Appendix A Materials of Lectures and Seminars

A-2 Structural Analysis General

Lecture on Structural Analysis General

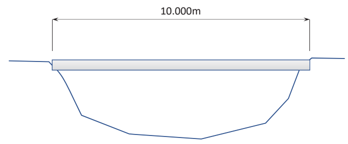
Lecture 01
Introduction
Design of simple span bridge

1. Introduction

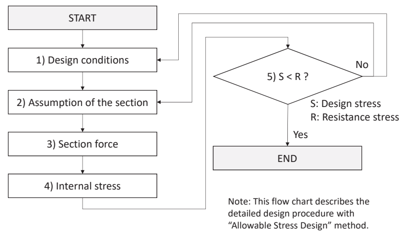
- Purpose of the lecture
  - Instruction of the structural analysis software MIDAS
  - Tips for the design of the bridge/structures
  - Basic lesson for the structural design
- Outline of the lecture
  - Design of simple span bridge
  - Design of 2-span bridge
  - Design of frame structure (truss bridge)
  - Basic lecture on presentation and other software
  - Others

2. Design of simple span bridge

- Question: If you are asked to design 10m bridge over small dimple, how do you design this? (superstructure only)



Tips1. Design procedure



1) Design conditions -1

- Subject for the design conditions
  - Which Standards do you apply?
  - Which materials do you use?
  - Which loads do you consider?
  - Which geometrical (road) conditions do you apply?
  - Which natural conditions do you consider?
  - Which conditions for the construction of the bridge do you consider?
- Structural designers should describe these conditions before starting structural analysis.

1) Design conditions -2

- Design Standard
  - In this lecture, Standards for Highway Bridges (JSHB) is applied.
  - Allowable Stress Method (ASD) is applied.
- Materials
  - Concrete: σ_{ck}=24N/mm^2
  - Reinforcing bar (rebar): SD345

  Note: Description of the strength of these materials is preferable.

1) Design conditions -3

Allowable stress of concrete

Item		Value (N/mm^2)
Design strength of concrete		24
Allowable compressive stress	Flexural compressive stress	8.0
	Axial compressive stress	6.5
Allowable shear stress	Concrete only	0.23
	Concrete with diagonal rebar	1.7
	Punching shear stress	0.90
Allowable bond stress for deformed bar		1.6
Young's modulus		2.5x10^4

1) Design conditions -4

Allowable stress of rebar (SD345)

Item			Value (N/mm^2)
Tensile stress	Principal loads w/o live load and impact		100
	Combination of load w/o collision load or earthquake load	General members	180
		Floor slab and slab bridges w/ a span of 10m or less	140
	Combination of load w/ collision load or earthquake load		200
	Value for calculation of lap joint length or bond length		200
Compressive stress			230
Young's modulus			2.0x10^5

1) Design conditions -5

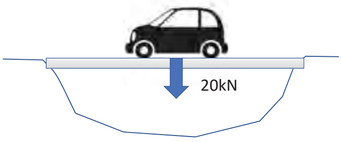
- Loads
  - Dead load (self weight)

Material	Unit weight (kN/m³)
Steel	77.0
Cast iron	71.0
Reinforced concrete	24.5
Prestressed concrete	24.5
Concrete	23.0
Cement mortar	21.0
Pitch (for waterproofing)	11.0
Asphalt	22.5

1) Design conditions -6

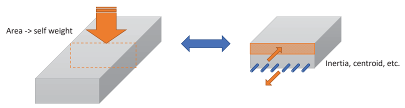
- Loads (cont.)
  - Live load

To simplify the question, a passenger car with 20kN (2.0t) weight is assumed for live load.



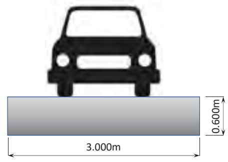
2) Assumption of the section -1

- This is one of the most important procedures in structural design, for the designers cannot conduct structural analysis without "dead load" and "rigidity" after determination of the section.

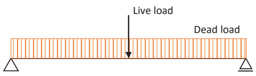


2) Assumption of the section -2

- Assume the girder as reinforced concrete slab
- 3.0m width and 0.6m depth without pavement, curb and guardrail.



3) Section force -1



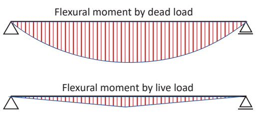
Dead load

$q=24.5 \times 3.0 \times 0.6 = 44.1$ (kN/m)

Live load

$P=20.0$ (kN)

3) Section force -2



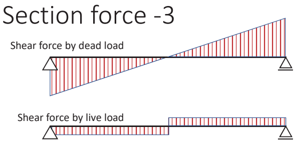
Max. value of flexural moment

Dead load $M_{DL} = \frac{ql^2}{8} = \frac{44.1\times10^2}{8} = 551.25$ (kNm)

Live load $M_{LL} = \frac{Pl}{4} = \frac{20\times10}{4} = 50.00$ (kNm)

$M_{DL} + M_{LL} = 551.25+50.00 = 601.25$ (kNm)

3) Section force -3



Max. value of shear force

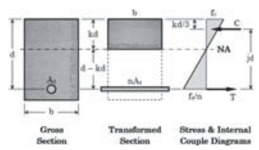
Dead load $S_{DL}=\frac{ql}{2} = \frac{44.1\times10}{2} = 220.5$ (kN)

Live load $S_{LL}=\frac{P}{2} = \frac{20}{2} = 10.0$ (kN)

$S_{DL}+S_{LL} = 220.5 + 10.0 = 230.5$ (kN)

4) Internal stress -1

- Reinforced concrete analysis
  - ➢Determination of diameter and nos of rebar (=As)



https://www.mathalino.com/reviewer/reinforced-concrete-design/working-stress-analysis-concrete-beams

4) Internal stress -2

Identity formula C = T

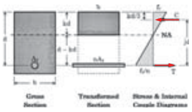
$$\sigma_c = \frac{2M}{kbjd^2}, \sigma_s = \frac{M}{A_s jd}$$

Here,

$$k = \sqrt{2np + (np)^2} - np$$

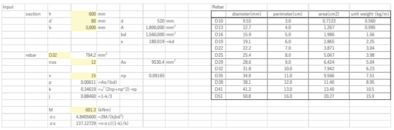
$$p = \frac{A_s}{bd}$$

$$j = 1 - \frac{k}{3}$$



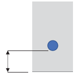
4) Internal stress -3

Please check the Excel spreadsheet "rc_section.xlsx"



Tips2. Concrete cover

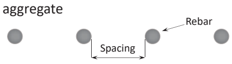
- Function of concrete cover (JSHBIII 6.6)
  - Necessary bond between concrete and rebar
  - Prevention of steel corrosion
  - Protection of the steel against fire
- Minimum concrete cover for superstructure



Member type		Minimum cover (mm)
Floor slab, curb, railing, slab bridge w/ a span of less than 10m		30
Girder	Factory-made prestressed concrete structure	25
	Girders other than named above, and slab bridges w/ a span exceeding 10m	35

Tips3. Rebar pitches -1

- Minimum pitch (JSHB IV 7.5)
  - Workability (concrete can spread fully around the bars and make it possible to compact the concrete firmly)
  - Adequate bond between concrete and rebar
  - ➢Larger than 40mm and 4/3 times the maximum size of coarse aggregate



Example: Use 25mm coarse aggregate
4/3 x 25 = 33.3mm < 40mm

Tips3. Rebar pitches -2

- Minimum amount of rebar (JSHB III 6.4)
  - The cross-sectional area of main axial tensile reinforcement placed in a reinforced concrete structure shall be determined in accordance with Equation;

$$A_{st} \geq 0.005 b_w \cdot d$$

- Ductile fracture and brittle fracture

4) Internal stress -3

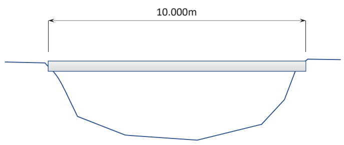
- Shear stress

$$\tau_m = \frac{S_n}{bd} = \frac{230{,}500}{3{,}000 \times 600} = 0.128 < 0.23$$

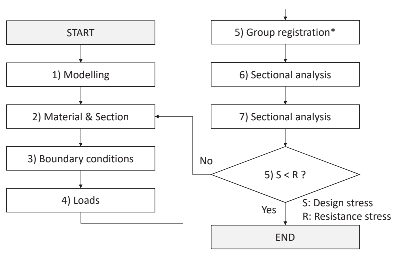
➢No need to arrange the diagonal rebar

3. Design of simple span bridge with analysis program MIDAS

- Question: If you are asked to design 10m bridge over small dimple, how do you design this? (superstructure only)



Tips4. Analysis procedure



1) Modelling

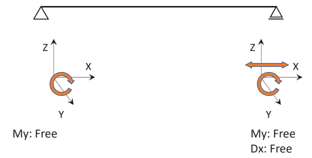
- Node
  - [Node/Element] -> [Nodes] -> [Create Nodes]
- Element
  - [Element] -> [Create Elements]

2) Material & Section

- Material
  - [Properties] -> [Material Properties]
- Section

3) Boundary conditions

- Boundary conditions



4) Loads

- “Load Case”
  - [Load] -> [Load Type -> Static Load] -> [Static Load Cases]
- Self Weight
  - [Structure Loads/Masses] -> [Self Weight]
  - Select elements with Z=-1 and “Add”
- Live load (as concentrate load at node)

5) Group registration

- “Group Type”
  - [Tree Menu] -> [Group]tab
  - Structure Group, Boundary Group, Load Group, etc.
- Characteristic function of MIDAS

6) Perform analysis

- Perform analysis

Practice 1

- Design the same bridge with thinner depth of concrete girder
- Pitch of rebar can be used @125mm

Practice 2

- Design 12.0m long bridge with 5.0m width
- Live load is 50kN (single)

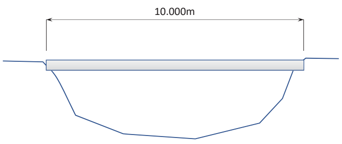
Lecture on Structural Analysis General

Lecture 02

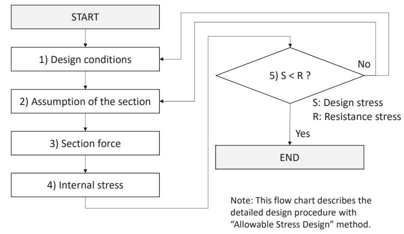
Design of simple span bridge with shaped steel

1. Design of simple span bridge with shaped steel

- Question: If you are asked to design 10m bridge over small dimple using shaped steel, how do you design this? (superstructure only)



Tips1. Design procedure



1) Design conditions -1

- Design Standard
  - In this lecture, Standards for Highway Bridges (JSHB) is applied.
  - Allowable Stress Method (ASD) is applied.
- Materials
  - Steel: SM400
  - Concrete: σ_{ck}=24N/mm^2
  - Reinforcing bar (rebar): SD345

  Note: Description of the strength of these materials is preferable.

