2.850	-0.570
do (right)	—	0.200	2.850	0.570
Curb (left)	2.50 t/m³ × 0.30 × 0.20	0.150	-2.850	-0.428
do (right)	2.50 × 0.30 × 0.25	0.188	2.825	0.531
Ballast stopper	2.50 × 0.30 × 0.15	0.133	2.325	0.263
Duct cover	2.50 × 0.05 × 0.30	0.038	2.550	0.097
Cable		0.060	2.550	0.153
Total		$\Sigma N = 5.93$		$\Sigma N \cdot x = -0.036$

$$e = \frac{\Sigma N \cdot x}{\Sigma N} = -\frac{0.036}{5.93} = -0.006^{m}$$

3-2. Train load

KS-16 $l = 9.30^{m}$

Bending moment

$M_a = 27.22 \times 2 \times 16/18 = 48.39^{t.m}$

$M_b = 44.44 \times 2 \times$ 〃 $= 79.00$ 〃

$M_c = 55.54 \times 2 \times$ 〃 $= 98.74$ 〃

$M_d = 58.39 \times 2 \times$ 〃 $= 103.80$ 〃

$M_E = 58.45 \times 2 \times$ 〃 $= 103.91$ 〃

Shearing force

$S_A = 28.00 \times 2 \times 16/18 = 49.78^{t}$

$S_a = 23.40 \times 2$ 〃 $= 41.60$ 〃

$S_b = 18.35 \times 2$ 〃 $= 32.62$ 〃

$S_c = 13.28 \times 2$ 〃 $= 23.61$ 〃

$S_d = 8.63 \times 2$ 〃 $= 15.34$ 〃

3 - 3 Train lateral load

$$S = \frac{4 \times 16 \times 0.15}{9.30} = 1.03 \ ^{t}/_{m}$$

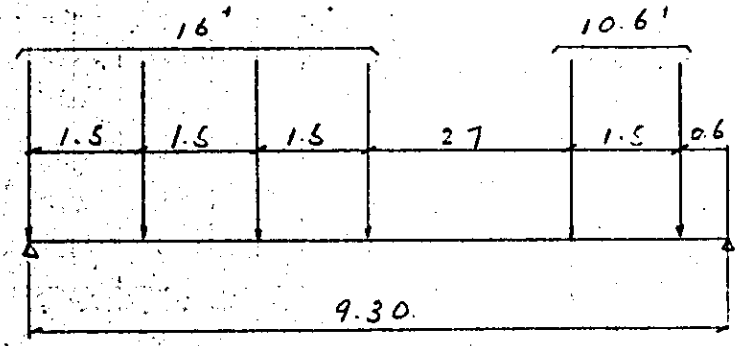
$y = 0.748^{m}$

3 - 4 Centrifugal load

$R = 500^{m}$ $\alpha = 0.12$

$y = 2.548^{m}$

3 - 5 Breake load or Traction load



Breoke load

$H_1 = (16 \times 4 + 10.6 \times 2) \times 0.15 \qquad = 12.78^{t}$

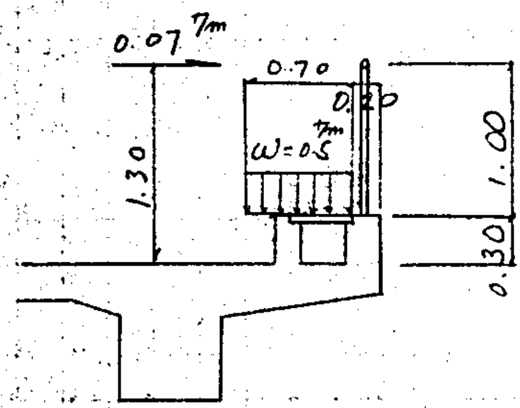
Traction load

$H_2 = 16 \times 4 \times 0.25 \qquad = 16.0^{t} > H_1$

Hence,

$H = 16.0^{t}$

3-6 Sidewalk live load and Thrust load

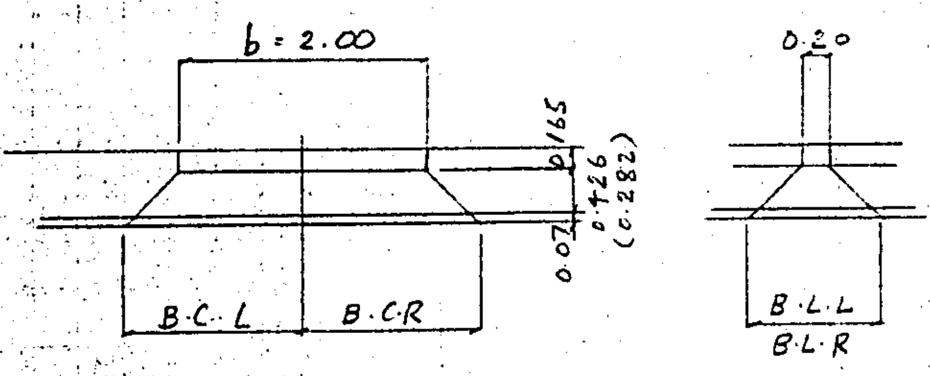


Sidewalk live load : 0.5 T/m²

Thrust load : 0.07 T/m

$W = 0.5 \times 0.70 = 0.35$ T/m

3-7 Effective width



$B \cdot C \cdot L = 1.00 + 1.5 \times (0.426 + 0.07) \times 1/2 = 1.372$ m

$B \cdot C \cdot R = 1.00 + 1.5 \times (0.282 + 0.07) \times 1/2 = 1.264$ m

$B \cdot L \cdot L = 0.20 + 1.5 (0.426 + 0.07) = 0.944$ m

$B \cdot L \cdot R = 0.20 + 1.5 (0.282 + 0.07) = 0.728$ m

R.C GIRDER L=9.30 (KS-16)

TAN T-GATA KETA NO SEKKEI

L = 9.300 (M)

SYOWA 58 NEN 11 GATSU

No. 18

SIMPLE BEAM INPUT DATA

KENMEI R.C GIRDER L=9.30 (KS-16) 11/29/83
CASE 0 KETA NO SHURUI TAN T GETA KAJYU NO SHURUI KS-16
KATAMOCHIBAN NO TYPE LEFT T3 RIGHT T3 YOKOBARI HONSU -0

DANMEN SHOGEN				BANJYO KAJYU						KATSU KAJYU NI YORU DANMENRYOKU		KYOYOORYOKUDO WARIMASHIKEISU	
KEIJYO SUNPO		OORYOKU KEISAN		KAJYU		SAYOICHI		SAIKAHABA					
SMALL.B0	.700	KS.NP	16	SMALL.W0	.450	XW0	-.025			MA	48.390	SHIGUMA.SAU1	8000.
SMALL.B1	1.025			SMALL.W1	.560			B1	.325	MB	79.000	SHIGUMA.SAU2	8000.
SMALL.B2	.000	THETA	90.000	SMALL.W2	1.150			B2	.875	MC	98.740	SHIGUMA.SAU3	8000.
SMALL.B3	1.075			SMALL.W3	.750					MD	103.800		
SMALL.B4	.000	SMALL.A	1.500					DELTA.C	0.000	ME	103.910	SHIGUMA.CAU1	900.
SMALL.B5	.300	SMALL.B	2.000										
SMALL.B6	1.800	BLR	.728	NR1	.190	XR1	.900			SMALL.E	.117	TAU.AL1	39.
SMALL.B7	-0.000	BLL	.944	NR2	.200	XR2	.925					TAU.AL2	39.
SMALL.B6	-0.000	BCR	1.264	NR3	.110	XR3	.400			SAA	49.780	TAU.AL3	39.
		BCL	1.372	NR4	.100	XR4	.625			SA	41.600	TAU.AU1	170.
SMALL.H0	.900			NR5	0.000	XR5	0.000			SB	32.620	TAU.AU2	170.
SMALL.H1	.200	GAMMA.C	2.500	NL1	.350	XL1	.975			SC	23.610	TAU.AU3	221.
SMALL.H2	0.000			NL2	0.000	XL2	0.000			SD	15.340		
SMALL.H3	.150	SMALL.BEOA	1.025	NL3	0.000	XL3	0.000					ALPHA.1	1.000
SMALL.H4	.200	SMALL.BEOB	1.075	NL4	0.000	XL4	0.000					ALPHA.2	1.000
SMALL.H5	0.000			NL5	0.000	XL5	0.000					ALPHA.3	1.150
SMALL.H6	.150	DO1.DASHU	.025									ALPHA.4	1.150
SMALL.H7	.250	DO2.DASHU	.030	NDO	5.930	XDO	-.031					ALPHA.5	1.250
SMALL.H8	.100											ALPHA.6	1.000
SMALL.H9	-0.000	P.DASHU/P	-0.000	NCR1	.350	XCR1	.475					ALPHA.7	1.000
SMALL.H10	-0.000			NCR2	0.000	XCR2	0.000					ALPHA.8	1.150
SMALL.H11	-0.000	T-DANMEN	0	NCR3	0.000	XCR3	0.000						
SMALL.H12	-0.000			NCR4	0.000	XCR4	0.000					DELTA.A	800.000
		N	5	NCR5	0.000	XCR5	0.000						
DELTA.H	.050	BEHTA	45.000	NCL1	0.000	XCL1	0.000						
DELTA.H0	.050			NCL2	0.000	XCL2	0.000						
HOMAX	.900	EHTA	0	NCL3	0.000	XCL3	0.000						
SMALL.L	9.300			NCL4	0.000	XCL4	0.000						
L	9.980	E1	.270E+07	NCL5	0.000	XCL5	0.000						
SMALL.L1	-0.000	E2	.270E+07										
SMALL.L2	-0.000			HCR	.070	YC	1.300						
SMALL.L3	-0.000	GUZAI	1.000	HCL	.070								
SMALL.L4	-0.000												
SMALL.L5	-0.000	D22MIN	.059	NKR1	0.000	XKR1	0.000						
		D25MIN	.063	NKR2	0.000	XKR2	0.000						
SMALL.U0	.600	D29MIN	.073	NKL1	0.000	XKL1	0.000						
SMALL.U1	-0.000	D32MIN	.080	NKL2	0.000	XKL2	0.000						
				HWR	0.000	YW	0.000						
				HWL	0.000								
						XL	-.025						
				S	1.030	YS	.748						
				ALPHA.F	-.120	YF	2.548						
				BR.L	0.000	YBRL	2.560						
				TR.L	16.000	YTRL	-0.000						
				LONG	0.000	YLON	.748						
				K	.100								

NO. 19

SHUBARI NO KEISAN *Calculation of main girder*

KAJYUKEISAN OYOBI KAJYUSAYOICHI

SHIKAJYU WD = 12.999	SMALL. E(D) = -.022		
YOKOBARI WDP = 0.000			
KATSUKAJYU WL = 9.743	SMALL. E(L) = -.025	SMALL. E(D.L) = -.023	
SHOGEKIKEISU I = .437			
SHOGEKIKAJYU WI = 4.258	SMALL. E(L.LI) = -.025	SMALL. E(D.L.LI) = -.023	
ENSHINKAJYU F = -1.169	SMALL. E(L.LI.F) = -.238	SMALL. E(D.L.LI.F) = -.134	
YOKOKAJYU S = -1.030	SMALL.E(L.LI.F.S) = -.293	SMALL.E(D.L.LI.F.S) = -.162	

NEJIRIKEISU NO KEISAN

YD = .303

I = .07698

IS = .00533

IT = .07851

K = .43185

KD = .43185

K1 = .33184

K2 = -.11780

KT = .67626

BUNPUHABA SMALL.B 2DASHU = 3.036

BUNPUKAJYU	SAIKAHABA	SHOGEKIKEISU
SMALL. W6 = .148	B 7 = 0.000 B 8 = .047	
SMALL. WL3 = 3.209		
SMALL. WLI6 = 0.000	B13 = 0.000	LI6 = 0.000
SMALL. WLI7 = 1.922	B14 = .047	LI7 = .599
SMALL. WLI8 = 1.687	RAMDA = 3.100	LI8 = .526
SMALL. WLI9 = 0.000	B15 = 0.000	LI9 = 0.000
SMALL.WLI10 = 1.905	B16 = .260	LI10 = .594
SMALL.WLI11 = 0.000	B17 = 0.000	LI11 = 0.000
SMALL.WLI12 = 1.901	B18 = .315	LI12 = .592

DANMENRYOKU NO KEISAN *Bending Moment*

MAGE MOMENT NO SOKATSU

A BARI	D	L.LI	L.LI.F	L.LI.F.S	CASE 6 D.L.LI	CASE 7 D.L.LI.F	CASE 8 D.L.LI.F.S	CASE 6 ALPHA 6	CASE 7 ALPHA 7	CASE 8 ALPHA 8
MA	30.56	34.53	32.46	31.93	65.08	63.02	62.49	65.08	63.02	54.34
MB	52.38	56.37	53.00	52.13	108.75	105.38	104.51	108.75	105.38	90.88
MC	65.48	70.45	66.24	65.16	135.93	131.72	130.63	135.93	131.72	113.60
MD	69.84	74.06	69.64	68.50	143.90	139.48	138.34	143.90	139.48	120.29
ME	69.80	74.14	69.71	68.57	143.94	139.51	138.37	143.94	139.51	120.32
B BARI										
MA	30.93	35.01	37.07	37.60	65.94	68.00	68.53	65.94	68.00	59.59
MB	53.02	57.16	60.52	61.39	110.18	113.54	114.41	110.18	113.54	99.49
MC	66.27	71.44	75.64	76.73	137.71	141.92	143.01	137.71	141.92	124.35
MD	70.69	75.10	79.52	80.66	145.79	150.21	151.36	145.79	150.21	131.61
ME	70.65	75.18	79.61	80.75	145.83	150.25	151.40	145.83	150.25	131.65

SENDANRYOKU NO SOKATSU *Shearing Force*

A BARI	D	L.LI	L.LI.F	L.LI.F.S	CASE 6 D.L.LI	CASE 7 D.L.LI.F	CASE 8 D.L.LI.F.S	CASE 6 ALPHA 6	CASE 7 ALPHA 7	CASE 8 ALPHA 8
SAA	30.04	35.52	33.40	32.85	65.56	63.44	62.89	65.56	63.44	54.69
SAD	28.36	34.14	32.11	31.58	62.50	60.47	59.94	62.50	60.47	52.12
SA	22.53	29.68	27.91	27.45	52.21	50.44	49.98	52.21	50.44	43.46
SB	15.02	23.27	21.88	21.53	38.29	36.90	36.55	38.29	36.90	31.78
SC	7.51	16.85	15.84	15.58	24.36	23.35	23.09	24.36	23.35	20.08
SD	0.00	10.95	10.29	10.12	10.95	10.29	10.12	10.95	10.29	8.80
B BARI										
SAA	30.41	36.02	38.14	38.68	66.42	68.54	69.09	66.42	68.54	60.08
SAD	28.70	34.62	36.66	37.19	63.33	65.37	65.89	63.33	65.37	57.30
SA	22.80	30.10	31.87	32.33	52.90	54.67	55.13	52.90	54.67	47.94
SB	15.20	23.60	24.99	25.35	38.60	40.19	40.55	38.80	40.19	35.26
SC	7.60	17.08	18.09	18.35	24.68	25.69	25.95	24.68	25.69	22.56
SD	0.00	11.10	11.75	11.92	11.10	11.75	11.92	11.10	11.75	10.37