1) Design conditions -2

Allowable stress of steel (SM400)

Item		Value (N/mm^2)
Allowable tension stress and flexural tension stress	Thickness less than 40mm	140
	Thickness over 40mm	125
Allowable flexural compression stress w/o considering buckling	Thickness less than 40mm	140
	Thickness over 40mm	125
Allowable shear stress	Thickness less than 40mm	80
	Thickness over 40mm	75

1) Design conditions -3

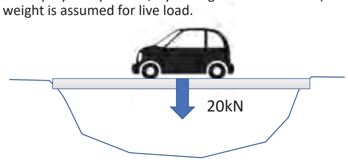
- Loads
  - Dead load (self weight)

Material	Unit weight (kN/m^3)
Steel	77.0
Cast iron	71.0
Reinforced concrete	24.5
Prestressed concrete	24.5
Concrete	23.0
Cement mortar	21.0
Pitch (for waterproofing)	11.0
Asphalt	22.5

1) Design conditions -4

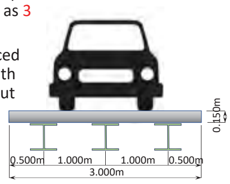
- Loads (cont.)
  - Live load

  To simplify the question, a passenger car with 20kN (2.0t) weight is assumed for live load.



2) Assumption of the section -1

- Assume the girder as shaped steel H-300x300x10x15 as 3 main beam
- Slab is made by reinforced concrete with 3.0m width and 0.15m depth without pavement, curb and guardrail.

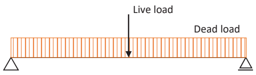


2) Assumption of the section -2

- Characteristics of shaped steel H-300x300x10x15

A = 118.4cm²
I = 20200cm⁴
W = 93kg/m

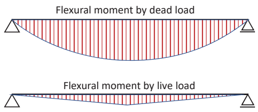
3) Section force -1



Dead load
q_{slab} = 24.5 x 3.0 x 0.15 = 11.03 (kN/m)
q_{girder} = 93 x 9.8 x 3 = 2734.2(N/m) = 2.73 (kN/m)
Σq = 11.03 + 2.73 = 13.76 (kN/m)
Live load
P=20.0 (kN)

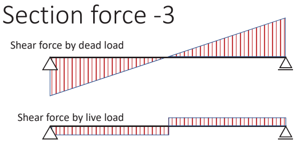
[Structural Analysisi General_L02]

3) Section force -2



Max. value of flexural moment
Dead load $M_{DL} = \frac{ql^2}{8} = \frac{13.76\times10^2}{8}$ =172.0 (kNm)
Live load $M_{LL} = \frac{Pl}{4} = \frac{20\times10}{4}$ =50.00 (kNm)
$M_{DL} + M_{LL}$ = 172.0+50.00 = 222.0 (kNm)

3) Section force -3



Max. value of shear force
Dead load $S_{DL} = \frac{ql}{2} = \frac{13.76\times10}{2}$ = 68.8 (kN)
Live load $S_{LL} = \frac{P}{2} = \frac{20}{2}$ =10.0 (kN)
$S_{DL}+S_{LL}$ = 68.8 + 10.0 =78.8 (kN)

[Structural Analysisi General_L02]

4) Internal stress

- Tension and compression stress of beam

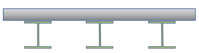
$\sigma_{u,l} = \frac{M}{I}y = \frac{222.0/3\times10^6}{20200\times10^4}\times 150 = 54.95$(N/mm²) < 140 N/mm²

- Shear stress

$\tau = \frac{S}{A} = \frac{78.8\times10^3/3}{118.4\times10^2}$ = 2.22 (N/mm²) < 80 N/mm²

Tips5. multiply and/or divide

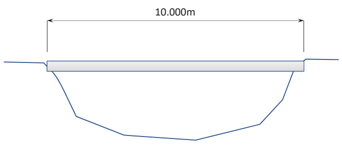
- Structural engineer tend to forget to multiply and/or divide the numbers of the same structures when she or he conduct the structural analysis and/or cost estimate



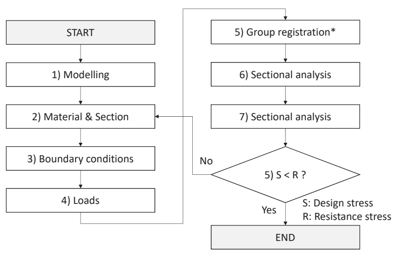
[Structural Analysisi General_L02]

2. Design of simple span bridge with analysis program MIDAS

- Question: If you are asked to design 10m bridge over small dimple using shaped steel, how do you design this? (superstructure only)



Tips4. Analysis procedure



1) Modelling

- Node
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- Element
  - [Element] -> [Create Elements]

2) Material & Section

- Material
  - [Properties] -> [Material Properties]
- Section

3) Boundary conditions

- Boundary conditions

My: Free

My: Free
Dx: Free

4) Loads

- “Load Case”
  - [Load] -> [Load Type -> Static Load] -> [Static Load Cases]
- Self Weight
  - [Structure Loads/Masses] -> [Self Weight]
  - Select elements with Z=-1 and “Add”
  - “Element beam load” is applied as slab self weight
- Live load (as concentrate load at node)

5) Group registration

- “Group Type”
  - [Tree Menu] -> [Group]tab
  - Structure Group, Boundary Group, Load Group, etc.
- Characteristic function of MIDAS

6) Perform analysis

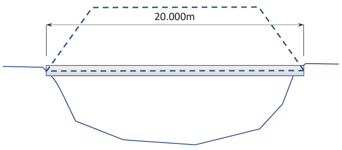
- Perform analysis

Lecture on Structural Analysis General

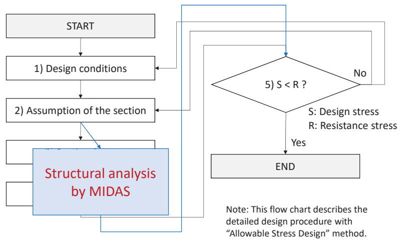
Lecture 03
Design of truss bridge
Modelling of structural models

1. Design of truss bridge

- Question: If you are asked to design 20m pedestrian bridge over small dimple, how do you design this? (Mainly by MIDAS)



Tips1. Design procedure



1) Design conditions -1

- Design Standard
  - In this lecture, Standards for Highway Bridges (JSHB) is applied.
  - Allowable Stress Method (ASD) is applied.
- Materials
  - Steel: SM400
  - Concrete: σ_{ck}=24N/mm^2
  - Reinforcing bar (rebar): SD345

  Note: Description of the strength of these materials is preferable.

1) Design conditions -2

Allowable stress of steel (SM400)

Item		Value (N/mm^2)
Allowable tension stress and flexural tension stress	Thickness less than 40mm	140
	Thickness over 40mm	125
Allowable flexural compression stress w/o considering buckling	Thickness less than 40mm	140
	Thickness over 40mm	125
Allowable shear stress	Thickness less than 40mm	80
	Thickness over 40mm	75

1) Design conditions -3

- Loads
  - Dead load (self weight)

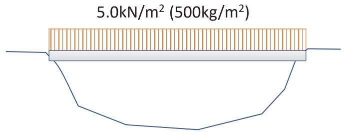
Material	Unit weight (kN/m^3)
Steel	77.0
Cast iron	71.0
Reinforced concrete	24.5
Prestressed concrete	24.5
Concrete	23.0
Cement mortar	21.0
Pitch (for waterproofing)	11.0
Asphalt	22.5

1) Design conditions -4

- Loads (cont.)
  - Live load

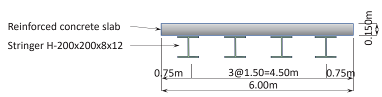
  To simplify the question, distribution load (pedestrian load) with 5.0kN/m^2 (500kg/m^2) weight is assumed for live load.

5.0kN/m^2 (500kg/m^2)



2) Assumption of the section -1

- Assume the chord, diagonal member, cross beam as shaped steel H-300x300x10x15
- Slab is made by reinforced concrete with 3.0m width and 0.15m depth supported by the stringer of H-200x200x8x12



2) Assumption of the section -2

- Characteristics of shaped steel
  - Please see the table of H-sections in JIS

	A(cm^2)	w(kg/m)	Ix(cm^4)	iy(cm)	Zx(cm^3)
H-300x300x10x15	118.3	93.0	20200	7.55	1350
H-200x200x8x12	63.53	49.9	4720	5.02	472

A: area
w: unit weight per length
Ix: moment of inertia
iy: radius of gyration of area, $iy=(Iy/A)^{1/2}$
Zx: modulus of section, Zx=Ix/e

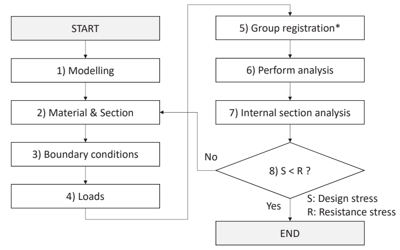
2) Assumption of the section -3

- Preparation of model of truss
  - Structural engineer should avoid modelling directly to MIDAS if the model becomes large and complexed
  - Drawing of the truss model, table of nodes, elements should prepare before input
  - Using spreadsheet program (Microsoft Excel) is better way to prepare the table of nodes, elements
  - The output of the spreadsheet could be the report (and checking sheet) for the analysis

2) Assumption of the section -4

- Modelling with spreadsheet
  - We can use function
  - We can use copy & paste operation
  - We can easily change the values of model
- Assumption of types of truss
  - Pony truss (without strut)
  - Warren truss

Tips4. Analysis procedure



1) Modelling

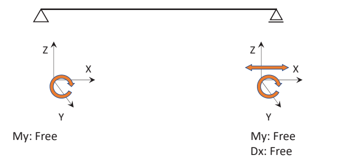
- Node
  - [Node/Element] -> [Nodes] -> [Nodes Table]
  - Copy (Ctrl+C) from spreadsheet -> Paste (Ctrl+V) to the Nodes table
- Element
  - [Elements] -> [Elements Table]
  - Copy (Ctrl+C) from spreadsheet -> Paste (Ctrl+V) to the Elements table

2) Material & Section

- Material
  - [Properties] -> [Material Properties]
- Section
  - First assumption is “Stringer” with H-200x200 and “Other members” with H-300x300

3) Boundary conditions

- Boundary conditions



4) Loads -1

- “Load Case”
  - [Load] -> [Load Type -> Static Load] -> [Static Load Cases]
  - In this lecture, please make 2 load cases, “Dead load” and “Live load”
    - “Dead load” -> “Dead Load (D)”
    - “Live load” -> “Live Load (L)”
- Self Weight
  - [Structure Loads/Masses] -> [Self Weight]
  - Load Case Name -> ”Dead load”
  - Select elements with Z=-1 and “Add”

4) Load -2

Distribution load (Element beam load)

Pedestrian load

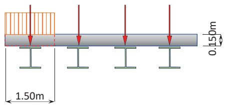
q_{ped} = 5.00 x 1.50 = 7.50 kN/m

Slab self weight

q_{slab} = 24.5 x 1.50 x 0.15 = 5.51 kN/m

$\Sigma q = q_{ped} + q_{slab}$ = 7.50 + 5.51= 13.01 kN/m

For 4 girders, Σq = 52.04 kN/m



4) Loads -3

- Slab self weight -> Dead load
  - [Element beam load]
  - Load Case Name -> "Dead load"
  - w= -5.51 -> add
- Pedestrian load -> Live load
  - [Element beam load]
  - Load Case Name -> "Live load"
  - w= -7.50 -> add

5) Group registration

- "Group Type"
  - [Tree Menu] -> [Group]tab
  - Structure Group, Boundary Group, Load Group, etc.
- Characteristic function of MIDAS

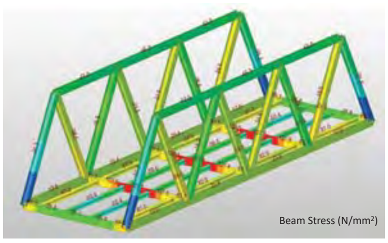
6) Perform analysis

- [Perform analysis]

7) Results -1

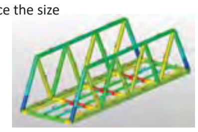
- [Results] -> [Load Combinations]
  - [Load Combination List] -> please name "Total"
  - [Load Cases and Factors]
    "Dead load" as 1.00
    "Live load" as 1.00
- Please check "Beam Forces/Moments Fx" and "Beam stresses" with N-mm unit

7) Results -2



7) Results -3

- From the result of "Beam Stress"
  - Cross Beam satisfies the maximum bending stress
    Note: This function does not separate "bending stress" and "axial stress", only the max/minimum values
  - Diagonal member can reduce the size (21.5 <<140)
  - Lower chord can also reduce the size
  - Upper chord ...?



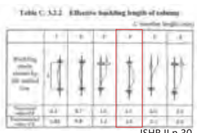
Tips6. Allowable stress of compression members

- Allowable axial compressive stress should consider
- Local buckling does not consider in this lecture

Allowable axial compressive stress
SM400 and t≤40mm

σa (N/mm²)	l/r
140	$\frac{l}{r} \le 18$
$140 - 0.82\left(\frac{l}{r} - 18\right)$	$18 < \frac{l}{r} \le 92$
$\frac{1,200,000}{6,700 + \left(\frac{l}{r}\right)^2}$	$92 < \frac{l}{r}$

JSHB II p.21



JSHB II p.30

7) Results -4

σ=91.3N/mm^2

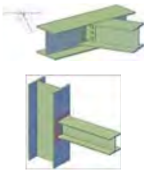
l=5590x1.0=5590(mm)
r=i_y=7.55(cm)=75.5(mm)
l/r=5590/75.5=74.0

σ_a=140-0.82x(l/r-18)
=140-0.82x(74.0-18)
=94.1 (N/mm^2)

$\sigma < \sigma_a$ OK

Tips7. Selection of the truss member

- Consider how the force will be transmitted
- Arrangement of H-beam (H or I ?)



[Structural Analysisi General_L03]

Practice

1. Select the different truss types shown in the distributed papers
2. Draw the model (with nodes and elements) of the truss
3. Input these nodes and elements in the table of Microsoft Excel
4. Assume the members with H-300x300 and calculate
5. (If possible) optimize the members

Lecture on Structural Analysis General

Lecture 04
Presentation

Contents

1. Request for presentation
2. Sample presentation
3. Approach to presentation

1. Request for presentation

Please introduce the result of your result with;

1. Introduction
2. Description of analysis model
3. Design conditions
4. Analysis procedure
5. Analysis results
6. Arrangement of members
7. Comparison with Warren Truss model, and other issues you want to explain
8. Conclusions

2. Sample presentation

Please see 2 presentations

First presentation

1. Introduction

I would like to explain the result of truss bridge design. Structural software MIDAS/Civil was used for the structural analysis.

First, I will explain the analysis model ,design condition of the bridge and analysis procedure. After the explanation, I will show the analysis result and arrangement of truss members.

Conclusions will be stated at the end of this presentation.

2. Description of analysis model

3D truss model was assumed to design 20m long and 6m width pedestrian bridge.

Warren truss was selected as truss type.

No strut was arranged, which means the truss is pony truss.

The height of the upper chord is 5.0m.

3. Design conditions

For bridge design, Standard for Highway Bridge (JSHB) was applied.

Allowable Stress Design (ASD) method was selected for sectional calculation.

Live load is 5.0kN/m^2 pedestrian load on the RC slab with 0.15m thickness.

Truss members was chosen from shaped steel in Japanese Industrial Standard (JIS).

4. Analysis procedure

For the first step, modelling was conducted on MIDAS/Civil with using table of nodes and elements on Microsoft Excel.

After inputting material, section, boundary conditions, load conditions and group registration, analysis was performed.

Result of the analysis can be seen graphically on the MIDAS/Civil interface.

5. Analysis results

From the result of the analysis, maximum bending moment was observed at crossbeam, the value was 191.4kNm.

Maximum compressive axial force was found in the center of upper chord, which was 315.7kN.

Maximum tension axial force was affected 216.6kN on lower chord.

6. Arrangement of members

First assumption was shaped steel H-300x300, which was not satisfied at crossbeam.

H-350x350 was selected as crossbeam.

On the other hand, center of the diagonal member was replaced to H-300x150 because only the smaller compression and tension was working.

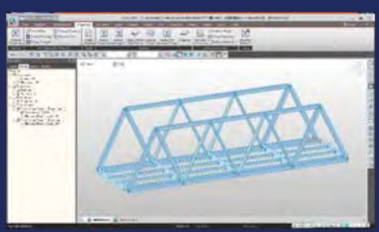
7. Conclusions

Warren truss bridge was modelled and analyzed by the program MIDAS/Civil.

The member was selected H-350x350 for crossbeam and H-300x150 for some diagonal member, instead of H-300x300 of first assumption.

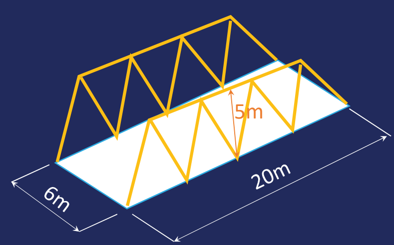
Second presentation

MIDAS/Civil



Contents

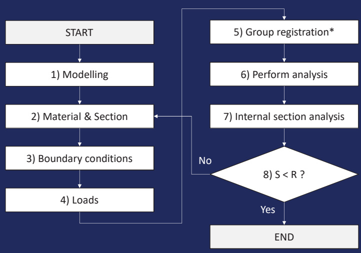
Analysis model



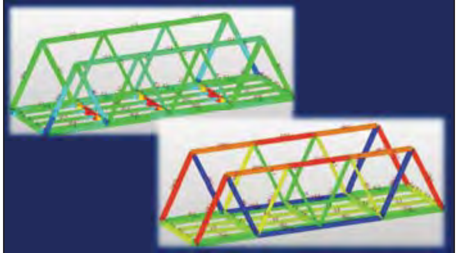
Design conditions

JSHB
ASD
5.0kN/m^2 pedestrian load
RC slab with 0.15m thickness
JIS steel member

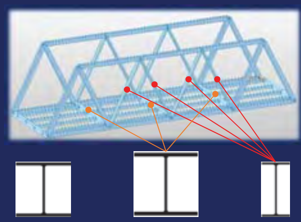
Analysis procedure



Analysis results



Arrangement of members



Conclusions

Warren truss bridge by MIDAS/Civil
H-350x350 for crossbeams
H-300x150 for diagonal members

How do you feel about these 2 presentations?