NEJIRI MOMENT NO SOKATSU Torsional Moment

	D	L.LI	L.LI.F	L.LI.F.S	CASE 6 D.L.LI	CASE 7 D.L.LI.F	CASE 8 D.L.LI.F.S	CASE 6 ALPHA 6	CASE 7 ALPHA 7	CASE 8 ALPHA 8
A BARI.SHITEN										
HENSHIN	-.37	-.46	-4.40	-5.42	-.83	-4.77	-5.79	-.83	-4.77	-5.03
MOMENT SA	.09	-8.19	-8.10	-8.06	-8.10	-8.01	-7.97	-8.10	-8.01	-6.93
TOTAL	-.28	-8.66	-12.50	-13.47	-8.94	-12.78	-13.76	-8.94	-12.78	-11.96
SHUBARI NO BUNTAN	-.19	-5.85	-8.45	-9.11	-6.04	-8.64	-9.30	-6.04	-8.64	-8.09
A BARI CHUOTEN										
HENSHIN	0.00	-.14	-1.36	-1.67	-.14	-1.36	-1.67	-.14	-1.36	-1.45
MOMENT SA	0.00	-2.53	-2.50	-2.48	-2.53	-2.50	-2.48	-2.53	-2.50	-2.16
TOTAL	0.00	-2.67	-3.85	-4.15	-2.67	-3.85	-4.15	-2.67	-3.85	-3.61
SHUBARI NO BUNTAN	0.00	-1.80	-2.61	-2.81	-1.80	-2.61	-2.81	-1.80	-2.61	-2.44
B BARI SHITEN										
HENSHIN	-.37	-.46	-4.40	-5.42	-.83	-4.77	-5.79	-.83	-4.77	-5.03
MOMENT SA	-.80	8.19	7.93	7.81	7.39	7.13	7.01	7.39	7.13	6.09
TOTAL	-1.17	7.73	3.53	2.39	6.55	2.36	1.22	6.35	2.36	1.06
SHUBARI NO BUNTAN	-.79	5.23	2.39	1.62	4.43	1.60	.82	4.43	1.60	.72
B BARI CHUOTEN										
HENSHIN	0.00	-.14	-1.36	-1.67	-.14	-1.36	-1.67	-.14	-1.36	-1.45
MOMENT SA	0.00	2.52	2.44	2.41	2.52	2.44	2.41	2.52	2.44	2.09
TOTAL	0.00	2.38	1.09	.74	2.38	1.09	.74	2.38	1.09	.64
SHUBARI NO BUNTAN	0.00	1.61	.74	.50	1.61	.74	.50	1.61	.74	.43

NO. 21

TAWAMI NO KEISAN Calculation of deflection


```
WD =   13.00      E1 =   .270E+07    I1 =   .15397    SMALL.L =   9.30
ME =  103.91      E2 =   .270E+07    I2 =   .18890    GUZAI   =   1.00

DELTA.D =   1/ 3053
DELTA.L =   1/ 5066
 TOTAL  =   1/ 1905
```

No 22

No.23

SHITEN HANRYOKU NO KEISAN

ENCHOKU SHITEN HANRYOKU (REACTION)

	D	L	L.F	L.F.S	L.LI	L.LI.F	L.LI.F.S	D.E
RA	33.11	26.52	23.44	22.15	38.11	35.04	33.74	32.30
RB	33.51	26.90	29.98	31.27	38.65	41.73	43.03	34.32

KYOZIKU CHOKKAKU HOKO NO SUIHEI SHITEN HANRYOKU (1 SHOE ATARI)

HS	3.19
HF	-3.89
HE	4.45

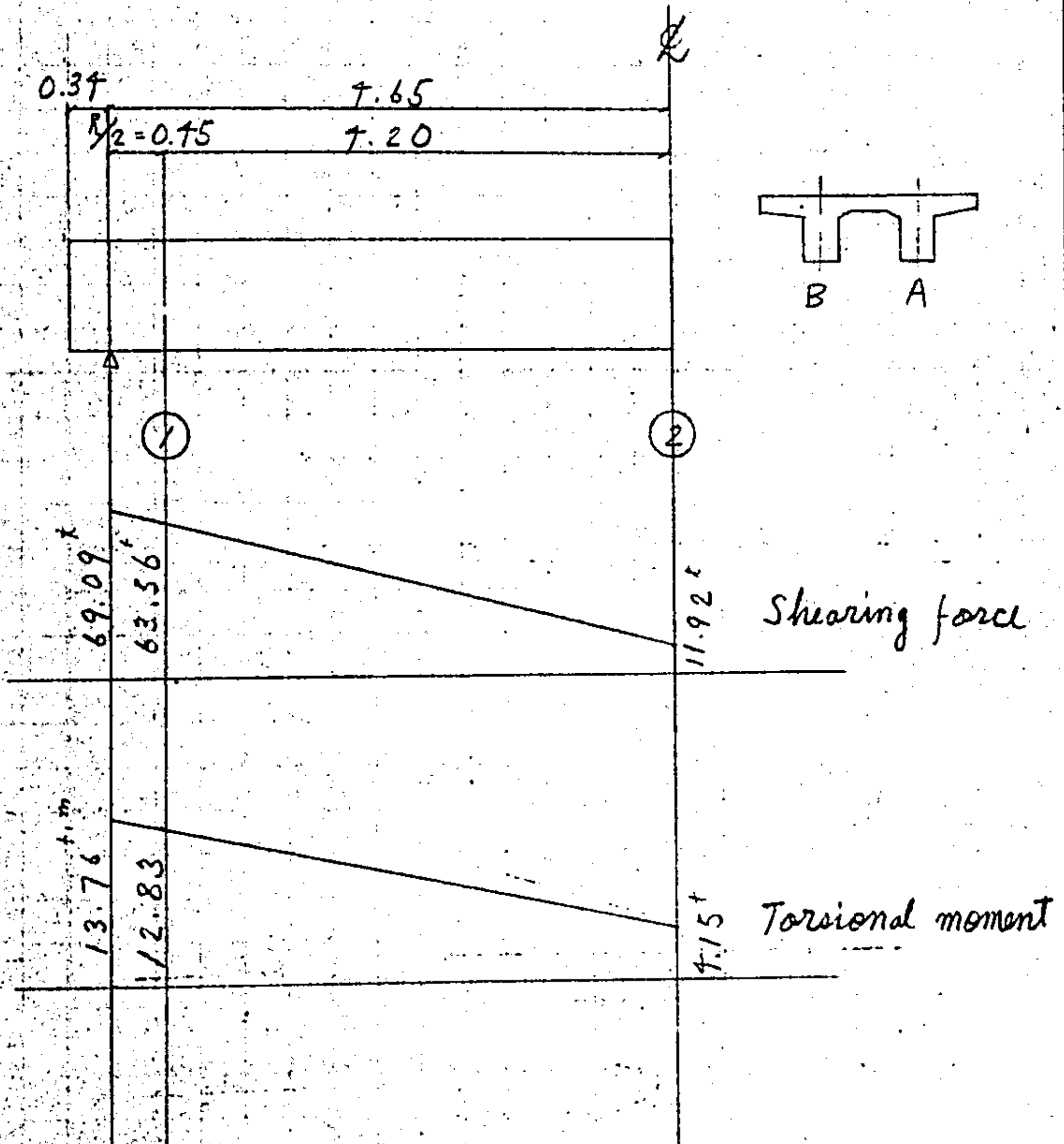
KYOZIKU HOKO NO TATE KAJYU (1 SYUBARI ATARI) KAJYU SAYO TAKASA

TBR	0.00	YBR	3.460
TTR	6.00	YTR	.900
TLN	0.00	YLN	1.648
TE	6.67	YE	1.493

Bending stress

	center	
M (tm)	150.21	
N (t)		
S (t)	B = 297.5	
b (cm)	70	
h (cm)	90	
d (cm)	80.9	
d' (cm)	9.1	
As (cm^2)	D32 - 16 =127.072	
p	0.00528	
As' (cm^2)		
p'		
e = M/N (cm)	x = 26.5	
e = M/N + u (cm)		
e = M/N − u (cm)		
e/h		
d/e		
d'/h		
d'/d		
Ne/bd^2 (kg/cm^2)		
k	0.326	
c		
j	0.892	
1/Lc		
1/Ls		
$\beta = \sigma s/\sigma c$		
σc (kg/cm^2)	53.1	
σs (kg/cm^2)	1640	
τ (kg/cm^2)		
σsa (kg/cm^2)	1800	
σca (kg/cm^2)	90	
τa (kg/cm^2)		

Calculation of shearing stress



(Note)

For the purpose of sefety design, shearing stress / torsional moment is chosen the value of beam B / beam A respectively.

(1) Shearing stress

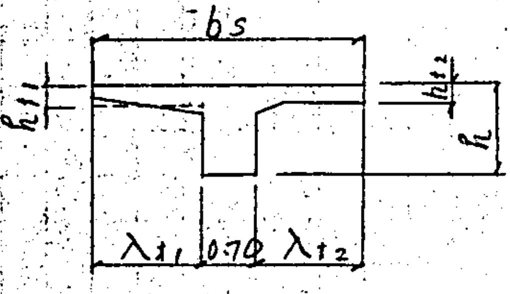
$$\tau = \frac{S}{b \cdot d}$$

$$\tau_1 = \frac{63.56 \times 10^3}{70 \times 80.9} = 11.22 \, kg/cm^2 > 3.9 \, kg/cm^2$$

$$\tau_2 = \frac{11.92 \times 10^3}{70 \times 80.9} = 2.10 \, " < 3.9 \, "$$

(2) Shearing stress caused by Torsional moment

1) Effective width



One side effective width of projected flange subjected to the Torsional moment is calculated followed the equation

$$\lambda_t = 3 \cdot h_t$$

Cantilever part $\lambda_{t1} \leqq l_c$

Intermediate part $\lambda_{t2} \leqq l_b/2$

Where,

λ_t : One side effective width of projected flange (m)

h_t : Thickness of projected flange (m)

l_b : Net clearance between girders $l_b = 2.40^m$

l_c : Projecting length of cantilever slab $l_c = 1.075^m$

$h_{t1} = 0.275^m$ (Average thickness) $h_{t2} = 0.25^m$

$\lambda_{t1} = 3 \times 0.275 = 0.875^{m} < 1.075^{m}$

$\lambda_{t2} = 3 \times 0.25 = 0.75 < \frac{l_b}{2} = 1.20^{m}$

Effective height $d = 80.9^{cm}$

2) Shearing stress caused by torsion on T section

Torsional shearing stress is calculated followed the equation.

$$\tau_{ti} = \frac{M_T}{I_t} \times b_i \times \eta_i$$

Where,

τ_{ti} : Shearing stress of concrete calculated on each rectangular section (kg/cm^2)

M_t : Torsional moment (kg/cm^2)

b_i : Shorter side of each rectangular section (cm)

η_i : Referred table - 40 (2)

I_t : Torsional moment of inertia (cm^4)

$I_t = \Sigma k_i \cdot a_i \cdot b_i{}^3$

a_i : Longer side of each rectangular section

k_i : Refferred Table - 40 (2)

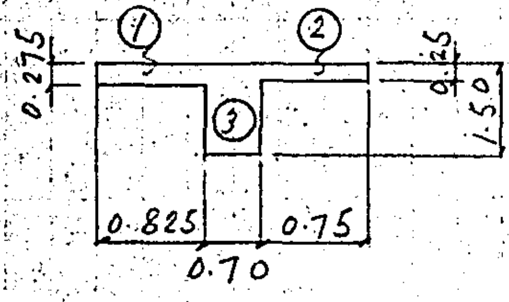
Table - 40 (2) coefficient η_i

a/b	1.0	1.2	1.5	1.75	2.0	2.5	3.0	4.0	5.0
η_i	0.675	0.759	0.848	0.895	0.930	0.968	0.985	0.997	1.0

Table - 40 (3) coefficient ki

a/b	1.0	1.2	1.5	1.75	2.0	2.5	3.0	4.0	5.0
ki	0.140	0.166	0.196	0.214	0.229	0.249	0.263	0.281	0.292

(a) Torsional moment of inertia



	a(m)	b(m)	a/b	k	$I_t = k \cdot a \cdot b^3$ (m^4)
①	0.825	0.275	3.00	0.263	$0.263 \times 0.825 \times 0.275^3 = 0.00451$
②	0.750	0.25	3.00	0.263	$0.263 \times 0.75 \times 0.25^3 = 0.00308$
③	0.90	0.70	1.286	0.175	$0.175 \times 0.90 \times 0.70^3 = 0.05402$
ΣI_t					0.06161

$\Sigma I_t = 6.161 \times 10^{6}$ cm^4

(b) Torsional moment beared by longitudinal beam

$$M_t = M_T \times \frac{I_{t3}}{\Sigma I_t}$$

Support point

$$M_{t0} = 13.76 \times \frac{5.402 \times 10^6}{6.161 \times 10^6} = 12.06^{t.m}$$

h/2 point

$$M_{t1} = 12.83 \times \frac{5.402 \times 10^6}{6.161 \times 10^6} = 11.25^{t.m}$$

Center point

$$M_{t2} = 4.15 \times \frac{5.402 \times 10^6}{6.161 \times 10^6} = 3.64^{t.m}$$

(C) Torsional shearing stress of longitudinal beam

h/2 point

$$M_t = 11.25^{t.m}$$

$$h = 90^{cm} \quad b = 70^{cm}$$

$$\frac{h}{b} = \frac{90}{70} = 1.286$$

Table - 40 (2) $\quad \eta_i = 0.785$

$$\tau_{ti} = \frac{11.25 \times 10^5}{6.161 \times 10^6} \times 70 \times 0.785 = 10.03^{kg/cm^2} > 3.9^{kg/cm^2}$$

(d) Combined shearing stress

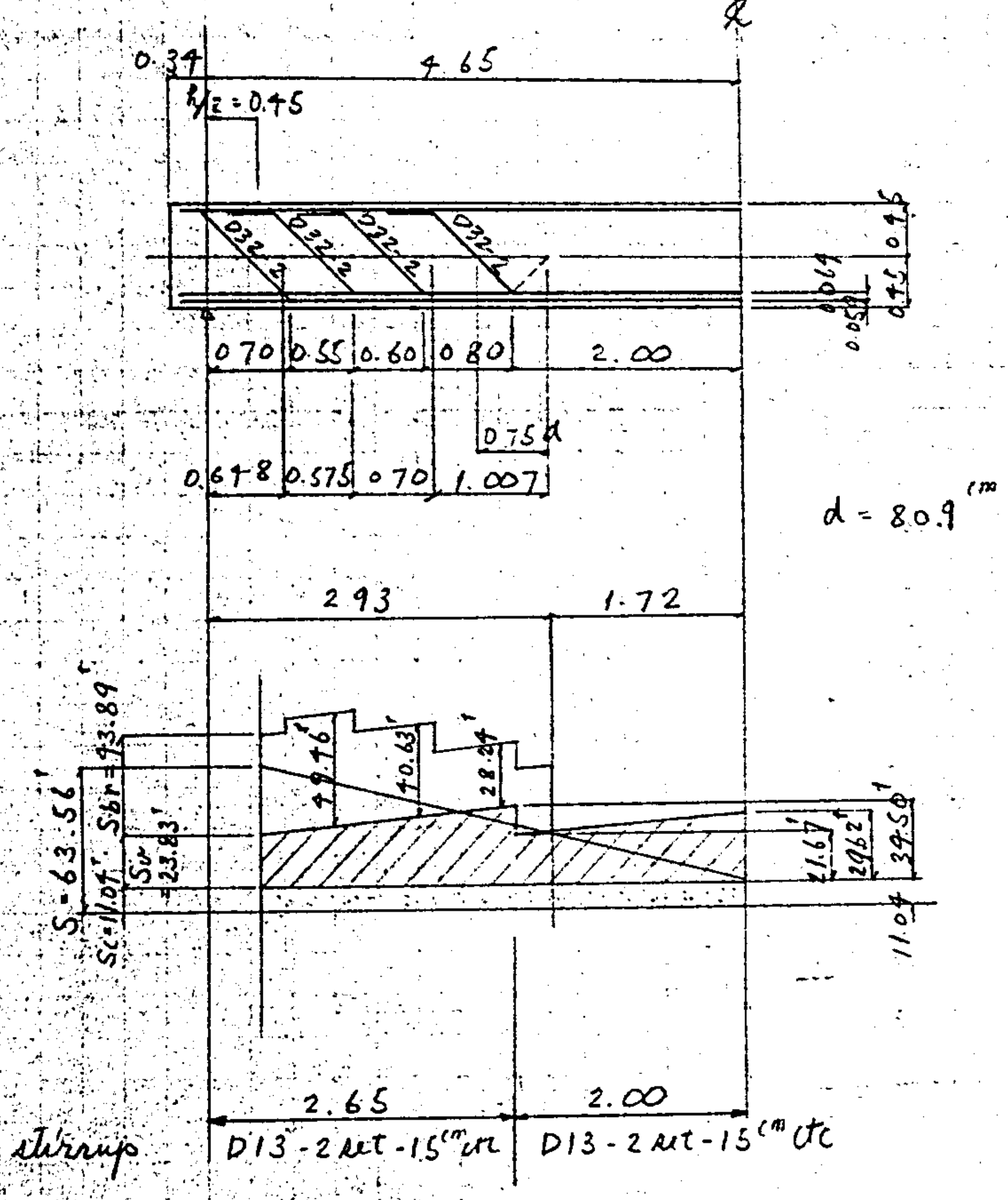
Torsion is considered.

$\tau_a = 17 \times 1.30 = 22 \ kg/cm^2$

$\Sigma \tau = 11.22 + 10.03 = 21.25 \ kg/cm^2 < 22 \ kg/cm^2$

Calculated as above, diagonal tension re-bars are examined.

(3) Calculation of diagonal tension re-bars
shearing stress caused by bending



1) Shearing force beared by concrete

$$Sc = 1/2 \times \tau a \times b \times d$$

Where,

Sc : Shearing force beared by concrete (t)

τa : $\sigma ck = 240\ kg/cm^2$ $\tau_c = 3.9\ kg/cm^2$

b : Width of cross section of member (cm)

d : Effective height of member

$$Sc = 1/2 \times 3.90 \times 70 \times 80.9 \times 10^{-3} = 11.0t$$

2) Shearing force beared by stirrup

i) Torsional shearing stress

$$\sigma_{st} = \frac{Mt \cdot s}{0.8\, Av \cdot b_1 \cdot h_1} \times \frac{a_1}{b_1}$$

Where,

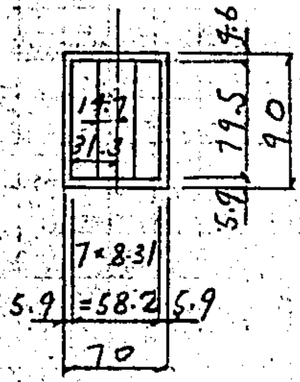
Mt : Torsional moment (t·m)

s : ctc distance of stirrup (cm)

Av : Gross cross section of coupled stirrups

b_1, h_1 : Length of short/long side of stirrup

a) At the $h/2$ point



$M_t = 11.25^{t \cdot m}$

Arrange stirrup D13 - 2 sets in 15 cm ctc.

$s = 15^{cm}$

$A_v = 1.267 \times 4 = 5.07^{cm^2}$

$h_1 = 79.5 + 1.6 + 0.8 + 1.3 = 83.2^{cm}$

$b_1 = \dfrac{14.7^2 + 31.3}{14.7 + 31.3} \times 2 = 52.00^{m}$

$$\sigma_{s1} = \frac{11.25 \times 10^5 \times 15}{0.80 \times 5.07 \times 52.0 \times 83.2} \times \frac{31.3 \times 2}{52.00}$$

$= 1158^{kg/cm^2} < 1800^{kg/cm^2}$

b) At the change point of stirrup

(2.0 m point from center)

$M_t = \dfrac{11.25 - 3.64}{4.65} \times 2.00 + 3.64 = 6.91^{t}$

Arrange stirrup D13 - 2 sets in 20 (15) cm ctc.

$s = 20^{cm}$ (15^{cm})

$A_v = 5.07^{cm^2}$

$h_1 = 83.2^{cm}$, $b_1 = 52.0^{cm}$

$$\sigma_{s2} = \frac{6.91 \times 10^5 \times 20\ (15)}{0.8 \times 5.07 \times 52.0 \times 83.2} \times \frac{31.2 \times 2}{52.0}$$

$= 945^{kg/cm^2}$ (709)

c) At the center point

$M_t = 3.64^{t \cdot m}$

Arrange stirrup D13 - 2 sets in 20^{cm} ctc.

$s = 20^{cm}$

$A_v = 5.07^{cm^2}$

$h_1 = 83.2^{cm}$, $b_1 = 52^{cm}$

$$\sigma_{st} = \frac{3.64 \times 10^5 \times 20}{0.8 \times 5.07 \times 52.0 \times 83.2} \times \frac{31.3 \times 2}{52.0}$$

$$= 499^{kg/cm^2} < 1800^{kg/cm^2}$$

ii) Bending shear beared by stirrup

In the case when combined with torsional moment, allowable shearing stress is 20 percent increased.

$\sigma_{sa} = 1800 \times 1.2 = 2160^{kg/cm^2}$

$$S_v = \frac{(\sigma_{sa} - \sigma_{st}) \times A_v \cdot d}{1.15 \times s}$$

a) At the h/2 point

$2160 - 1158 = 1002^{kg/cm^2}$

$d = 80.9^{cm}$

$$S_v = \frac{1002 \times 5.07 \times 80.9}{1.15 \times 15 \times 10^3} = 23.83^{t}$$

b) At the change point of stirrup

$$2160 - \underset{}{\overset{(709)}{945}} = \overset{(1451)}{1215}\ ^{kg/cm^2}$$

$d = 80.9^{cm}$

$$S_v = \frac{\overset{(1451)}{1215} \times 5.07 \times 80.9}{1.15 \times \underset{(15)}{20} \times 10^3} = \overset{(34.50)}{21.67}^{t}$$

c) At the center point

$2160 - 499 = 1661^{kg/cm^2}$

$d = 80.9^{cm}$

$$S_v = \frac{1661 \times 5.07 \times 80.9}{1.15 \times 20 \times 10^3} = 29.62^{t}$$

3) Shearing force beared by Turned up bar

$$S_{br} = \frac{\sigma_{sa} \cdot A_s \cdot d \cdot (\sin\theta + \cos\theta)}{1.15 \cdot s}$$

Where,

σ_{sa} : Allowable Tensile stress of bar (kg/cm²)

A_s : Cross section of turned up bar (cm²)

A_s = D32 - 2 = 15.884 cm²

d : Effective height of member d = 80.9 cm

θ : Elevation angle of Turned up bar with the axis of member $\theta = 45°$

s : Spacing of turned up bars in axial direction of member (m)

$$S_{br_1} = \frac{1800 \times 15.884 \times 80.9 \times 1.414}{1.15 \times 0.648 \times 10^5} = 43.89^t$$

$$S_{br_2} = \frac{1800 \times 15.884 \times 80.9 \times 1.414}{1.15 \times 0.575 \times 10^5} = 49.46^t$$

$$S_{br_3} = \frac{1800 \times 15.884 \times 80.9 \times 1.414}{1.15 \times 0.70 \times 10^5} = 40.63^t$$

$$S_{br_4} = \frac{1800 \times 15.884 \times 80.9 \times 1.414}{1.15 \times 1.007 \times 10^5} = 28.24^t$$

(4) Calculation of bars in axial direction

Required bars are calculated followed the equation

$$A_s = \frac{M_t\,(b_1 + h_1)}{0.8 \times \sigma_{sa} \times b_1 \times h_1}$$

Where

A_s : Bars in axial direction

M_t : Torsional moment

σ_{sa} : Allowable stress of bar

b_1, h_1 : Length of shoreter / Longer side of stirrup

$M_t = 12.06^{t}$

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

$b_1 = 31.3 \times 2 = 62.6^{cm}$

$h_1 = 83.2^{cm}$

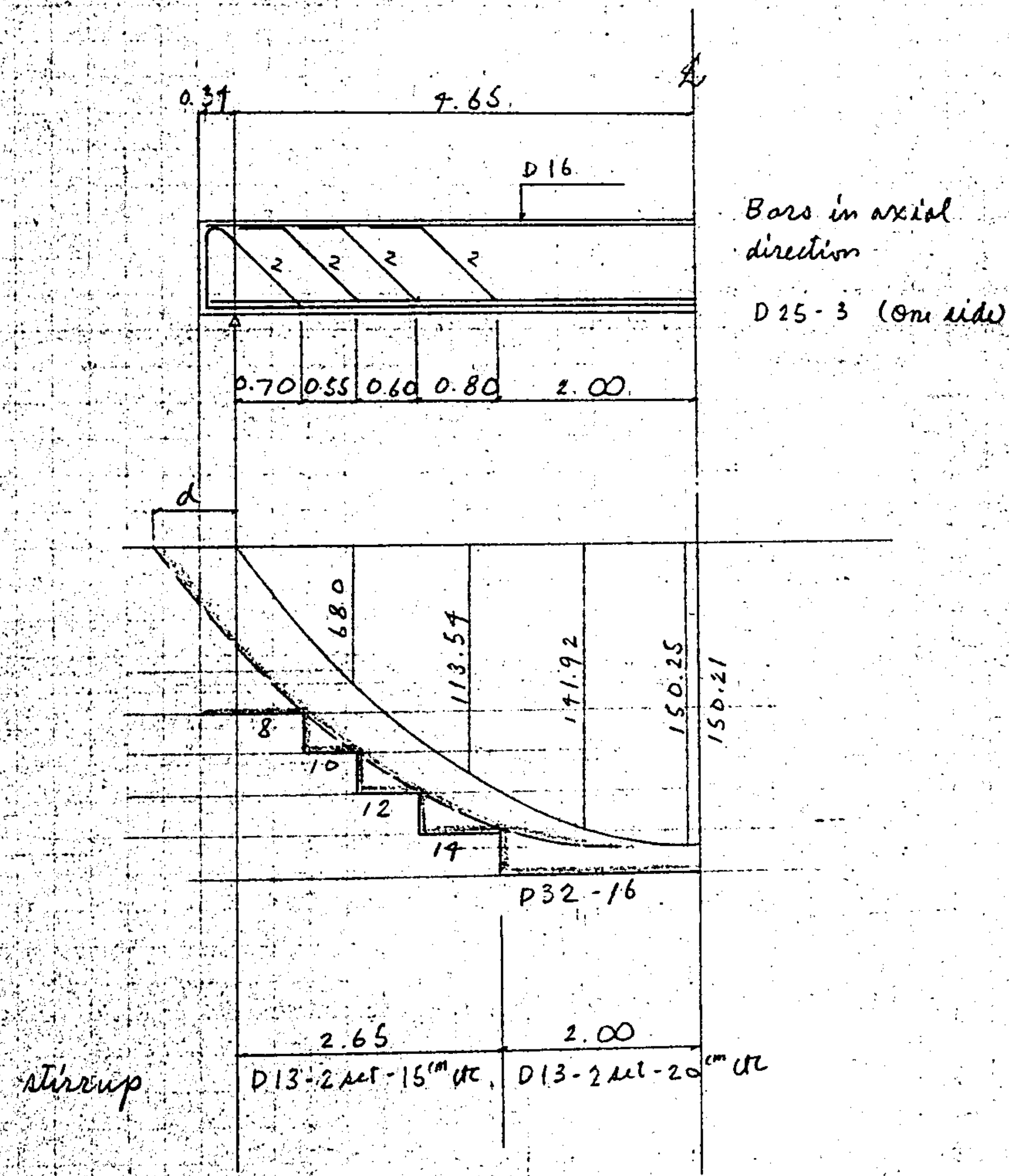
$$A_s = \frac{12.06 \times 10^5 (62.6 + 83.2)}{0.8 \times 1800 \times 62.6 \times 83.2} = 23.44^{cm^2}$$

Required bar arrongement for longer side

$$A_{sh_1} = 23.44 \times \frac{83.2}{(62.6 + 83.2)} = 13.38^{cm^2}$$

A_s : D25 - 3 $_{(20^{cm} ctc)}$ $= 15.20^{cm^2} > A_{sh_1} = 13.38^{cm^2}$

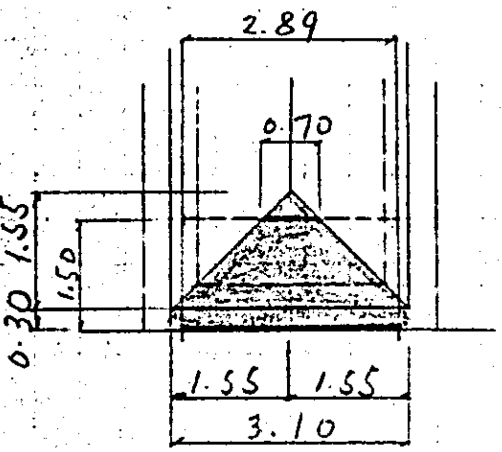
Resisting moment diagram



4. Calculation of cross beam

4-1 Calculation of loads

(1) Dead load



Both ends simpl beam: Span is the distance between main beam centers.