3. Approach to presentation

Please check these points;

A) Font size, color
B) Volume of contents
C) Manner of contents
D) Explanation of the sheet
E) Function of PowerPoint
F) Other issues

A) Font size, color -1 (44 point)

40 point	Red
36 point	Blue
32 point	Green
28 point	Cyan
24 point	Yellow
20 point	
18 point	Magenta
16 point	
14 point	Black
12 point	

A) Font size, color -2

40 point	Red
36 point	Blue
32 point	Green
28 point	Cyan
24 point	Yellow
20 point	Magenta
18 point	White
16 point	
14 point	
12 point	

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A) Font size, color -3

40 point	40 point	Red
36 point	36 point	Blue
32 point	32 point	Green
28 point	28 point	Cyan
24 point	24 point	Yellow
20 point	20 point	Magenta
18 point	18 point	White
16 point	16 point	Black
14 point	14 point	
12 point	12 point	

Structural Analysis General #04 26

[Structural Analysisi General_L04]

A) Font size, color -4

40 point	40 point	Red
36 point	36 point	Blue
32 point	32 point	Green
28 point	28 point	Cyan
24 point	24 point	Yellow
20 point	20 point	Magenta
18 point	18 point	White
16 point	16 point	Black
14 point	14 point	
12 point	12 point	

Structural Analysis General #04 27

A) Font size, color -5

၄၀ မှတ်	အနီ
၃၆ မှတ်	အပြာ
၃၂ မှတ်	အစိမ်း
၂၈ မှတ်	စိမ်းပြာ
၂၄ မှတ်	အဝါ
၂၀ မှတ်	ပန်းခရမ်း
၁၈ မှတ်	အနက်
၁၆ မှတ်	
၁၄ မှတ်	
၁၂ မှတ်	

Structural Analysis General #04 28

[Structural Analysisi General_L04]

A) Font size, color -6

40 ポイント	あか
36 ポイント	あお
32 ポイント	みどり
28 ポイント	みずいろ
24 ポイント	きいろ
20 ポイント	むらさき
18 ポイント	くろ
16 ポイント	
14 ポイント	
12 ポイント	

Structural Analysis General #04 29

A) Font size, color -7

- Use bigger size font
- Use appropriate color of font. Using only black/white and red is preferable
- Use appropriate background. Plain color is preferable. Avoid graphic background
- Visibility of the text changes the choice of fonts, characters and languages

(This text is using 32 point)

Structural Analysis General #04 30

[Structural Analysisi General_L04]

B) Volume of the contents

- Volume of the contents is preferable if the explanation time is 1 minutes / 1 sheet
- Avoid too rich contents and/or too poor contents
- Even if the sheets are made with rich contents for distribution purpose, you should explain within 1 minutes / 1 sheet

Structural Analysis General #04 31

Sample of B) -1

Table-B.1 Population and fertility rate of the world

Country	Population (2016, '000)	Fertility rate (2015)
World	7,442,136	2.5
China	1,378,665	1.6
Niger	20,673	7.3
Myanmar	52,885	2.2
Japan	126,995	1.5

Source: The World Bank website https://data.worldbank.org/indicator/

Structural Analysis General #04 32

Sample of B) -2

Table-B.2 Population and fertility rate of the ASEANs

Country	Population (2016, '000)	Fertility rate (2015)
World	7,442,136	2.5
Indonesia	261,115	2.4
Philippines	103,320	3.0
Vietnam	92,701	2.0
Thailand	68,864	1.5
Myanmar	52,885	2.2
Malaysia	31,187	2.1
Cambodia	15,762	2.6
Lao PDR	6,758	2.8
Singapore	5,607	1.2
Brunei Darussalam	423	1.9

Source: The World Bank website https://data.worldbank.org/indicator/

Structural Analysis General #04 33

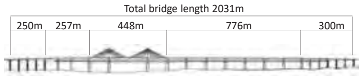
C) Manner of contents

- 1 topic / 1 sheet
- Please separate some topics from another sheet(s)
- Please stand on the listener's view

Structural Analysis General #04 34

Sample of C)

- Description of Bago River Bridge



- Structural Merit of the Cable-stayed bridge
  - Longer center span
  - Cantilever erection method
  - Aesthetically good with cables and slender girder

Structural Analysis General #04 35

D) Explanation of the sheet

- It is better to read texts on the sheet
- No need to write all the sentences which you would like to speak
- Sometimes the text on the sheet would help you to explain what you are going to speak

Structural Analysis General #04 36

Sample of D)

- Self introduction
- My profession
- My hobby
- Next visit to Yangon

Structural Analysis General #04 37

E) Functions of PowerPoint

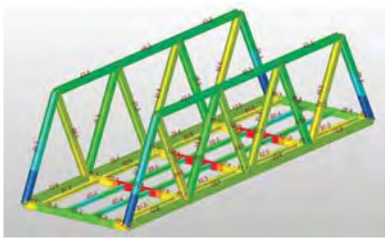
- You can use many kinds of animation effects
- Avoid too many effects in one sheet
- Please use the effects in a polite way
- Effects should use effectively
- Distinguish yourself by contents itself, not by animation effect

Structural Analysis General #04 38

F) Other issues

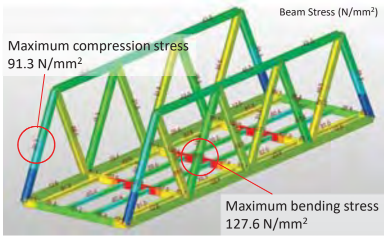
- Please insert page number
- Inserting presentation title and/or name of the speaker is preferable
- Please check resolution of the projector before the preparation of the presentation (this projector has 1024 x 768, 4:3 ratio)

Result of the MIDAS



Structural Analysis General #04 40

Result of the MIDAS + explanation



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Lecture on Structural Analysis General

Lecture 05
AASHTO LRFD design with MIDAS/Civil
Tutorial (PC simple span bridge)

Contents

[Structural Analysisi General_L05]

1. What is AASHTO LRFD? -1

- American Association of State Highway and Transportation Officials (AASHTO) publishes Standard Specifications for road and bridge on design and construction
- Every State (50 states in US) regulates the specifications based on AASHTO Standard Specifications

1. What is AASHTO LRFD? -2

- AASHTO adopted Load and Resistance Factor Design (LRFD), a kind of Limited State Design (LSD), for bridge design
- Allowable Stress Design (ASD) was used until 2002 in AASHTO

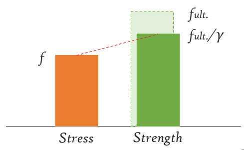
[Structural Analysisi General_L05]

1. What is AASHTO LRFD? -3

- Allowable Stress Design

$$f \leq f_{ult.}/\gamma$$

Here, *f: stress, $f_{ult.}$: strength, γ: safety factor*

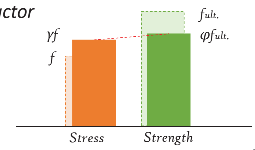


1. What is AASHTO LRFD? -4

- Load and Resistance Factor Design

$$\gamma f \leq \varphi f_{ult.}$$

Here, *f: stress, $f_{ult.}$: strength, γ: load factor, φ: resistance factor*



[Structural Analysisi General_L05]

2. Limit state -1

LRFD equation in AASHTO (1.3.2, p.1-3)

$$\Sigma \eta_i \gamma_i Q_i \leqq \phi R_n$$

Here, η : Load modifier
γ : Load factor
ϕ : Resistance factor
Q : Force effect
R : Nominal resistance

2. Limit state -2

Load modifier η_i (1.3.2, p.1-3)

$$\eta_i = \frac{1}{\eta_D \eta_R \eta_I} \leqq 1.0$$

Here, η_i : Load modifier
η_D : Ductility (1.3.3)
η_R : Redundancy (1.3.4)
η_I : Operational importance (1.3.5)

2. Limit state -3

Limit states defined in AASHTO are;

i. Service limit state
ii. Strength limit state
iii. Extreme events limit state
iv. Fatigue (and fracture) limit state

in “1.3.2 Limit States”

2. Limit state -4

i) Service limit state

- The service limit state shall be taken as restrictions on stress, deformation, and crack width under regular service conditions

2. Limit state -5

ii) Strength limit state

- Strength limit state shall be taken to ensure that strength and stability, both local and global, are provided to resist the specified statistically significant load combinations that a bridge is expected to experience in its design life

2. Limit state -6

iii) Extreme event limit state

- The extreme event limit state shall be taken to ensure the structural survival of a bridge during a major earthquake or flood, or when collided by a vessel, vehicle, or ice flow, possibly under scoured conditions

2. Limit state -7

iv) Fatigue and fracture limit state

- The fatigue limit state shall be taken as restrictions on stress range as a result of a single design truck occurring at the number of expected stress range cycles
- The fracture limit state … et of material toughness r… AASHTO Materials Spec…

3. Load factor and resistance factor

Equations of limit state (1.3.2, p.1-3)

$$\Sigma \eta_i \gamma_i Q_i \leqq \phi R_n$$

Here, η : Load modifier

γ : Load factor

ϕ : Resistance factor

Q : Force effect

R : Nominal resistance

Load and Load Designations (p.3-8)

- Permanent Loads

CR = force effects due to creep
DD = downdrag force
DC = dead load of structural components and nonstructural attachments
DW = dead load of wearing surfaces and utilities
EH = horizontal earth pressure load
EL = miscellaneous locked-in force effects resulting from the construction process, including jacking apart of cantilevers in segmental construction
ES = earth surcharge load
EV = vertical pressure from dead load of earth fill
PS = secondary forces from post-tensioning for strength limit states; total prestress forces for service limit states
SH = force effects due to shrinkage

- Transient Loads

BL = blast loading
BR = vehicular braking force
CE = vehicular centrifugal force
CT = vehicular collision force
CV = vessel collision force
EQ = earthquake load
FR = friction load
IC = ice load
IM = vehicular dynamic load allowance
LL = vehicular live load
LS = live load surcharge
PL = pedestrian live load
SE = force effect due to settlement
TG = force effect due to temperature gradient
TU = force effect due to uniform temperature
WA = water load and stream pressure
WL = wind on live load
WS = wind load on structure