1) Distributed load

From the slab calculation,

a) Dead load

$w = 1.94\ t/m^2$

$wd_1 = 1.94\ t/m \times 1.55 = 3.01\ t/m$

b) One weight of cross beam and weight of slab haunch

$wd = 2.50 \times (0.60 \times 0.65 + 0.10 \times 0.3 \times 1/2) = 1.01\ t/m$

$wd = 1.94 \times 0.30 = 0.58$ "

$wd_2 = 1.59$ "

(2) Train load + Impact

KS-16

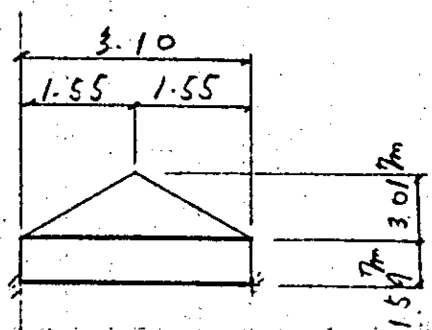
$$w_l = \frac{16}{2.89} = 5.54^{t/m}$$

$l = 3.10^m$ $\quad$ $i = 0.526$

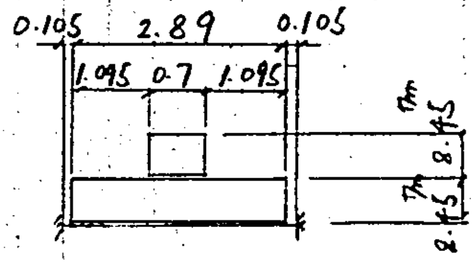
$$w_{l+i} = 5.54 \times 1.526 = 8.45^{t/m}$$

4-2 Loading diagram

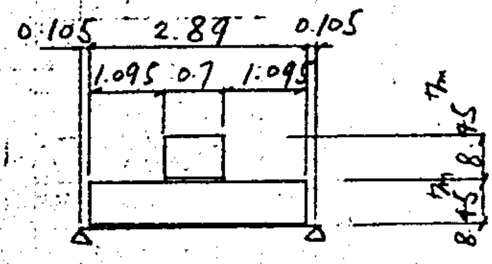
(1) Dead load case 1



(2) Train load + Impact (1) Case 2



(3) Train load + Impact (2) Case 3



NO. 42

SIDE BEAM [CRC547 RAHMEN]

```
** CONTROL DATA **
   SETTEN SU                2
   BUZAI  SU                1
   SHITEN SU                2
   KIHON KAJYU CASE SU      3
   KUMIAWASE   CASE SU      0
   PICK UP     CASE SU      0
   BUNPU BANE TYPE  SU      0
   SUPPORT    TYPE  SU      2

** JOINT DATA **
   PT.          X(M)     Y(M)
   1           0.000    0.000
   2           3.100    0.000

** MEMBER DATA **
   K ITAN JTAN  IP  JP   L (M)      A(M2)       I(M4)      E(T/M2)     EPS
   1   1    2   0   0   3.1000   1.000000   1.000000   .2700E+07   .1000E-04

** SUPPORT TYPE  **

  <TYPE  NO.  1>
   SUPPORT      KX (T/M)        KY (T/M)     KZ (T-M/RAD)
       1             0.              0.             0.
       2             0.              0.             0.

  <TYPE  NO.  2>
   SUPPORT      KX (T/M)        KY (T/M)     KZ (T-M/RAD)
       1             1.              0.             1.
       2             0.              0.             1.

** CHAKUMOKU TEN DATA  &  LENGTH **

   MEMBER          I-DISTANCE
        1  0.000   .350   .800  1.550  2.300  2.750  3.100
```

SIDE BEAM [CRC547 RAHMEN]

KIHON KAJYU CASE 1
BUNPU BANE TYPE NO. 1
SUPPORT TYPE NO. 1
LOAD TITLE D

[SW]	[NN]	[LL]	[A]	[B]	[C]	[D]
4	1	2	-1.590	-4.600	0.000	1.550
4	1	2	-4.600	-1.590	1.550	1.550

KIHON KAJYU CASE 2
BUNPU BANE TYPE NO. 1
SUPPORT TYPE NO. 1
LOAD TITLE T+I (1)

[SW]	[NN]	[LL]	[A]	[B]	[C]	[D]
4	1	2	-8.450	-8.450	.105	2.890
4	1	2	-8.450	-8.450	1.200	.700

KIHON KAJYU CASE 3
BUNPU BANE TYPE NO. 1
SUPPORT TYPE NO. 2
LOAD TITLE D+L (2)

[SW]	[NN]	[LL]	[A]	[B]	[C]	[D]
4	1	2	-8.450	-8.450	.105	2.890
4	1	2	-8.450	-8.450	1.200	.700

REACTION

CASE 1 D

SUPPORT	X (TON)	Y (TON)	Z (TON.M)
1	0.000	4.797	-2.780
2	0.000	4.797	2.780

CASE 2 T+I (1)

SUPPORT	X (TON)	Y (TON)	Z (TON.M)
1	0.000	15.168	-8.975
2	0.000	15.168	8.975

CASE 3 D+L (2)

SUPPORT	X (TON)	Y (TON)	Z (TON.M)
1	0.000	15.168	0.000
2	0.000	15.168	0.000

No. 44

SIDE BEAM [CRC547 RAHMEN]

D E F L E C T I O N

CASE 1 D

JOINT	X (MM)	Y (MM)	Z (M.RAD)
1	0.000	0.000	0.000
2	0.000	0.000	0.000

CASE 2 T+I (1)

JOINT	X (MM)	Y (MM)	Z (M.RAD)
1	0.000	0.000	0.000
2	0.000	0.000	0.000

CASE 3 D+L (2)

JOINT	X (MM)	Y (MM)	Z (M.RAD)
1	0.000	0.000	-.005
2	0.000	0.000	.005

SIDE BEAM [CRC547 RAHMEN]

No. 46

MEMBER FORCE

CASE 1 D

* * MEMBER 1 (1 - 2) * *

I	L(M)	B.M(T.M)	S.F(T)	A.F(T)
1	0.000	-2.780	4.797	0.000
	.350	-1.212	4.122	0.000
	.800	.383	2.904	0.000
	1.550	1.541	-.000	0.000
	2.300	.383	-2.904	0.000
	2.750	-1.212	-4.122	0.000
2	3.100	-2.780	-4.797	0.000

CASE 2 T+I (1)

* * MEMBER 1 (1 - 2) * *

I	L(M)	B.M(T.M)	S.F(T)	A.F(T)
1	0.000	-8.975	15.168	0.000
	.350	-3.920	13.098	0.000
	.800	1.119	9.295	0.000
	1.550	5.196	.000	0.000
	2.300	1.119	-9.295	0.000
	2.750	-3.920	-13.098	0.000
2	3.100	-8.975	-15.168	0.000

CASE 3 D+L (2)

* * MEMBER 1 (1 - 2) * *

I	L(M)	B.M(T.M)	S.F(T)	A.F(T)
1	0.000	0.000	15.168	0.000
	.350	5.055	13.097	0.000
	.800	10.093	9.295	0.000
	1.550	14.171	.000	0.000
	2.300	10.093	-9.295	0.000
	2.750	5.055	-13.098	0.000
2	3.100	0.000	-15.168	0.000

	Top side	Bottom side	
M (tm)	-6.77	15.71	
N (t)			
S (t)			
b (cm)	60	60	
h (cm)	90	90	
d (cm)	82.2	81.7	
d' (cm)	7.8	8.3	Top side (Semi-fixed span)
As (cm^2)	D16-4 = 7.96	D16-6 = 11.92	$M = -2.28 - 8.98 \times 1/2 = -6.77^{t.m}$
p	0.00161	0.00243	
As' (cm^2)			Bottom side (Simple span)
p'			$M = 1.54 + 14.17 = 15.71^{t.m}$
e=M/N (cm)			
e=M/N+u (cm)			
e=M/N−u (cm)			
e/h			
d/e			
d'/h			
d'/d			
Ne/bd^2 (kg/cm^2)	1.66	3.92	
k			
c			
j			
1/Lc	10.86	9.20	
1/Ls	663	446	
$\beta = \sigma s/\sigma c$			
σc (kg/cm^2)	18.13	36.1	
σs (kg/cm^2)	1110	1750	
τ (kg/cm^2)			
σsa (kg/cm^2)	1800	1800	
σca (kg/cm^2)	90	90	
τa (kg/cm^2)			
	D+T+I	D+T+I	

Shearing stress

At the $\ell/2$ point

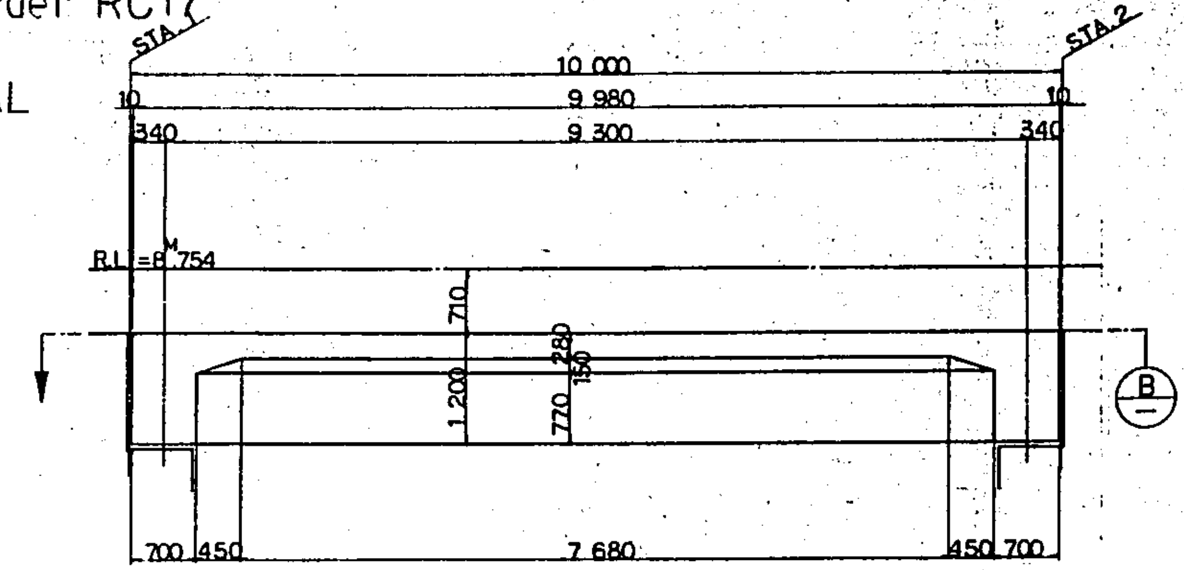
$S = 12.20^t$

$$\tau = \frac{12.20 \times 10^3}{60 \times 81.7} = 2.49 \, kg/cm^2 < 3.9 \, kg/cm^2$$

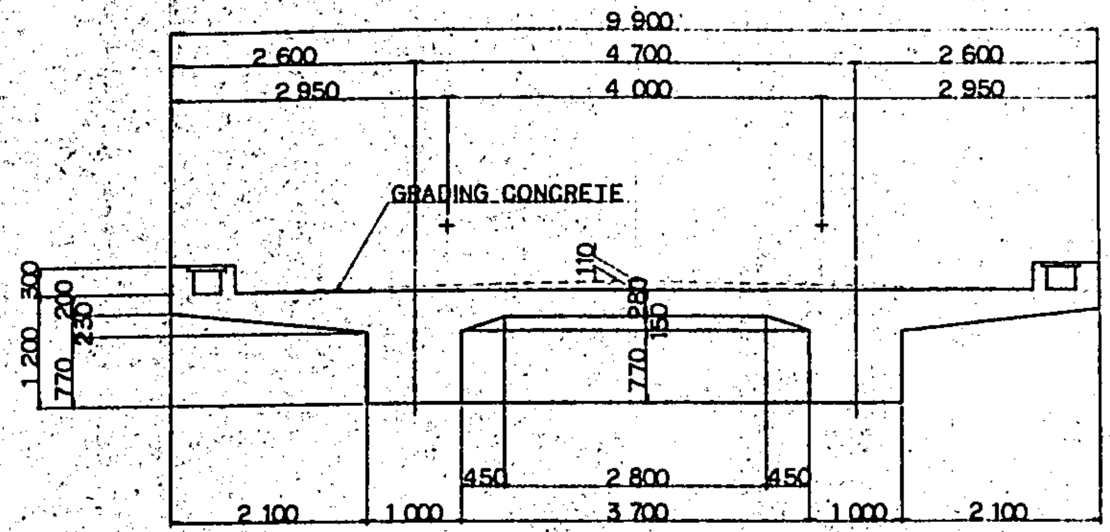
Arrange stirrups D13 - 1 sets in 20cm ctc