Load Combinations and Load Factors (p.3-14 Table 3.4.1-1)

Load Combination Limit State	DC DD DW EH EV ES EL PS CR SH	LL IM CE BR PL LS	WA	WS	WL	FR	TU	TG	SE	Use One of These at a Time: EQ	BL	IC	CT	CV
Strength I (unless noted)	γ_p	1.75	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength II	γ_p	1.35	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength III	γ_p	—	1.00	1.40	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength IV	γ_p	—	1.00	—	—	1.00	0.50/1.20	—	—	—	—	—	—	—
Strength V	γ_p	1.35	1.00	0.40	1.0	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Extreme Event I	γ_p	γ_{EQ}	1.00	—	—	1.00	—	—	—	1.00	—	—	—	—
Extreme Event II	γ_p	0.50	1.00	—	—	1.00	—	—	—	—	1.00	1.00	1.00	1.00
Service I	1.00	1.00	1.00	0.30	1.0	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Service II	1.00	1.30	1.00	—	—	1.00	1.00/1.20	—	—	—	—	—	—	—
Service III	1.00	0.80	1.00	—	—	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Service IV	1.00	—	1.00	0.70	—	1.00	1.00/1.20	—	1.0	—	—	—	—	—
Fatigue I—LL, IM & CE only	—	1.50	—	—	—	—	—	—	—	—	—	—	—	—
Fatigue II—LL, IM & CE only	—	0.75	—	—	—	—	—	—	—	—	—	—	—	—

Load Factors for Permanent Loads γ_P (p.3-15 Table 3.4.1-2)

Type of Load, Foundation Type, and Method Used to Calculate Downdrag		Load Factor	
		Maximum	Minimum
DC: Component and Attachments		1.25	0.90
DC: Strength IV only		1.50	0.90
DD: Downdrag	Piles, α Tomlinson Method	1.4	0.25
	Piles, λ Method	1.05	0.30
	Drilled shafts, O'Neill and Reese (1999) Method	1.25	0.35
DW: Wearing Surfaces and Utilities		1.50	0.65
EH: Horizontal Earth Pressure			
• Active		1.50	0.90
• At-Rest		1.35	0.90
• AEP for anchored walls		1.35	N/A
EL: Locked-in Construction Stresses		1.00	1.00
EV: Vertical Earth Pressure			
• Overall Stability		1.00	N/A
• Retaining Walls and Abutments		1.35	1.00
• Rigid Buried Structure		1.30	0.90
• Rigid Frames		1.35	0.90
• Flexible Buried Structures			
○ Metal Box Culverts, Structural Plate Culverts with Deep Corrugations, and Fiberglass Culverts		1.5	0.9
○ Thermoplastic Culverts		1.3	0.9
○ All others		1.95	0.9
ES: Earth Surcharge		1.50	0.75

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Resistance factors ϕ for concrete structures (Section 5, pp.5-26~27)

Resistance factor φ shall be taken as:

- For tension-controlled reinforced concrete sections as specified in Article 5.7.2.1 .... 0.90
- For tension-controlled prestressed concrete sections as specified in Article 5.7.2.1 .... 1.00
- For shear and torsion:
  - normal weight concrete 0.90
  - lightweight concrete 0.80
- For compression-controlled sections with spirals or ties, as specified in Article 5.7.2.1, except as specified in Articles 5.10.11.3 and 5.10.11.4.1b for Seismic Zones 2, 3, and 4 at the extreme event limit state 0.75
- For bearing on concrete 0.70
- For compression in strut-and-tie models 0.70
- For compression in anchorage zones:
  - normal weight concrete 0.80
  - lightweight concrete 0.65
- For tension in steel in anchorage zones 1.00
- For resistance during pile driving 1.00

Structural Analysis General #05 18

Resistance factors ϕ for steel structures (Section 6, pp.6-31~32)

[illegible]

Structural Analysis General #05 19

4. Loadings

- Dead Load (DC)
- Live Load (LL)
- Vehicular Dynamic Load Allowance (IM)

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Unit Weights (p.3-18 Table 3.5.1-1)

1kcf = 157.1kN/m³

Material		Unit Weight (kcf)
Aluminum Alloys		0.175
Bituminous Wearing Surfaces		0.140
Cast Iron		0.450
Cinder Filling		0.060
Compacted Sand, Silt, or Clay		0.120
Concrete	Lightweight	0.110
	Sand-Lightweight	0.120
	Normal Weight with $f'_c \le 5.0$ ksi	0.145
	Normal Weight with $5.0 < f'_c \le 15.0$ ksi	$0.140 + 0.001 f'_c$
Loose Sand, Silt, or Gravel		0.100
Soft Clay		0.100
Rolled Gravel, Macadam, or Ballast		0.140
Steel		0.490
Stone Masonry		0.170
Wood	Hard	0.060
	Soft	0.050
Water	Fresh	0.0624
	Salt	0.0640
Item		Weight per Unit Length (klf)
Transit Rails, Ties, and Fastening per Track		0.200

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Tips7. Major units used in US

Unit	Description	Conversion to SI
lb	pound	0.4536kg = 4.448N
kip	kilopound	4.448kN
inch		0.0254m
feet		0.3048m = 12inch
lb/ft	pound per feet	14.59N/m
ksi	kilopound per square inch	6.894N/mm²
psf	pound per square feet	47.88N/m²
kcf	kilopound per cubic feet	157.1kN/m³

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Live Load (vehicular load)

- HL-93 loading (3.6.1.2, p.3-20)
  - Design track or design tandem, and
  - Design lane load

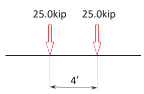
Design track or Design tandem + Design lane load

Structural Analysis General #05 23

Design Truck and Design Tandem

Design Truck (3.6.1.2.2)

Design Tandem (3.6.1.2.3)

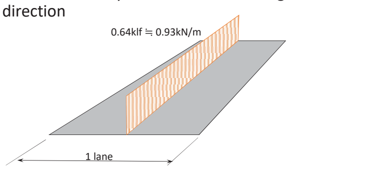


1kip=4.448kN,
8.0kip=35.6kN, 32.0kip=142.3kN

Structural Analysis General #05 24

Design lane load (3.6.1.2.4)

0.64klf uniformly distributed in the longitudinal direction



Dynamic load allowance (IM)

- "Dynamic load allowance" is a kind of <u>impact factor</u>

Table 3.6.2.1-1, p.3-33

Component	IM
Deck Joints—All Limit States	75%
All Other Components:	
• Fatigue and Fracture Limit State	15%
• All Other Limit States	33%

[Structural Analysisi General_L05]

5. Actual input to MIDAS/Civil -1

- Sample is referred from Tutorial of MIDAS
  MIDAS distributes the sample data as Tutorials
- PC simple span bulb-tee girder bridge

5. Actual input to MIDAS/Civil -2

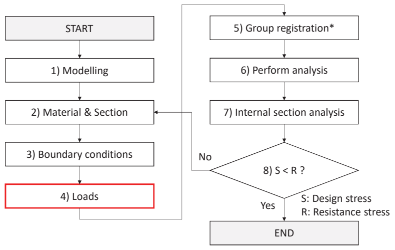
<u>This tutorial has too many topics</u>

- Construction stage analysis (with using time dependent materials)
- Arrangement of PC tendon (cable)
- AASHTO live loading

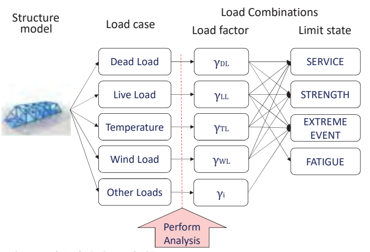
Some functions of MIDAS/Civil are difficult to understand intuitively (directly)

[Structural Analysisi General_L05]

Tips4. Analysis procedure



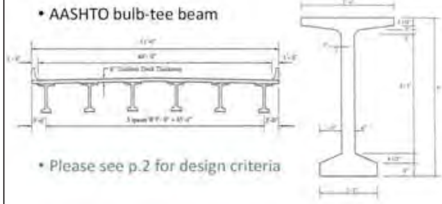
Actual design procedure in MIDAS



[Structural Analysisi General_L05]

Design descriptions

- 120-ft single span
- AASHTO bulb-tee beam



- Please see p.2 for design criteria

1) Material and Section properties -1 pp.4~8

- Material
  - Deck: ASTM C4000 but w=0
  - Cross beam: ASTM C4000 but w=0
  - Precast beam: ASTM C6500
  - Prestress Tendon: ASTM A416 270 Grade
- Time Dependent Material

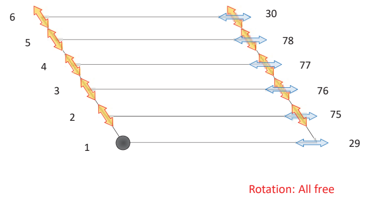
1) Material and Section properties -2
pp.9~11

- Section Properties
  - Interior Precast Beam
  - Exterior Precast Beam
  - End Cross Beam
  - Interior Cross Beam

2) Nodes and Elements
pp.12~14

- 6 Nodes of the edge of the precast beams
- Making precast beam elements using "Extrude" command
- Making cross beam elements using same manner

3) Boundary Conditions (Structure Support Conditions)
pp.15~16



4) Loading data -1
p. 17 of pp.17~35

- Making "Load Groups" before input loads
  - PC&C/B
  - Deck
  - Barrier
  - Wearing surface
  - Prestress

4) Loading data -2
pp. 17~18 of pp.17~35

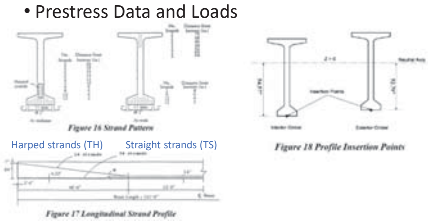
- Static Loads
  - PC&C/B as "Construction Stage Load (CS)"
  - Deck as "Construction Stage Load (CS)"
  - Barrier as "Construction Stage Load (CS)"
  - Wearing surface as "Construction Stage Load (CS)"
  - Prestress as "Construction Stage Load (CS)"