§3. R.C. Girder RC17

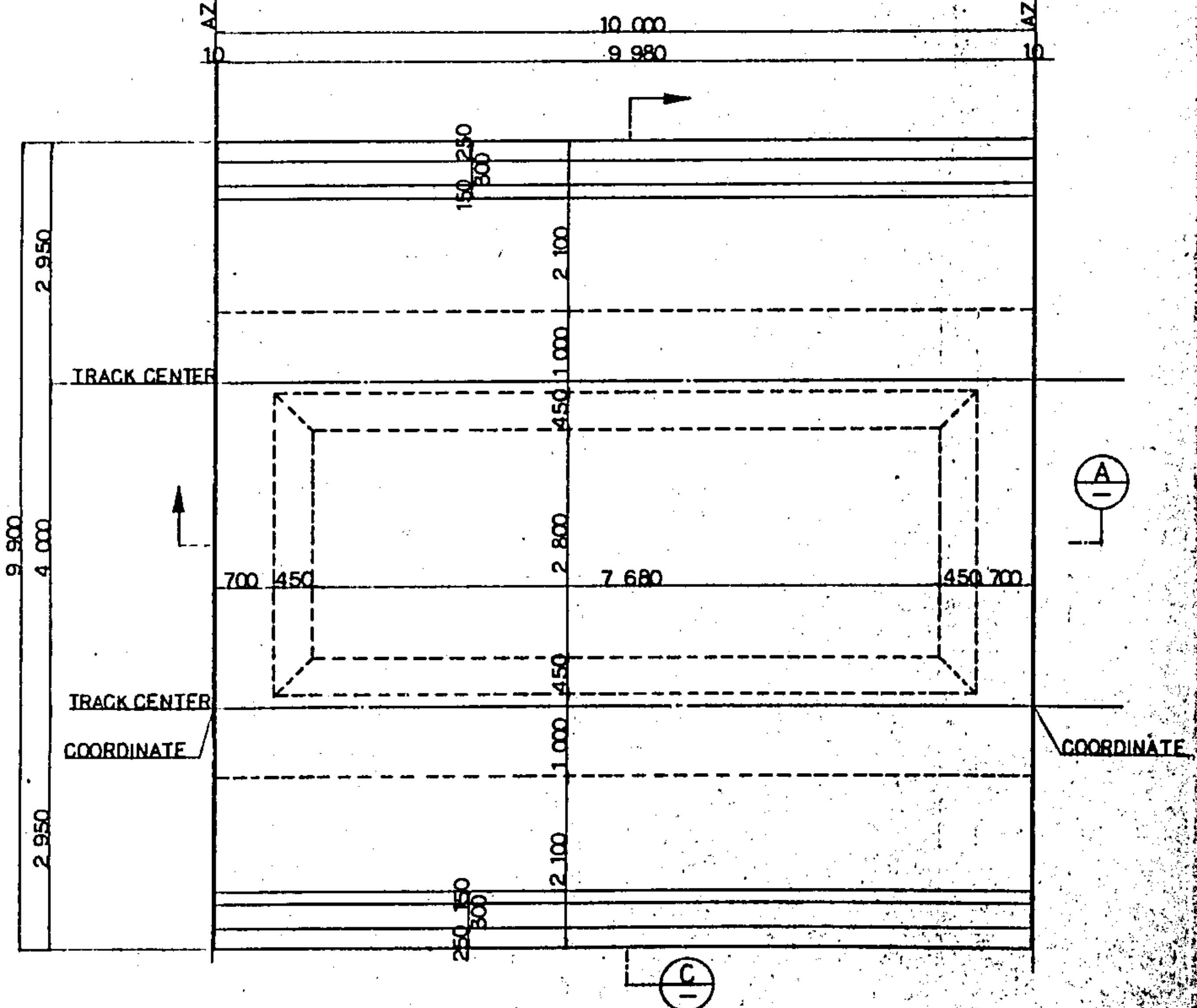
1. GENERAL VIEW



SECTION (A)



SECTION (C)



SECTION (B)

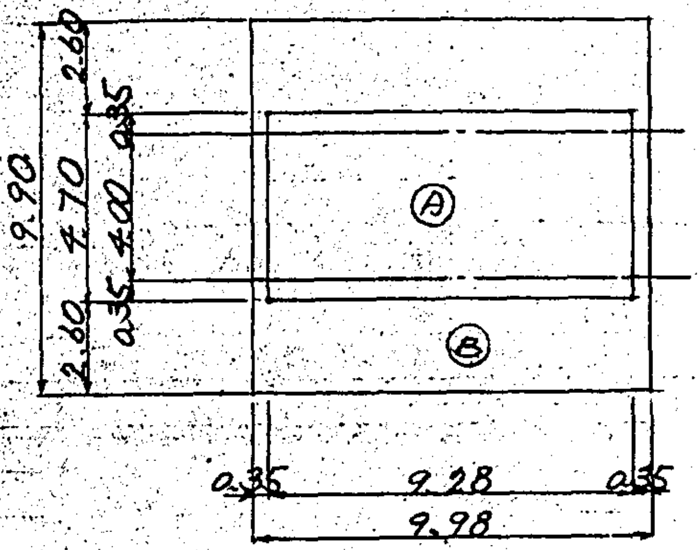
DIMENSION SCHEDULE

		STATION	R.L.	AZIMUTH ANGLE	CENGKAREN AIRPORT LINE COORDINATE
RC 17	STA.1	$17^{K}\ 212^{M}000$	$8^{M}.754$	345° 30′ 45″	U. 12 $106^{M}.906$ T. 1 $014^{M}.477$
	STA.2	$17^{K}\ 222^{M}000$	〃	〃	U. 12 $109^{M}.407$ T. 1 $024^{M}.159$
RC 18	STA.1	$17^{K}\ 260^{M}000$	$8^{M}.754$	345° 30′ 45″	U. 12 $118^{M}.914$ T. 1 $060^{M}.951$
	STA.2	$17^{K}\ 270^{M}000$	〃	〃	U. 12 $121^{M}.415$ T. 1 $070^{M}.633$
RC 19	STA.1	$17^{K}\ 300^{M}000$	$8^{M}.754$	345° 30′ 45″	U. 12 $128^{M}.920$ T. 1 $099^{M}.679$
	STA.2	$17^{K}\ 310^{M}000$	〃	〃	U. 12 $131^{M}.422$ T. 1 $109^{M}.361$
RC 20	STA.1	$17^{K}\ 340^{M}000$	$8^{M}.754$	345° 30′ 45″	U. 12 $138^{M}.927$ T. 1 $138^{M}.407$
	STA.2	$17^{K}\ 350^{M}000$	〃	〃	U. 12 $141^{M}.429$ T. 1 $148^{M}.089$
RC 21	STA.1	$17^{K}\ 380^{M}000$	$8^{M}.754$	345° 30′ 45″	U. 12 $148^{M}.934$ T. 1 $177^{M}.135$
	STA.2	$17^{K}\ 390^{M}000$	〃	〃	U. 12 $151^{M}.435$ T. 1 $186^{M}.817$
RC 22	STA.1	$17^{K}\ 420^{M}000$	$8^{M}.754$	345° 30′ 45″	U. 12 $158^{M}.941$ T. 1 $215^{M}.863$
	STA.2	$17^{K}\ 430^{M}000$	〃	〃	U. 12 $161^{M}.442$ T. 1 $225^{M}.545$
RC [illegible]	STA.1	$17^{K}\ 460^{M}000$	$8^{M}.754$	345° 30′ 45″	U. 12 $168^{M}.947$ T. 1 $254^{M}.591$
	STA.2	$17^{K}\ 470^{M}000$	〃	〃	U. 12 $171^{M}.449$ T. 1 $264^{M}.273$

NOTES :

1. ALL DIMENSIONS ARE SHOWN IN MILLIMETERS UNLESS OTHERWISE INDICATED
2. REFERENCE DRAWING FOR BAR ARRANGEMENT : CS-217~218

2. Calculation of slab



(1) Slab for calculation

Slab Ⓐ -------- Two-way Slab

Slab Ⓑ -------- Cantilever Slab

(2) Calculation of Slab Ⓐ

Four sides fixed span

$l_{dx} = 4.70 - 1.00 = 3.70^m$

$l_{dy} = 9.98 - 0.70 \times 2 = 8.58^m$

Four sides semi-fixed span

$l_{ex} = 3.70 + 0.28 = 3.98^m$

$l_{ey} = 8.58 + 0.28 = 8.86$

Span ratio

$$m_d = \frac{l_{dx}}{l_{dy}} = \frac{3.70}{8.58} = 0.43 > 0.4$$

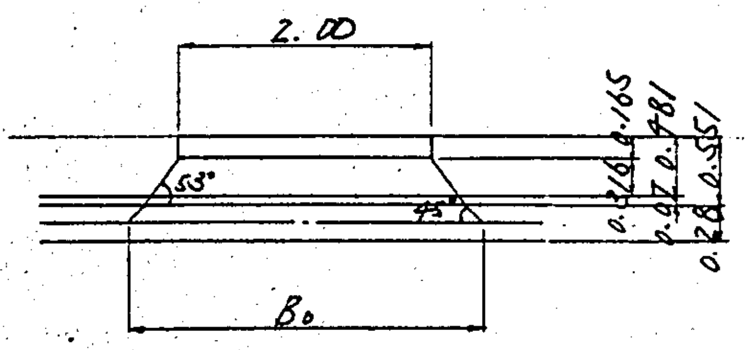
$$m_e = \frac{l_{ex}}{l_{ey}} = \frac{3.98}{8.86} = 0.45 > 0.4$$

From the above, the slab is considered as a two - way slab for calculation.

2-1. Load Calculations

(1) Dead Load

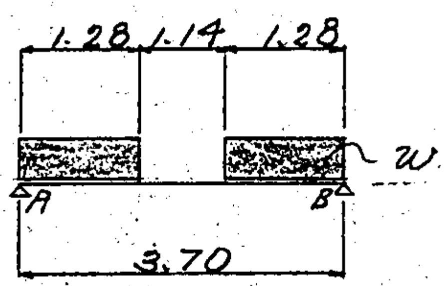
Effective width



$B_0 = 2.00 + 1.5 \times (0.316 + 0.07) + 0.28 \doteqdot 2.86^{m}$

(a). Weight of track assembly

$w = 0.45\ ^{t}/_{m} / 2.86 \doteqdot 0.157\ ^{t}/_{m^2}$



$R_A = R_B = 0.157^{t/m} \times 1.28 = 0.20^{t}$

(i) At the $l/4$ point

$M_{l/4} = 0.20 \times 0.925 - 0.157 \times 0.925^2 \times 1/2 = 0.12^{tm}$

$w_{l/4} = \frac{32 \times 0.12}{3 \times 3.70^2} = 0.09^{t/m^2} > w_{l/2} = 0.08^{t/m^2}$

(ii) At the $\ell/2$ point

$$M_{\ell/2} = 0.20 \times 1.85 - 0.157 \times 1.28 \times (1.85 - \frac{1.28}{2})$$

$$= 0.13^{tm}$$

$$W_{\ell/2} = \frac{8 \times 0.13}{3.70^2} = 0.08\ t/m^2$$

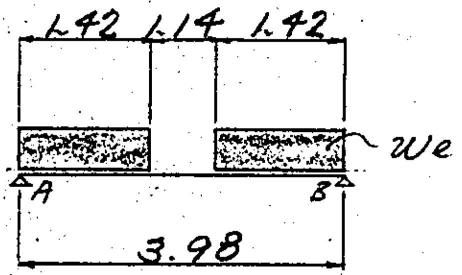
Sloping concrete	$2.35\ t/m^3 \times 0.07$	$= 0.165\ t/m^2$
Ballast	$1.9\ " \times 0.481$	$= 0.914\ "$
Slab	$2.5\ " \times 0.28$	$= 0.700\ "$
	W_{d1}	$= 1.78\ t/m^2$

(b) Uniformly distributed load

$$\Sigma W_d = 0.09 + 1.78 = 1.87\ t/m^2$$

(2) Train Load (single track)

$$w_e = \frac{16}{1.50 \times 2.86} = 3.73\ t/m^2$$



$$R_A = R_B = 3.73^{t/m} \times 1.42 = 5.30^{t}$$

(i) At the $l/4$ point

$$M_{l/4} = 5.30^{t} \times 0.995 - 3.73^{t/m} \times 0.995^2 \times 1/2 = 3.43^{tm}$$

$$w_{l/4} = \frac{32 \times 3.43}{3 \times 3.98^2} = \underline{2.31\ t/m^2} > w_{l/2} = 1.90\ t/m^2$$

(ii) At the $l/2$ point

$$M_{l/2} = 5.30^{t} \times 1.99 - 3.73^{t/m} \times 1.42 \times \left(1.99 - \frac{1.42}{2}\right)$$

$$= 3.77^{tm}$$

$$w_{l/2} = \frac{8 \times 3.77}{3.98^2} = 1.90\ t/m^2$$

(3) Impact coefficient

$l = 3.98^m \longrightarrow i_o = 0.504$

. Reduction of impact coefficient

$i = 0.504 \times (1 - \frac{3.98}{200}) = 0.494$

$\therefore W_{l+i} = 2.31 \times (1 + 0.494) = 3.45\ t/m^2$

2.. Bending moment

(1) Dead Load

(a) Sharing of load

$l_{dx} = 3.70^m \qquad l_{dy} = 8.58^m$

Coefficient of load sharing in the direction of X or y

$C_x = \frac{8.58^4}{3.70^4 + 8.58^4} = 0.967$

$C_y = \frac{3.70^4}{3.70^4 + 8.58^4} = 0.033$

(b) Shared load

$W_{dx} = 1.87 \times 0.967 = 1.81\ t/m^2$

$W_{dy} = 1.87 \times 0.033 = 0.06$ "

(c) Torsional coefficient

$$\varphi dx = \varphi dy = \frac{5}{18} \times \frac{3.70^2 \times 8.58^2}{3.70^4 + 8.58^4} = 0.050$$

(d) Bending moment

(i) At the support point

$$Mdx = -1/12 \times 1.81 \times 3.70^2 = -2.06^{tm}$$

$$Mdy = -1/24 \times 1.87 \times 3.70^2 = -1.07''$$

(ii) At the span center point

$$Mdx = 1/24 \times 1.81 \times 3.70^2 \times (1 - 0.050) = 0.98^{tm}$$

$$Mdy = 1/24 \times 0.06 \times 8.58^2 \times (1 - 0.050) = 0.17''$$

(2) Train Load (Single track)

(a) Sharing of load

$ldx = 3.98^m$ $ldy = 8.86^m$

Coefficient of load sharing in the direction of x or y

$$Cex = \frac{8.86^4}{3.98^4 + 8.86^4} = 0.961$$

$$Cey = \frac{3.98^4}{3.98^4 + 8.86^4} = 0.039$$

(b) Coefficient of load sharing

$W_{\ell+ix} = 3.45 \times 0.961 = 3.32$ t/m²

$W_{\ell+iy} = 3.45 \times 0.039 = 0.13$ "

(c) Torsional Coefficient

$$\varphi_x = \varphi_y = \frac{25}{36} \times \frac{3.98^2 \times 8.86^2}{3.98^4 + 8.86^4} = 0.135$$

(d) Bending moment

Train Load and Impact

(i) At the support point

$M_{\ell+ix} = -1/12 \times 3.32 \times 3.98^2 = -4.38$ tm

$M_{\ell+iy} = -1/24 \times 3.45 \times 3.98^2 = -2.28$ "

(ii) At the span center point

$M_{e+ix} = 1/12 \times 3.32 \times 3.98^2 \times (1 - 0.135) = 3.79$ tm

$M_{e+iy} = 1/12 \times 0.13 \times 8.86^2 \times (1 - 0.135) = 0.74$ "

(3) Combined moment

		Dead Load	Train Load and Impact	TOTAL
At the support point	x	− 2.06	− 4.38	− 6.44
	y	− 1.07	− 2.28	− 3.35
At the span center point	x	0.98	3.79	4.77
	y	0.17	0.74	0.91

Allowable stress, safe against cracking

$$\Sigma M \times 0.25 = 6.44 \times 0.25 = 1.61^{tm}$$

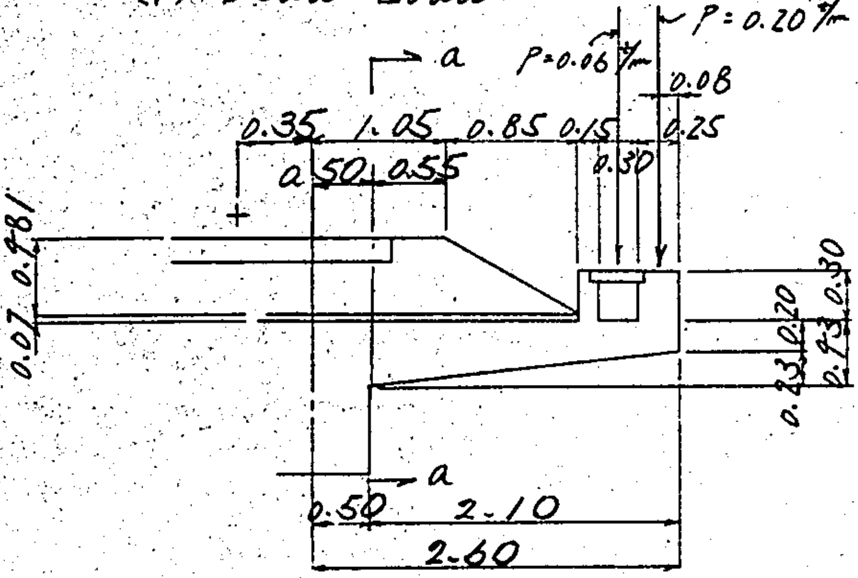
$$< M_{\ell+i} = 4.38^{tm}$$

Therefore $\sigma_{sa} = 800$ kg/cm²

[3] Calculation of Slab Ⓑ

1. Calculation of Cantilever Slab

(1) Dead Load



a-a section

	Calculation	N	x	N·x
handrail		0.20	2.02	0.40
curb	2.5 t/m³ × 0.30 × 0.25	0.19	1.975	0.38
Duct cover	2.5 " × 0.05 × 0.30	0.04	1.700	0.07
cable		0.06	1.700	0.10
ballast stopper	2.5 × 0.15 × 0.30	0.11	1.475	0.16
sloping concrete	2.35 × 0.07 × 1.40	0.23	0.700	0.16
bellast (A)	1.9 × 0.481 × 0.85 × 1/2	0.39	0.833	0.32
bellast (B)	1.9 × 0.481 × 0.55	0.50	0.275	0.14
Distributed load by Track Weight	0.45 × 1/2.86 × 0.58	0.09	0.290	0.03
Slab (A)	2.5 × 0.20 × 2.10	1.05	1.050	1.10
Slab (B)	2.5 × 0.23 × 2.10 × 1/2	0.60	0.700	0.42
TOTAL				3.28

(2) Pedestrian Load

$P = 0.50^{t/m^2} \times 0.50 = 0.25^{t}$

$M = 0.25 \times 1.61 = 0.40$

(3) Dead Load and Pedestrian Load

$Md+w = 3.28 + 0.40 = 3.68^{tm}$

(4) Train Load and Impact

$We = \frac{16}{1.5 \times 2.86} = 3.73^{t/m^2}$

$Me = 3.73 \times 0.58^2 \times 1/2 = 0.63^{tm}$

(a) Impact Coefficient

$l = 0.58^{m} \longrightarrow i = 0.587$

$Me+i = 0.63 \times (1 + 0.587) = 1.00^{tm}$

(b) Combined Stress

Dead Load + Train Load and Impact ($\alpha = 1.00$)

$M = 3.28 + 1.00 = 4.28^{tm} > 4.07^{tm}$

(c) Dead Load + Train Load and Impact
Pedestrian Load ($\alpha = 1.15$)

$M = (3.68 + 1.00) \times 1/1.15 = 4.07^{tm}$

Allowable stress, safe against cracking

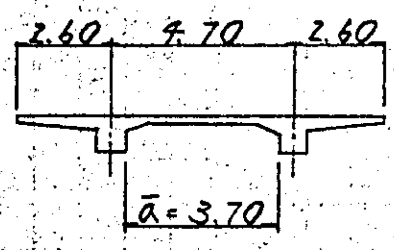
$M \times 0.25 = 4.28 \times 0.25 = 1.07^{tm} > M_{cri} = 1.00^{tm}$

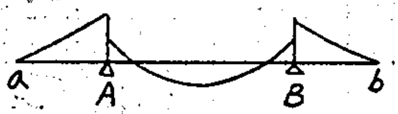
There fore $\sigma_{sa} = 1000\ ^{kg}/_{cm^2}$

	Ⓐ Slab				Ⓑ Slab	
	Direction of railway cross section		Direction of railway Profile		Cantilever slab	
	At support point	At span centerpoint	At support point	At span centerpoint		
M (tm)	(2.06) 2.44	4.77	−3.35	0.91	3.28	4.28
N (t)						
S (t)						
b (cm)	100	100	100	100	100	100
h (cm)	43	28	43	28	43	43
d (cm)	39.7	24.7	38.1	23.1	39.7	39.7
d' (cm)	3.3	3.3	4.9	4.9	3.3	3.3
As (cm^2)	D16−4 D13−4 (25 cm ctc) 13.01	D16−4 D13−4 (25 cm ctc) 13.01	D16−2.5 D13−2.5 (40 cm ctc) 8.13	D16−2.5 D13−2.5 (40 cm ctc) 8.13	D16−4 D13−4 (25 cm ctc) 13.01	D16−4 D13−4 (25 cm ctc) 13.01
p	0.00328	0.00527	0.00213	0.00352	0.00328	0.00328
As' (cm^2)						
p'						
e = M/N (cm)						
e = M/N + u (cm)						
e = M/N − u (cm)						
e/h						
d/e						
d'/h						
d'/d						
M/bd² (kg/cm²)	(1.31) 4.09	7.82	2.31	1.71	2.08	2.72
k						
c						
j						
1/Lc	8.19	6.88	9.69	7.97		8.19
1/Ls	335	213	506	313	335	335
β = σs/σc						
σc (kg/cm²)	33.5	53.8	22.4	13.6		22.2
σs (kg/cm²)	(440) 1,370	1,670	1,170	530	700	910
τ (kg/cm²)						
σsa (kg/cm²)	(800) 1,800	1,800	〃	〃	1,000	1,800
σca (kg/cm²)	90	90	〃	〃		90
τa (kg/cm²)						
combination	(D) D+T+I	D+T+I	〃	〃	D	D+T+I
Nomogram number	M−1	〃	〃	〃	〃	〃

3. Calculation of torsional moment of longitudinal beam (Calculation of main beam)

3-1. Torsional moment of main beam caused by the moment difference between both fixed ends





Torsional moment of beam A at support point

$$M_{TA} = \ell/2\,(m_A K_1 + m_B K_2)$$

Torsional moment of beam B at support point

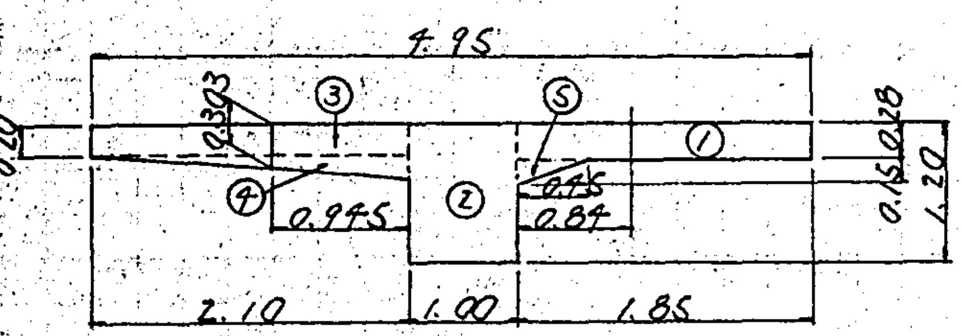
$$M_{TB} = \ell/2\,(m_A K_2 + m_B K_1)$$

Where,
$$K_1 = \frac{1 + \alpha}{1 + 2\alpha + 0.75\alpha^2}$$

$$K_2 = \frac{0.5\alpha}{1 + 2\alpha + 0.75\alpha^2}$$

$$\alpha = \frac{I_s \cdot \ell^2}{I_t \cdot \bar{a}}$$

3-2 Polar moment of inertia of cross sectional area of main



$It = \Sigma cab^3$

where

a: Length of longer side at each dividing point

b: Length of shorter side at each dividing point

c: Coefficient obtained from a/b

	a	b	a/b	c	$I_t = c \cdot a \cdot b^3$
①	0.840	0.280	3.000	0.263	$0.263 \times 0.840 \times 0.280^3 = 0.00485$
②	1.200	1.000	1.200	0.163	$0.163 \times 1.200 \times 1.000^3 = 0.19560$
③	0.945	0.303	3.119	0.266	$0.266 \times 0.945 \times 0.303^3 = 0.00699$
④					Omitted
⑤					〃
					$\Sigma I_t = 0.20744\ m^4$

$$I_s = \frac{1}{12} \times 1.000 \times 0.280^3 = 0.00183 \ m^4/m$$

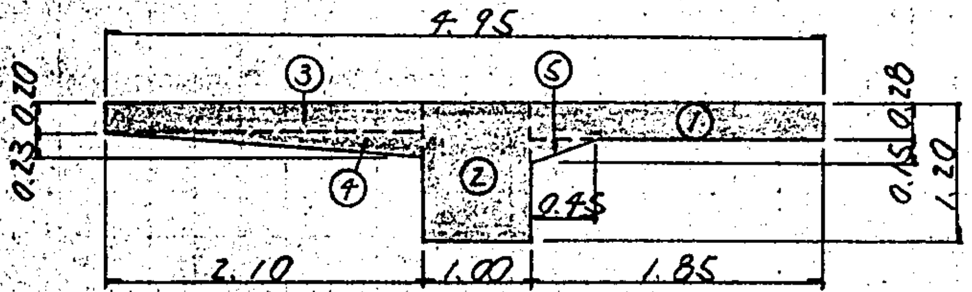
$$\bar{a} = 4.70 - 1.00 = 3.70^m$$

$$\alpha = \frac{0.00183 \times 9.30^2}{0.20744 \times 3.70} = 0.20622$$

$$K_1 = \frac{1 + 0.20622}{1 + 2 \times 0.20622 + 0.75 \times 0.20622^2} = 0.8351$$

$$K_2 = \frac{0.5 \times 0.20622}{1 + 2 \times 0.20622 + 0.75 \times 0.20622^2} = 0.0714$$

3-3 Moment of inertia of the area of main beam



	b (m)	h (m)	A (m²)	y (m)	A·y (m³)
①	1.850	0.280	0.5180	0.140	0.07252
②	1.000	1.200	1.2000	0.600	0.72000
③	2.100	0.200	0.4200	0.100	0.04200
④	2.100	1/2 × 0.230	0.2415	0.277	0.06690
⑤	0.450	1/2 × 0.150	0.0338	0.330	0.01115
Σ			2.4133		0.91257

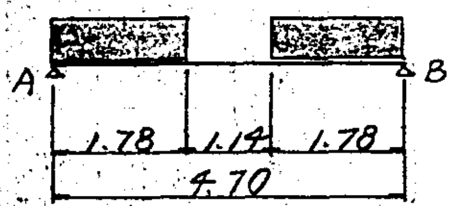
$$y = \frac{0.91257}{2.4133} = 0.378^{m}$$

	b (m)	h (m)	A (m²)	y_o (m)	I_o (m⁴)	$A \cdot y_o^2$ (m⁴)	$I_o + A \cdot y_o^2$ (m⁴)
①	1.850	0.280	0.5180	0.238	0.00338	0.02934	0.03272
②	1.000	1.200	1.2000	0.222	0.14400	0.05914	0.20314
③	2.100	0.200	0.4200	0.278	0.00140	0.03246	0.03386
④	2.100	1/2 × 0.230	0.2415	0.101	0.00071	0.00246	0.00317
⑤	0.450	1/2 × 0.150	0.0338	0.048	0.00004	0.00008	0.00012
Σ			2.4133		0.14953	0.12348	0.27301

Moment of Inertia $I = 0.27301^{m^4}$

3-4 Dead Load of torsional moment

(1) Equivalent uniformly distributed load at the span part



$w = 0.45\ t/m \times 1/2.86 = 0.16\ t/m^2$

$R_A = 0.16 \times 1.78 = 0.285^{t}$

$l/4$ Point

$M_{l/4} = 0.285 \times 1.175 - 1/2 \times 0.16 \times 1.175^2 = 0.22^{tm}$

$w_{l/4} = \dfrac{32 \cdot M_{l/4}}{3 \cdot l^2} = \dfrac{32 \times 0.22}{3 \times 4.70^2} = 0.11\ t/m^2$

Dead load Total

Track weight			= 0.11 t/m^2
Sloping Concrete	2.35 t/m^3	× 0.07	= 0.16 "
Slab	2.5 "	× 0.28	= 0.70 "
Ballast	1.9 "	× 0.481	= 0.91 "
			1.88 t/m^2