4) Loading data -3
pp. 18~20 of pp.17~35

- Element Beam Load
  - Deck : -0.922 for 1:Interior Precast Beams
    -0.772 for 2:Exterior Precast Beams
  - Wearing surface:
    -0.2 for all Precast Beams
  - Barrier:
    -0.1 for all Precast Beams
- PC&CB: Self Weight

4) Loading data -4
pp. 21~28 of pp.17~35

- Prestress Data and Loads



4) Loading data -5
pp. 28~35 of pp.17~35

- Moving Loads (HL-93)
  - Definition of "Traffic Line Lanes" pp.28~32
    - Lane 1~4 in every 12-feet
  - Assign of "Vehicles" p.33
    - TDM (Tandem) and TRK (Track)
  - Moving Load Cases pp.34~35

5) Construction Stage Analysis
pp.36~42

- Construction stages p.36

Stage	Day	Description
Stage 1 (30 days)	1	Placing of precast beams and cross beams. Prestressing of strands.
	21	Pouring deck slab.
Stage 2 (30 days)	1	Composite beam & slab behavior takes place.
	1	Installation of barrier.
	6	Placing of wearing surface.
Stage 3 (10000 days)	-	-

6) Moving Load Analysis Control p.43

- Input "Moving Load Analysis Control" data

7) Perform Analysis p.44

- Verification and Interpretation of Results
- "Auto Generation" of the "Load Combination" of AASHTO-LRFD 12

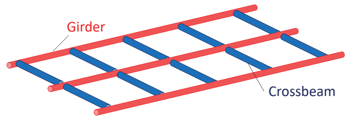
Lecture on Structural Analysis General

Lecture 06
AASHTO LRFD design with MIDAS/Civil (continue)
Lane loading of live load

Contents

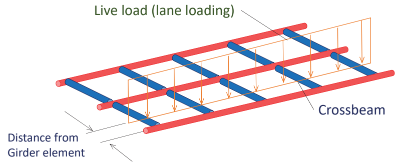
1. Conclusions of today's lecture -1

i. "Crossbeam" elements as much as Girder elements are needed for bridge design by MIDAS/Civil



1. Conclusions of today's lecture -2

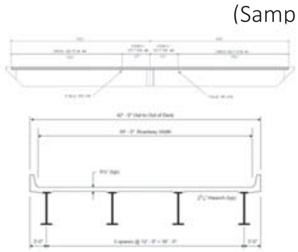
ii. Loading positions of live load are controlled with the Crossbeam element



1. Conclusions of today's lecture -3

iii. "Crossbeam" element and "Girder" element shall be registered in "Crossbeam" group and "Girder" group respectively.

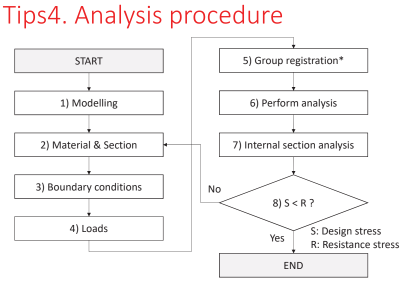
2. Actual input to MIDAS/Civil (Sample-1)



Design descriptions

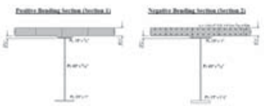
- 330-ft two span bridge (165-ft + 165-ft)
- 42-ft width
- Steel composite plate girder

Tips4. Analysis procedure



1) Material and Section properties -1

- Material
  - Steel: ASTM09 A529-50 (p.59)
  - Deck: ASTM C4500 (w=0)
- Section
  - Main girder



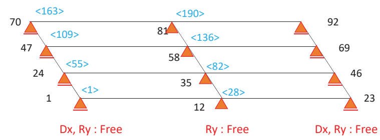
1) Material and Section properties -2

- Section (cont.)
  - Crossbeam as "Cross girder"
    AISC10(US) W44x290
    every 18-feet
  - Slab (End slab) as "Crossbeam"
    Assume this member has same thickness as slab of composite girder (12-ft x 9.5-in)

2) Nodes and Elements

- Copy & Paste from Excel spreadsheet
  - Element 1 to 216 : Girder
  - Element 217 to 273 : Cross girder
  - Element 274 to 375 : Slab

3) Boundary Conditions



4) Loading data -1

- Steel girder self weight -> Function of MIDAS
- Other loads: Element Beam Loads
  - Deck self weight : 1,425 lb/ft
  - Haunch self weight: 52.5 lb/ft
  - Barrier walls : 320 lb/ft
  - Wearing surface : 585 lb/ft

4) Loading data -2

- Moving Loads (HL-93)
  - Definition of "Traffic Line Lanes"
    - Lane 1~3 in every 12-feet
  - Assign of "Vehicles"
    - TDM (Tandem) and TRK (Track)
  - Moving Load Cases

4) Loading data -3

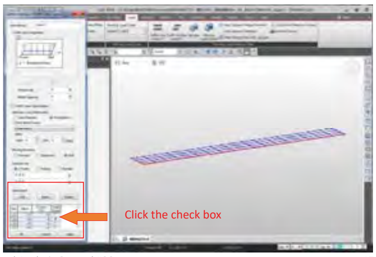
<u>Intermediate support of negative moment</u>

4) Loading data -3

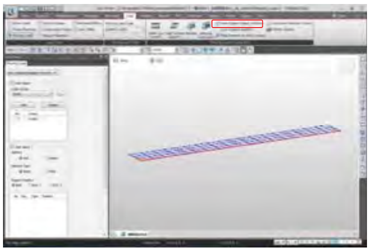
<u>Intermediate support of negative moment</u>

i. Input "Span start" elements to "Define Design Traffic Line Lane"
ii. Register "Girder" group to "Lane Supports (Negative Moment)"
iii. Add node number of intermediate supports to "Lane Supports (Reactions at Intermediate Supports)"

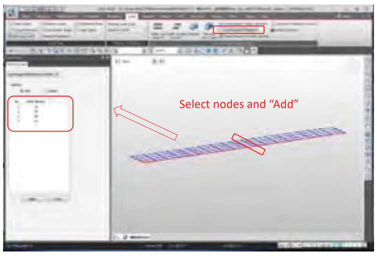
Span Start



Register “Girder” group



Lane Supports



6) Moving Load Analysis Control

- Input “Moving Load Analysis Control” data

7) Perform Analysis

- Verification and Interpretation of Results
- “Auto Generation” of the “Load Combination” of AASHTO-LRFD 12

Tips7. Major units used in US

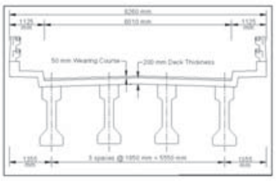
Unit	Description	Conversion to SI
lb	pound	0.4536kg = 4.448N
kip	kilopound	4.448kN
inch		0.0254m
feet		0.3048m = 12inch
lb/ft	pound per feet	14.59N/m
ksi	kilopound per square inch	6.894N/mm^2
psf	pound per square feet	47.88N/m^2
kcf	kilopound per cubic feet	157.1kN/m^3

Lecture on Structural Analysis General

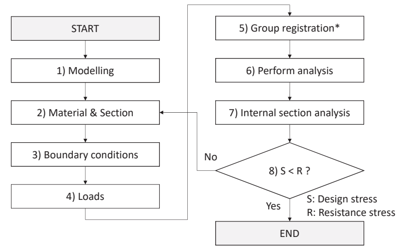
Lecture 07
AASHTO LRFD design with MIDAS/Civil (continue)
Prestressed concrete girder design

Prestressed concrete girder design

- Single span PC girder bridge
- 40.0m span
- 8.26m width



Tips4. Analysis procedure



1) Material and Section properties -1

- Material
  - PC girder:
    ASTM(RC) C5000 (≒34.47N/mm^2)
  - Deck: ASTM(RC) C3500 (≒24.13N/mm^2)
  - PC Strand: ASTM(S) A416-270 (Low)
    Low=Low relaxation

1) Material and Section properties -2

AASHTO LRFD

Table 5.9.3-1—Stress Limits for Prestressing Tendons

Condition	Tendon Type: Stress-Relieved Strand and Plain High-Strength Bars	Low Relaxation Strand	Deformed High-Strength Bars
Pretensioning			
Immediately prior to transfer (f_{pt})	$0.70f_{pu}$	$0.75f_{pu}$	—
At service limit state after all losses (f_{pe})	$0.80f_{py}$	$0.80f_{py}$	$0.80f_{py}$
Post-Tensioning			
Prior to seating—short-term f_{pt} may be allowed	$0.90f_{py}$	$0.90f_{py}$	$0.90f_{py}$
At anchorages and couplers immediately after anchor set	$0.70f_{pu}$	$0.70f_{pu}$	$0.70f_{pu}$
Elsewhere along length of member away from anchorages and couplers immediately after anchor set	$0.70f_{pu}$	$0.74f_{pu}$	$0.70f_{pu}$
At service limit state after losses (f_{pe})	$0.80f_{py}$	$0.80f_{py}$	$0.80f_{py}$

1) Material and Section properties -3

JSHB III Concrete

3.4 Allowable Stress of Prestressing Steel

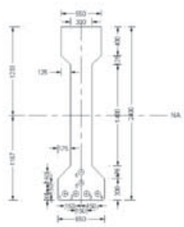
The allowable tensile stress of prestressing steel for prestressed concrete structure shall be the values in Table 3.4.1.