(2) Fixed end moment of span part

Load sharing of two-way slab

$$W_x = W_d \cdot C_x$$

$$C_x = \frac{l_y^4}{l_x^4 + l_y^4}$$

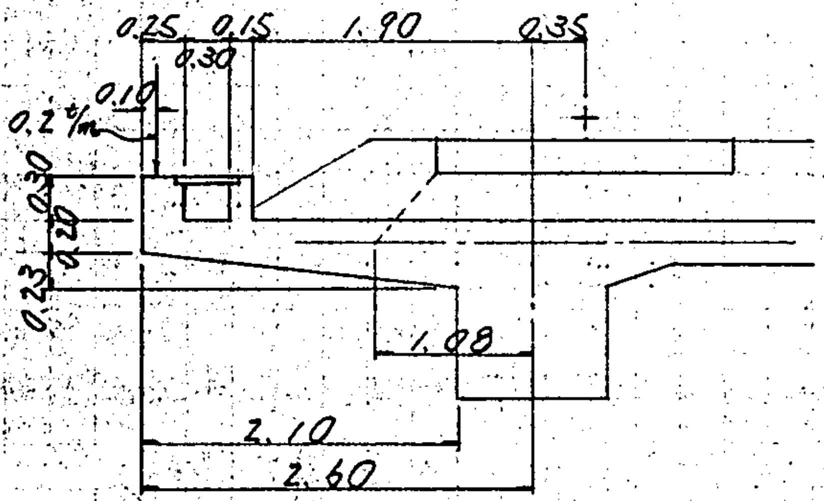
$$C_x = \frac{9.30^4}{4.70^4 + 9.30^4} = 0.939$$

$$W_x = 1.88\ t/m^2 \times 0.939 = 1.77\ t/m^2$$

$$M_x = \frac{1}{12} \times 1.77 \times 4.70^2 = 3.26\ ^{tm}$$

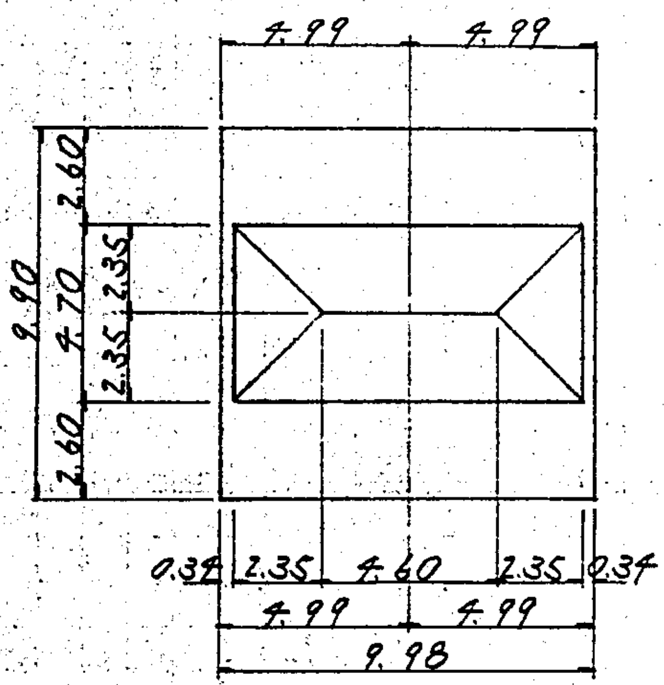
(3) Moment of cantilever slab

North side slab



	Calculation	N t/m	x m	N·x tm
hand rail		0.200	2.500	0.500
curb	2.5 t/m³ × 0.25 × 0.30	0.188	2.475	0.465
ballast stopper	2.5 " × 0.15 × 0.30	0.113	1.975	0.223
duct lib	2.5 " × 0.05 × 0.30	0.038	2.200	0.084
cable		0.060	2.200	0.132
Track weight	0.45 t/m × $\frac{1}{2.86}$ × 1.08	0.170	0.540	0.092
ballast	1.9 t/m³ × 0.481 × 1.90	1.736	0.950	1.649
Sloping concrete	2.35 " × 0.07 × 1.90	0.313	0.950	0.297
Slab	2.5 " × 0.20 × 2.60	1.300	1.300	1.690
"	2.5 " × 0.23 × 2.10 × 1/2	0.604	1.200	0.725
total		4.72		5.86

3-5 Torsional moment caused by dead load



Find the difference of end moment between both fixed ends

Cantilever slab $\frac{l}{2} M_{Aa} = -5.86 \times 4.65 = -27.25^{tm}$

intermediate slab $\frac{l}{2} M_{AB} = 3.26 \times (2.30 + 1/2 \times 2.35) = 11.33$ "

$$\frac{l}{2} m_A = \frac{l}{2}(M_{Aa} + M_{AB}) = -27.25 + 11.33 = -15.92^{tm}$$

Torsional moment at the support point

$$M_{TA} = \frac{l}{2}(m_A K_1 + m_B K_2)$$

$$= -15.92 \times 0.8351 + 15.92 \times (-0.0714) = -14.43^{tm}$$

Torsional moment caused by train load

Find the bending moment at $l/4$ point of $l = 9.30^m$.

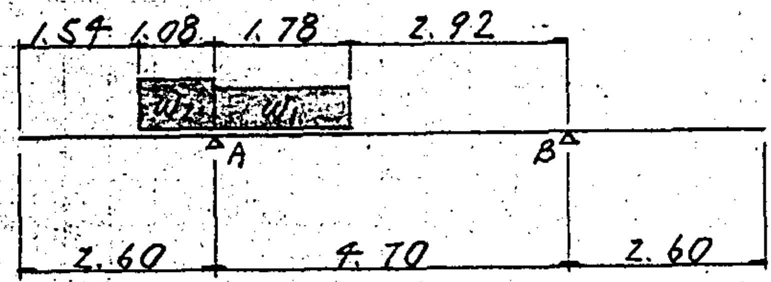
$M_b = 44.44 \times 2 \times 16/18 = 79.00^{tm}$ (per one track)

Equivalent uniformly distributed load at $l/4$ point.

$$w = \frac{32 \cdot M_b}{3 \cdot l^2}$$

$$= \frac{32 \times 79.00}{3 \times 9.30^2} = 9.74\ t/m$$

KS-16 single track loading



$$w = \frac{9.74}{2.86} = 3.41\ t/m^2$$

impact coefficient

$l = 4.70^m \quad i = 0.487 \times (1 - \frac{4.70}{200}) = 0.476$

$l = 1.08^m \quad i = 0.574 \times (1 - \frac{1.08}{200}) = 0.571$

$w_{1\,l+i} = 3.41 \times (1 + 0.476) = 5.03\ t/m$

$w_{2\,l+i} = 3.41 \times (1 + 0.571) = 5.36$ "

$$M_{AB} = \frac{5.03 \times 1.78}{12 \times 4.70^2} \times (6 \times 2.92^2 + 4 \times 2.92 \times 1.78 + 1.78^2) = 2.53^{tm}$$

$$M_{BA} = \frac{5.03 \times 1.78^3}{12 \times 4.70^2} \times (4 \times 2.92 + 1.78) = -1.44$$

$$M_{Aa} = 1/2 \times 5.36 \times 1.08^2 = -3.12$$

Cantilever Slab $\frac{l}{2} M_{Aa} = -3.12 \times 4.65 = -14.51^{tm}$

Intermediate Slab $\frac{l}{2} M_{AB} = 2.53 \times (2.30 + 1/2 \times 2.35) = 8.79$ "

" $\frac{l}{2} M_{BA} = -1.44 \times (2.30 + 1/2 \times 2.35) = -5.00$ "

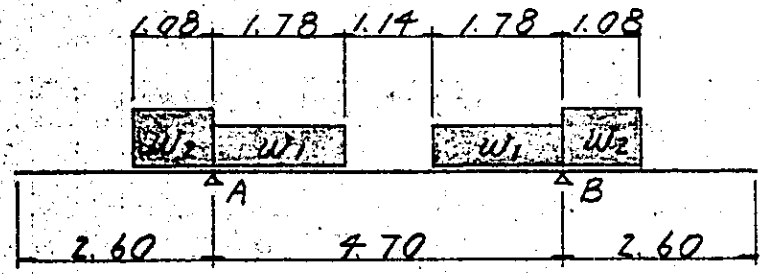
$$\frac{l}{2} m_A = -14.51 + 8.79 = -5.72^{tm}$$

$$\frac{l}{2} m_B = -5.00^{tm}$$

$$M_{TA} = -5.72 \times 0.8351 - 5.00 \times (-0.0714) = -4.42^{tm}$$

$$M_{TB} = -5.72 \times (-0.0714) - 5.00 \times 0.8351 = -3.77^{tm}$$

KS-16 double track loading



$w_{1\,l+i} = 5.03\ t/m$

$w_{2\,l+i} = 5.36$ "

$M_{Aa} = 1/2 \times 5.36 \times 1.08^2 = -3.13\ tm$

$M_{AB} = \dfrac{5.03 \times 1.78}{6 \times 4.70} \times (3 \times 4.70 - 2 \times 1.78) = 3.35$ "

Cantilever Slab $\frac{l}{2} M_{Aa} = -3.13 \times 4.65 = -14.55\ tm$

Intermediate Slab $\frac{l}{2} M_{AB} = 3.35 \times (2.30 + 1/2 \times 2.35) = 11.64$ "

$\frac{l}{2} m_A = -14.55 + 11.64 = -2.91\ tm$

$M_{TA} = -2.91 \times 0.8351 + 2.91 \times (-0.0714) = -2.64\ tm$

$M_{TB} = -2.91 \times (-0.0714) + 2.91 \times 0.8351 = 2.64$ "

3-6 Torsional moment of main beam caused by eccentric loading

$$M_T = \frac{P \cdot e}{2 \cdot n} \cdot \frac{\frac{G}{E} \cdot \frac{1}{n^2-1} \cdot \left(\frac{\ell}{\lambda}\right)^2 \cdot \frac{I_t}{I}}{1 + \frac{G}{E} \cdot \frac{1}{n^2-1} \cdot \left(\frac{\ell}{\lambda}\right)^2 \cdot \frac{I_t}{I}}$$

$I_t = 0.20744\ m^4$

$I = 0.27301$ "

$$K = \frac{1}{1 + \frac{G}{E} \cdot \frac{1}{n^2-1} \cdot \left(\frac{\ell}{\lambda}\right)^2 \cdot \frac{I_t}{I}}$$

$$= \frac{1}{1 + 0.43 \times \frac{1}{3} \times \left(\frac{9.30}{4.70}\right)^2 \times \frac{0.20744}{0.27301}}$$

$$= \frac{1}{1.42641} = 0.7011$$

$$M_T = \frac{P \cdot e}{2 \cdot n} \cdot (1 - K)$$

$$= \frac{P \cdot e}{4} \cdot (1 - K)$$

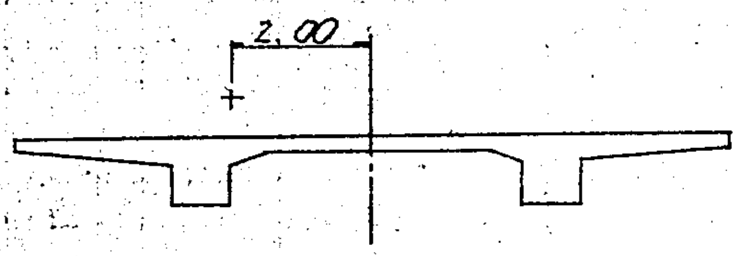
(1) Eccentric moment caused by dead load

Eccentricity

$e = 0^m$

(2) Eccentric moment caused by train load

KS-16 Single track loading



$w_e = 9.74\ ^t/m$

$e = 2.00^m$

$l = 9.30^m$ —— $i = 0.437 \times (1 - \frac{9.30}{200}) = 0.417$

$P = 9.74 \times 1.417 = 13.80\ ^t/m$

$M_T = \frac{13.80 \times 2.00}{4} \times (1 - 0.7011) \times 9.30$

$= 19.28^{tm}$

Train lateral load

$$S = \frac{4Q}{l} \qquad Q = 16.0 \times 0.15 = 2.40^{t}$$

Therefore, the equivalent uniformly distributed load will be

$$S = \frac{4 \times 2.40}{9.30} = 1.03\ ^{t}/_{m}$$

$$e = \frac{W_{l+i} \cdot e + S \cdot y_s}{W_{l+i}}$$

$$y_s = 0.710^{m}$$

Single track loading

$$e = \frac{13.80 \times 2.00 + 1.03 \times 0.710}{13.80} = 2.053^{m}$$

double track loading

$$e = \frac{13.80 \times 2 \times 0 + 1.03 \times 0.710}{13.80 \times 2} = 0.026^{m}$$

a) Single track loading

$$M_T = \frac{13.80 \times 2.053}{4} \times (1 - 0.7011) \times 9.30 = 19.69^{tm}$$

b) double track loading

$$M_T = \frac{27.60 \times 0.026}{4} \times (1 - 0.7011) \times 9.30 = 0.50^{tm}$$

Summary of torsional moment

Dead load

$M_{TA} = -14.43$ tm

$M_{TB} = 14.43$ "

KS-16 Single track loading

$M_{TA} = -4.42 - 19.28 = -23.70$ tm

$M_{TB} = -3.77 - 19.28 = -23.05$ "

KS-16 double track loading

$M_{TA} = -2.64$ tm

$M_{TB} = 2.64$ "

Train load and Train laterel load

KS-16 Single track loading

$M_{TA} = -4.42 - 19.69 = -24.11$ tm

$M_{TB} = -3.77 - 19.69 = -23.46$ "

KS-16 double track loading

$M_{TA} = -2.64 - 0.50 = -3.14$ tm

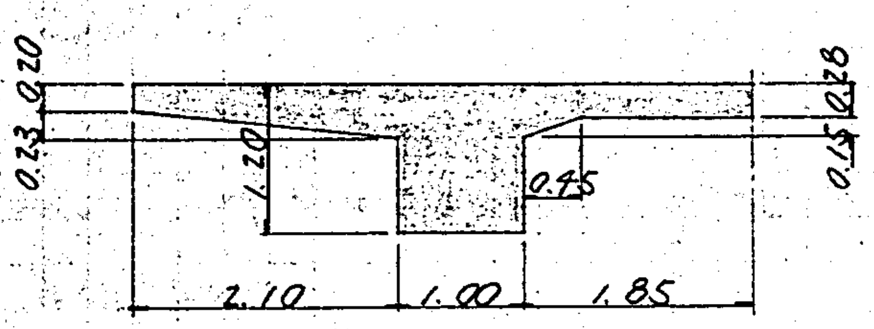
$M_{TB} = 2.64 - 0.50 = 2.14$ "

3-7 Design of main beam

Calculation of loads and load acting point

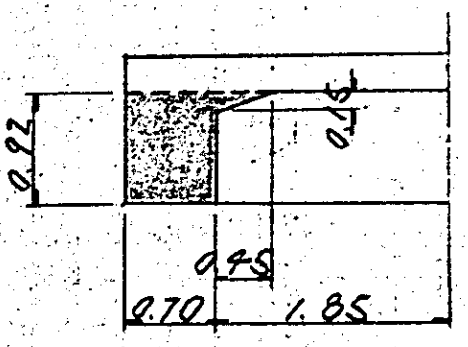
1. Dead load

(A) Own weight of main beam and slab



$$W_{d1} = 2.5 \times \{(0.20 + 0.43) \times 1/2 \times 2.10 + 1.00 \times 1.20 + 0.28 \times 1.85 + 0.45 \times 0.15 \times 1/2\} = 6.03\ t/m$$

(B) Cross beam



$$W_{d2} = 2.5 \times (1.85 \times 0.92 + 0.45 \times 0.15 \times 1/2) = 4.34\ t/m$$

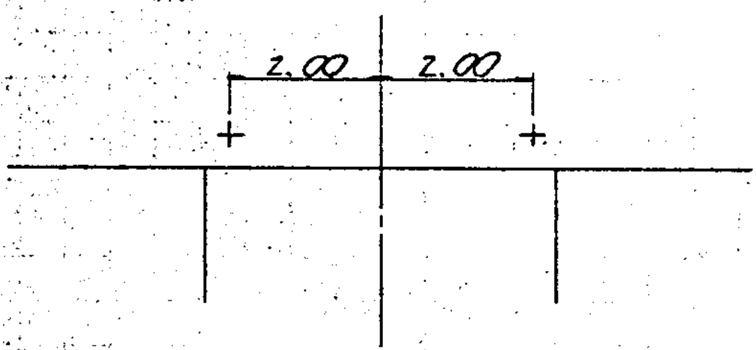
(c) Loads on slab

Track weight		=	0.450 t/m
ballast	1.9 t/m³ × 0.481 × 4.25	=	3.884 〃
sloping concrete	2.35 〃 × 0.07 × 4.25	=	0.699 〃
handrail		=	0.200 〃
curb	2.5 〃 × 0.25 × 0.30	=	0.188 〃
ballast stopper	2.5 〃 × 0.15 × 0.30	=	0.113 〃
duct cover	2.5 〃 × 0.05 × 0.30	=	0.038 〃
cable		=	0.060 〃
			5.63 t/m

Total of beam weight and loads on slab

$\Sigma W_d = 6.03 + 5.63 = 11.66$ t/m

2. Train load and Impact



$\ell_1 = 2.00^m$ (Single track loading)

$\ell_2 = 0^m$ (Double track loading)

3. Impact coefficient

For the case of double track loading, reduction of impact coefficient is applied as calculated by the following formula.