Table 3.4.1 Allowable Tensile Stress of Prestressing Steel

Stress state	Allowable tensile stress	Remarks
1) During prestressing	The value of 0.80 σ_{pu} or 0.90 σ_{py}, whichever is smaller	σ_{pu}: Tensile strength (N/mm^2) of prestressing steel σ_{py}: Yield point (N/mm^2) of prestressing steel
2) Immediately after prestressing	The value of 0.70 σ_{pu} or 0.85 σ_{py}, whichever is smaller	
3) Under design load	The value of 0.60 σ_{pu} or 0.75 σ_{py}, whichever is smaller	

1) Material and Section properties -4

- Section
  - Main girder
  - Start from
    "AASHTO TYPE1"



1) Material and Section properties -5

- Section
  - Slab as Solid Rectangular
    H=200mm x B=4000mm
  - End Slab as Solid Rectangular
    H=200mm x B=2000mm

1) Material and Section properties -6

- Time Dependent Material
  - Creep / Shrinkage

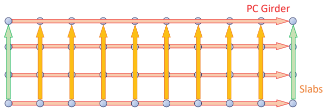
2) Nodes and Elements -1

- Create Nodes
  (0,0,0) -> Copy 3Nodes with
  (dx,dy,dz) = (0,1850,0)

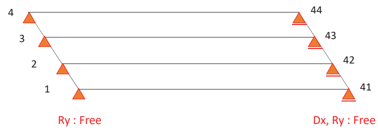
- Extrude Elements (PC girder)
  Extrude 4Nodes to 10Elements with
  (dx,dy,dz) = (4000,0,0)
  Material=C5000, Section=PC Girder

2) Nodes and Elements -2

- Extrude Elements (slabs)
  Extrude 11Nodes to 3x11Elements with
  (dx,dy,dz) = (0,1850,0)
  Material=C3500, Section=Slab and End Slab



3) Boundary Conditions



4) Group -1

- Structure Group (and registration)
  - Slab, End Slab -> "Crossbeam"
  - PC Girder -> "PC Girder"
  - Other members -> "All"

- Tendon Group
  - Please make 24 Tendon Groups (Tendon 1 to Tendon 24)

4) Group -2

- Load Group
  - PC Girder
  - Slab
  - Wearing surface
  - Prestress

5) Loading data -1

- Static Load Case
  - PC Girder, Slab (DC)
  - Wearing surface (DW)
  - Prestress (~~CS~~ User Defined)
- PC girder self weight -> Function of MIDAS
- Slab -> Element Beam Load (8.88kN/m)
- Wearing surface -> Element Beam Load (2.13kN/m)

5) Loading data -2

- Moving Loads (HL-93)
  - Definition of "Traffic Line Lanes"
    - Lane 1 only (925mm distance from Girder 2)
  - Assign of "Vehicles"
    - TDM (Tandem) and TRK (Track)
    - Dynamic Load Allowance = 33%
  - Moving Load Cases

5) Loading data -3

- Temp./Prestress
- Tendon Property
  - Internal (Post-Tension)
  - Total Tendon Area
    - ->12.7mm(0.5”)
    - ->12nos
  - Duct Diameter 70mm

5) Loading data -4

- Tendon Profile
  - Input type = 3-D
  - Curve Type = Spline
  - Profile – Reference Axis = Straight
  - Profile Insertion Point = (0,0,-1200)(mm)

  - Coordinates of the Tendons are shown in next page (for Girder 1)
  - Check “Fix” of 2 and 3 points

5) Loading data -5

Tendon 1

X(mm)	Y(mm)	Z(mm)
0	0	2100
9096	0	390
30904	0	390
40000	0	2100

Tendon 2

X(mm)	Y(mm)	Z(mm)
0	0	1750
8731	0	240
31269	0	240
40000	0	1750

Tendon 3

X(mm)	Y(mm)	Z(mm)
0	0	1400
9058	0	90
30942	0	90
40000	0	1400

Tendon 4

X(mm)	Y(mm)	Z(mm)
0	0	1050
8430	0	90
31570	0	90
40000	0	1050

Tendon 5

X(mm)	Y(mm)	Z(mm)
0	0	700
7409	0	90
32591	0	90
40000	0	700

Tendon 6

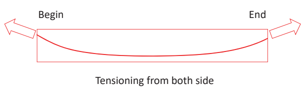
X(mm)	Y(mm)	Z(mm)
0	0	350
5223	0	90
34777	0	90
40000	0	350

5) Loading data -6

Girder1 0	Girder2 ->1850	Girder3 ->3700	Girder4 ->5550
Tendon1	Tendon7	Tendon13	Tendon19
Tendon2	Tendon8	Tendon14	Tendon20
Tendon3	Tendon9	Tendon15	Tendon21
Tendon4	Tendon10	Tendon16	Tendon22
Tendon5	Tendon11	Tendon17	Tendon23
Tendon6	Tendon12	Tendon18	Tendon24

5) Loading data -7

- Tendon Prestress
  - Begin = End = 1652kN



6) Construction stage data

- CS1: Fabrication of girder (30 days)
- CS2: Erection of girder (30 days)
- CS3: Slab, wearing surface (10000 days)

7) Perform Analysis

- Verification and Interpretation of Results
- “Auto Generation” of the “Load Combination” of AASHTO-LRFD 12

Lecture on
Structural Analysis General

Lecture 08
Key point for calculating cable structures
Suspension bridge and cable stayed bridge

Key point of today's lecture

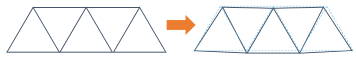
- Cables are always affected by the <u>tension force</u> even at dead load case
- Structural designer should consider the shape of the dead load case
- Keyword: <u>initial tension</u>

[Structural Analysisi General_L08]

Modelling of the cable structures -1

- Usual case (ex. Truss bridge)

Modelling   Dead load case

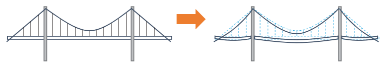


Very small deformation
(neglectable)

Modelling of the cable structures -2

- Cable structure case

Modelling   Dead load case
(without cable tension)



Large deformation
(not neglectable)

[Structural Analysisi General_L08]

Modelling of the cable structures -3

- Structural designer should <u>introduce cable tension</u> so that the shape of the structure should keep the design status at dead load case

Dead load case
(without cable tension)   Design status
(with cable tension)

Introduction of cable tension

1. Suspension bridge case

- Steel suspension bridge
- Single lane road bridge, W=6.0m
- Bridge length L = 223.6m = 40+153.6+30

[Structural Analysisi General_L08]

1) Properties -1

- Material properties
  - Cable   JIS-Civil(S) / SWPR7B
  - Steel member   JIS-Civil(S) / SM400
  - Concrete member   JIS-Civil(RC) / Fc30
  - Dummy member (for stringer)
    JIS-Civil(S) / SM400 but <u>Weight density = 0</u>

1) Properties -2

- Section properties
  - Main cable   19 – 52ϕ, 7x37
    Total area of cable = 24,890mm^2
    -> equivalent to <u>D=178.0mm Solid Round</u>
  - Hanger cable   1 – 42ϕ, 7x19
    Total area of cable = 846mm^2
    -> equivalent to <u>D=32.8mm Solid Round</u>

1) Properties -3

- Section properties
  - Chord H-350x350x12x19
  - Diagonal member H-340x250x9x14
  - Vertical member H-350x175x7x11
  - Crossbeam H-900x300x16x28
  - Bracing H-200x200x8x12
  - Diagonal bracing L-150x12
  - Tower column Solid Rectangular H-1100 x B-800

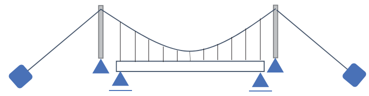
2) Nodes and Elements

- Copy & Paste from Excel spreadsheet

[Structural Analysisi General_L08]

3) Boundary conditions

- End of the cable: All fix
- Bottom of the tower: pin (Ry=free)
- Support of the girder: pin X-roller



4) Loads

- Static Load Cases
- Members: Self weight
- Slab: Element Beam Load (W=-24.3kN/m)

[Structural Analysisi General_L08]

5) Groups

- Please make “Structure Group”, ”Boundary Group” and ”Load Group”

6) After calculation of the structural model with cable tension=0

- Check the “Deformation” and “Tension force of Main cable”
- <u>Input “Initial tension” to the main cable</u>
  - “Pretension Loads” in Temp./Prestress
  - Temperature Load
    ΔT=N/(AEα)
    ΔT: Temperature, N:Axial force, A: Area of the cable, E: Young’s modulus, α: Thermal coefficient

[Structural Analysisi General_L08]

2. Cable stayed bridge case

- PC concrete cable stayed bridge
- Pedestrian bridge, W=4.0m
- Bridge length L=138.0m = 35.0+71.0+32.0

1) Properties -1

- Material properties (assumption)
  - Cable JIS-Civil(S) / SWPR7B
  - Concrete girder JIS-Civil(RC) / Fc40
  - Concrete tower JIS-Civil(RC) / Fc30
  - Dummy JIS-Civil(RC) / Fc40 but Weight Density = 0

1) Properties -2

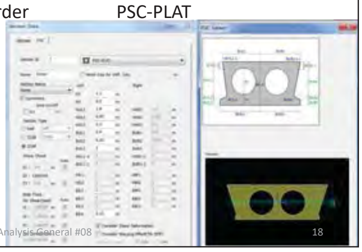
- Section properties (assumption)
  - Cable 31S 15.2ϕ

    Total area of cable = 4,300mm^2

    -> equivalent to D=74.0mm Solid Round

1) Properties -3

- Girder PSC-PLAT



[Structural Analysisi General_L08]

1) Properties -4

• Tower column	Solid Rectangular H-4000 x B-2000
• Beam	Solid Rectangular H-1650 x B-1500
• Tower column	Solid Rectangular H-3000 x B-7600

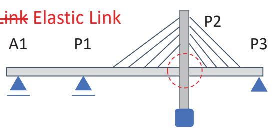
2) Nodes and Elements

- Copy & Paste from Excel spreadsheet

[Structural Analysisi General_L08]