Span $\ell = 9.30^m$ $i_0 = 0.437$

$$i = i_0 \times \left(1 - \frac{\ell}{200}\right)$$

$$= 0.437 \times \left(1 - \frac{9.30}{200}\right) = 0.417$$

Sharing of load

$$w_i = \frac{P}{n}\left[1 + \frac{b(n+1-2i)}{n^2-1} \cdot \frac{e}{\lambda} \cdot \frac{1}{1 + \frac{G}{E_c} \cdot \frac{1}{n^2-1}\left(\frac{\ell}{\lambda}\right)^2 \cdot \frac{I_t}{I}}\right]$$

From the above equation, loads beared by beam A and beam B are calculated as follows.

beam A

$$W_A = \frac{P}{n}\left[1 + \frac{2 \cdot e}{\lambda} \cdot \frac{1}{1 + \frac{G}{E_c} \cdot \frac{1}{n^2-1}\left(\frac{\ell}{\lambda}\right)^2 \cdot \frac{I_t}{I}}\right]$$

beam B

$$W_B = \frac{P}{n}\left[1 - \frac{2 \cdot e}{\lambda} \cdot \frac{1}{1 + \frac{G}{E_c} \cdot \frac{1}{n^2-1}\left(\frac{\ell}{\lambda}\right)^2 \cdot \frac{I_t}{I}}\right]$$

Train load (Single track loading)

beam A

$$W_A = \frac{1}{2} \times \left[1 + \frac{2 \times 2.00}{4.70} \times \frac{1}{1 + 0.43 \times \frac{1}{2^2 - 1} \times \left(\frac{9.30}{4.70} \right)^2 \times \frac{0.20744}{0.27301}} \right]$$

$$= 0.50 \times \left[1 + 0.8511 \times \frac{1}{1.42641} \right]$$

$$= 0.7983$$

beam B

$$W_B = 0.50 \times \left[1 - 0.8511 \times \frac{1}{1.42641} \right]$$

$$= 0.2017$$

Train load (double track loading)

beam A

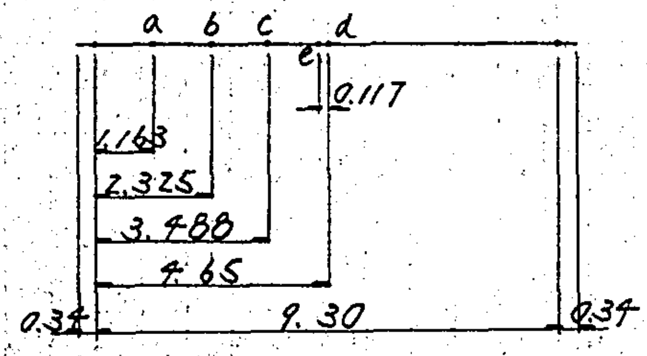
$$W_A = 0.500$$

beam B

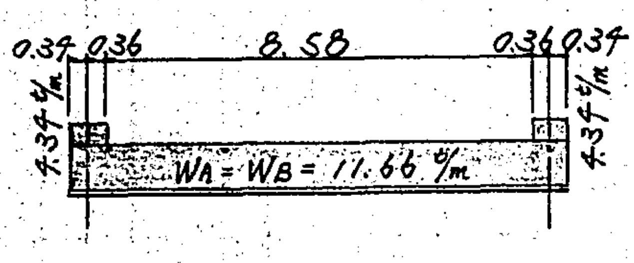
$$W_B = 0.500$$

Calculation of sectional forces

Calculation of bending moment



(A) Dead load



$$M_a = \frac{7}{128} \times 11.66 \times 9.30^2 = 55.15^{tm}$$

$$M_b = \frac{3}{32} \times 〃 \times 〃 = 94.54 〃$$

$$M_c = \frac{15}{128} \times 〃 \times 〃 = 118.18 〃$$

$$M_d = \frac{1}{8} \times 〃 \times 〃 = 126.06 〃$$

$$M_e = 1/2 \times 11.66 \times (1/2 \times 9.30 - 0.117) \times (1/2 \times 9.30 + 0.117) = 125.98^{tm}$$

Cross beam

$R_A = 4.34 \times 0.36 = 1.56^{t}$

$M_a = 1.56 \times 1.163 - 4.34 \times 0.36 \times 0.983 = 0.28^{tm}$

$M_b = 1.56 \times 2.325 - 4.34 \times 0.36 \times 2.145 = 0.28$ "

$M_c = 1.56 \times 3.488 - 4.34 \times 0.36 \times 3.308 = 0.27$ "

$M_d = 1.56 \times 4.65 - 4.34 \times 0.36 \times 4.47 = 0.27$ "

Train load and Impact

Double track loading (beam A = beam B)

$M_a = 27.22 \times 2 \times 16/18 = 68.57$ tm

$M_b = 44.44 \times$ 〃 $\times$ 〃 $= 111.95$ 〃

$M_c = 55.54 \times$ 〃 $\times$ 〃 $= 139.91$ 〃

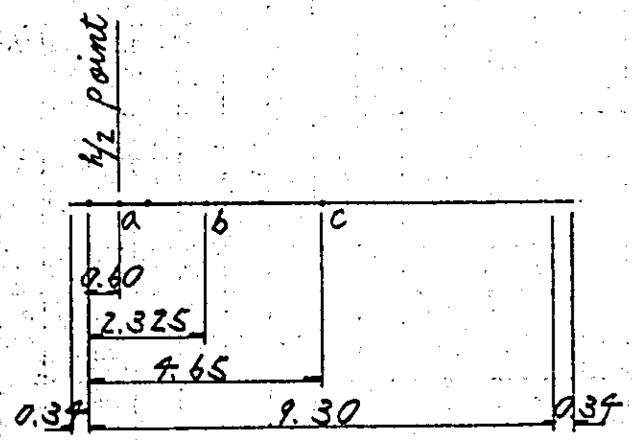
$M_d = 58.39 \times$ 〃 $\times$ 〃 $= 147.09$ 〃

$M_e = 58.45 \times$ 〃 $\times$ 〃 $= 147.24$ 〃

Summary of bending moment

	Ma	Mb	Mc	Md	Me
Dead load	55.15	94.54	118.18	126.06	125.98
Cross beam	0.28	0.28	0.27	0.27	0.27
Train load and Impact	68.57	111.95	139.91	147.09	147.24
Total	124.00	206.77	258.36	273.42	273.49

Calculation of bending shear



(A) Dead load

$R_A = 11.66 \times 4.65 + 4.34 \times 0.36 \quad = 55.78^t$

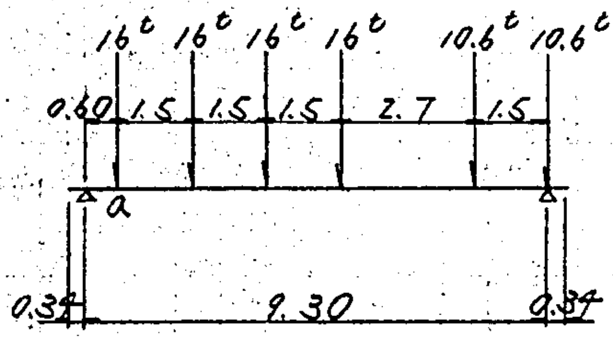
$S_a = 55.78 - (4.34 \times 0.36 + 11.66 \times 0.60) = 47.22$ "

$S_b = 55.78 - (4.34 \times 0.36 + 11.66 \times 2.325) = 27.11$ "

$S_c = 0$

(B) Train load and Impact (KS-16)

(a) Calculation at point a



$$Sa = \frac{16 \times 4 \times 6.45 + 10.6 \times 1.5}{9.30} \times 1.417 = 65.32^t$$

single track loading $65.32 \times 0.7983 = 52.14^t$

double track loading $65.32 \times 1.00 = 65.32^t$

(b) Calculation at point b

$$Sb = 18.35 \times 2 \times 16/18 \times 1.417 = 46.23^t$$

single track loading $46.23 \times 0.7983 = 36.91^t$

double track loading $46.23 \times 1.00 = 46.23^t$

(c) Calculation at point C

$$S_c = 13.28 \times 2 \times 16/18 \times 1.417 = 33.45^t$$

single track loading $33.45 \times 0.7983 = 26.70^t$

double track loading $33.45 \times 1.00 = 33.45^t$

(d) Summary of bending shear

	S_a	S_b	S_c
Dead load	47.22	27.11	0
Train load and Impact load (single track loading)	52.14	36.91	26.70
〃 (double track loading)	65.32	46.23	33.45
Dead load and Train (single track loading)	99.36	64.02	26.70
〃 (double track loading)	112.54	73.34	33.45

Stress Calculation

Effective width Calculation

$$be = b_o + 2(bs + \lambda)$$

$$\lambda = 1/8 \times 9.30 = 1.163^m$$

$$bs = 0.15^m$$

$$\therefore be = 1.00 + 2(0.15 + 1.163) = 3.626^m$$

M (tm)	273.49		
N (t)			
S (t)			
b (cm)	362.6		
h (cm)	120		
d (cm)	110.6		
d' (cm)	9.4		
As (cm²)	D32 < 9 11 158.84		
p	0.00396		
As' (cm²)			
p'			
e=M/N (cm)			
e=M/N+u (cm)			
e=M/N−u (cm)			
e/h			
d/e			
d'/h			
d'/d			
Ne/bd² (kg/cm²)			
k	0.293		
c			
j	0.906		
1/Lc			
1/Ls			
β=σs/σc			
σc (kg/cm²)	47.4		
σs (kg/cm²)	1720		
τ (kg/cm²)			
σsa (kg/cm²)	1800		
σca (kg/cm²)	90		
τa (kg/cm²)			
number	M-47, 48		
combination	D+L		

3-6 Shearing stress

(A) Double track loading

1. Bending shearing stress

$$\tau_b = \frac{S}{b \cdot d}$$

$b = 100^{cm}$, $d = 110.6^{cm}$

At the 1/2 H point from the support (point a)

$S_a = 112.54^{t}$

$$\tau_a = \frac{112.54 \times 10^3}{100 \times 110.6} = 10.18 \ kg/cm^2 > 3.9 \ kg/cm^2$$

(point b)

$S_b = 73.34^{t}$

$$\tau_b = \frac{73.34 \times 10^3}{100 \times 110.6} = 6.63 \ kg/cm^2 > 3.9 \ kg/cm^2$$

(point c)

$S_c = 33.45^{t}$

$$\tau_c = \frac{33.45 \times 10^3}{100 \times 110.6} = 3.02 \ kg/cm^2 < 3.9 \ kg/cm^2$$

2. Torsional shearing stress

$$\tau_{t1} = \frac{M_t}{K_2 \cdot h_0 \cdot b_0^2}$$

$h_0 = 120^{cm}$, $b_0 = 100^{cm}$

Coefficient of share of main beam

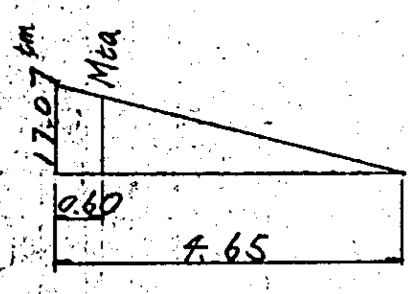
$\Sigma I_t = 0.20744\ m^4$

$$\alpha = \frac{0.19560}{0.20744} = 0.9429$$

At the 1/2 H point from the support (point a)

$M_{ta} = M_{td} + M_{tl}$

$= -14.43 - 2.64 = -17.07^{tm}$



$$M_{ta} = \frac{(4.65 - 0.60)}{4.65} \times 17.07 = 14.88^{tm}$$

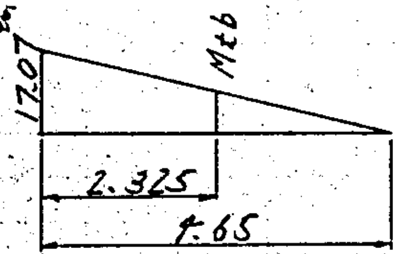
$\therefore M_{ta} = 14.88 \times 0.9429 = 14.03^{tm}$

$K_1 = 0.219$, $K_2 = 0.930$

$$\tau_{ta1} = \frac{14.03 \times 10^5}{0.219 \times 120 \times 100^2} = 5.34\ kg/cm^2 > 3.9\ kg/cm^2$$

$$\tau_{ta2} = 5.34 \times 0.930 = 4.97\ '' > ''$$

(point b)



$$Mtb = \frac{(4.65 - 2.325)}{4.65} \times 17.07 = 8.54\ tm$$

$$\therefore Mtb = 8.54 \times 0.9429 = 8.05\ ''$$

$$K_1 = 0.219$$

$$K_2 = 0.930$$

$$\tau_{tb1} = \frac{8.05 \times 10^5}{0.219 \times 120 \times 100^2} = 3.06\ kg/cm^2 < 3.9\ kg/cm^2$$

$$\tau_{tb2} = 3.06 \times 0.930 = 2.85\ '' < ''$$

At the center point (point c)

$$Mt = 0\ tm$$