3) Boundary conditions

- Bottom of the tower: All fix
- A1, P1: pin x-roller
- P3: pin
- P2: ~~Rigid Link~~ Elastic Link



4) Loads

- Static Load Cases
- Members: Self weight
- Prestress (PS)

[Structural Analysisi General_L08]

5) Groups

- Please make "Structure Group", "Boundary Group" and "Load Group"

6) After calculation of the structural model with cable tension=0

- Check the "Deformation" and "Tension force of Main cable"
- <u>Input "Initial tension" to the main cable</u>
  - "Pretension Loads" in Temp./Prestress
  - Temperature Load

    $\Delta T = N/(AE\alpha)$

    ΔT: Temperature, N:Axial force, A: Area of the cable, E: Young's modulus, α: Thermal coefficient

Lecture on Structural Analysis General

Lecture 09

Practice of MIDAS/Civil

Modelling and performing analysis of bridge by MIDAS/Civil

1. Draw the structural model with nodes and elements
2. Prepare Excel spreadsheet (coordinates for node, node1 and node2 for elements)
3. Input to MIDAS/Civil with assumed members (section properties)
4. Consider calculation results
5. Optimize members (if possible)

Target bridge for task-1

Assumptions for task-1 and task-2

- Live load: AASHTO LRFD HL-93 (4-lane)
- Slab thickness t=200mm -> unit weight (for Element Beam Load) 11.76kN/m
- Wearing surface (asphalt pavement) t=80mm -> unit weight 4.32kN/m

Schedule of Lecture 9 and 10

Program	Session	Activities
Lecture 9	Morning	Practice of structural analysis with MIDAS/Civil *Progress of analysis will be asked at the end of Lecture 9
	Afternoon*	
Lecture 10	Morning	
	Afternoon	Presentation (13:30~) 15 minutes maximum

Suggestions -1

- Material property: stronger material shall be used for the longer span bridge

  (ex. SM400 to SM490, SM520 or higher)
- Section property: shaped steels shall be changed to built-up sections

  (ex. I-section to box shape)
- Stringer and cross beam shall be designed by composite structure with concrete slab

Suggestions -2

- Applied standard shall carefully be chosen
  - Limit state design (AASHTO LRFD)
  - Allowable stress design (old JSHB)


Thank you very much for your attention.
ကျေးဇူးတင်ပါတယ်။
ありがとうございました
Structural Analysis General #09
9

Appendix A Materials of Lectures and Seminars

A-3 Superstructure Design (Concrete)

1

Technical Transfer on Bago River Bridge Construction Project

Superstructure 1 (Concrete Bridges)
JICA Study Team

October 2017

JICA Study Team 2

0. Self-introduction

Some of my project experiences

Agenda

1. **History of Concrete Bridges**
2. **What is "Prestressed Concrete"?**
3. **Planning of Prestressed Concrete Bridges**
4. **Structure Type of Prestressed Concrete Bridges**
5. **Basis of Design of Prestressed Concrete Bridges**

1. History of Concrete Bridges

1.1. Bridges from prehistoric times to 19th century

The two most important materials used in bridge design before 19th century are …

- Stone and Timber

(since prehistoric times)

Resource : Wikipedia

Pont du Gard, France

JICA Study Team 5

1. History of Concrete Bridges

1.1. Bridges from prehistoric times to 19th century

The forms used for stone bridges have been based on arches, retaining walls and piers.

Resource : Wikipedia

Kintai-kyo Bridge, Japan

JICA Study Team 6

1. History of Concrete Bridges

1.2. Major Transformations in Bridge Building during Industrial Revolution

The world's 1st iron bridge was built in England in 1779 from cast iron

Resource : Wikipedia

Iron Bridge, Coalbrookdale, UK

1. History of Concrete Bridges

1.2. Major Transformations in Bridge Building during Industrial Revolution

… However, no further development of cast-iron bridges, due to the brittleness of the material

Dramatic growth of iron bridges were brought by wrought iron and steel (higher tensile strength and ductility)

1. History of Concrete Bridges

1.2. Major Transformations in Bridge Building during Industrial Revolution

From prehistoric times to 19th century, bridges had been …

- designed by master builders
- using empirical guidelines (= based on experiences)
- built with simple tools and from traditional materials (stones and timbers)

By the early 19th century, bridges were …

- designed by engineers
- using newly developed theory of structures (graphic statics etc.)
- built from stronger, lighter, industrially produced materials (industrialized iron)

JICA Study Team 9

1. History of Concrete Bridges

1.2. Major Transformations in Bridge Building during Industrial Revolution (cont.)

Industrialized steel quickly became the pre-eminent material for railway bridge construction - However, some disadvantages for railways

	Steel	Concrete
Advantages	• Strength • Light weight • Speed of construction	• Maintenance-free • Lower ratio of live load to dead load
Disadvantages	• High maintenance cost • Higher ratio of live load to dead load (cannot carry heavier, faster trains)	• Lower strength • Heavier weight • Slower speed of construction

Need for application of another new material – Portland cement concrete

JICA Study Team 10

1. History of Concrete Bridges

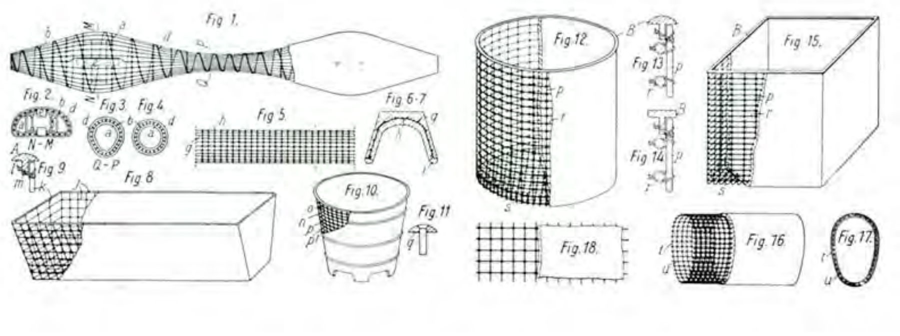
1.3. Development of concrete structures / bridges

Year	Name (Country)	Event
1850	Thaddeus Hyatt (U.S.A.)	• Investigation of reinforced concrete (RC) beams • Development of structural details
1855	A. Lambot (France)	• A patent for RC boat
1860s	(France & Spain)	• 1st plain concrete bridges (arches) – identical to masonry structures
1860	François Coignet (France)	• A patent for concrete slabs w/ embedded iron mesh
1867	Joseph Monier (France)	• A patent for wire-reinforced concrete flowerpot – the 1st to recognize the vast potential of RC as a material for structures
1873	Joseph Monier (France)	• The world's 1st reinforced concrete bridge

Resource : JICA Study Team (based on "Prestressed Concrete Bridges" by Christian Menn)

JICA Study Team 11

1. History of Concrete Bridges
1.3. Development of concrete structures / bridges



Joseph Monier's patent for various reinforced concrete items (1867)

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1. History of Concrete Bridges
1.3. Development of concrete structures / bridges

Resource : Wikipedia

The world's 1st reinforced concrete bridge at Chazelet, France (1873) by Joseph Monier

JICA Study Team 13

1. History of Concrete Bridges

1.4. Development of reinforced concrete bridges

2 engineers who significantly contributed to the expansion of design and construction of reinforced concrete:

François **Hennebique**
(1842 – 1931, France)

- **Took full advantages of the monolithic behavior of reinforced concrete**
- **Concrete members to fulfill several different structural functions**

Emil Mörsch
(1872 – 1950, Germany)

- **Contribution to the theory of reinforced concrete guided by practical knowledge**
- **Development of truss models for reinforced concrete**

JICA Study Team 14

1. History of Concrete Bridges

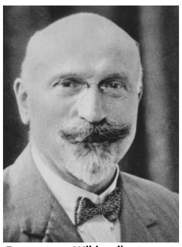
1.4. Development of reinforced concrete bridges (cont.)

Design of reinforced concrete bridges until the early 20th century

- **Strongly influenced by masonry or steel designs**
- **With little or no structural interaction among the individual components**

Robert Maillart
(1872~ 1940, Switzerland)

- **Structural elements to carry out more than one function simultaneously**
- **Interactive structural behavior of the entire system**



Resource : Wikipedia

JICA Study Team 15

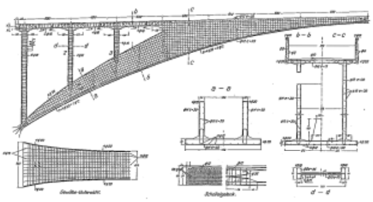
1. History of Concrete Bridges

1.4. Development of reinforced concrete bridges (cont.)

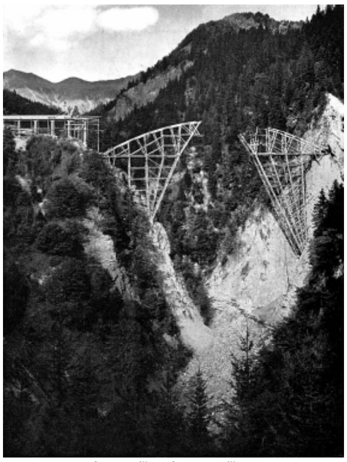
Works of Robert Maillart

- **Salginatobel Bridge (completed in 1930)**

Resource : Wikipedia



Resource : "Robert Maillart" by Max Bill



Resource : "Robert Maillart" by Max Bill

JICA Study Team 16

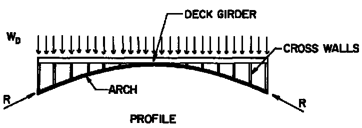
1. History of Concrete Bridges

1.4. Development of reinforced concrete bridges (cont.)

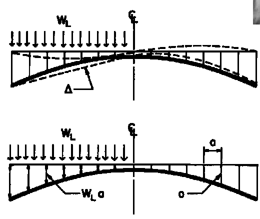
Works of Robert Maillart

- **Val Tschiel Bridge (completed in 1925)**

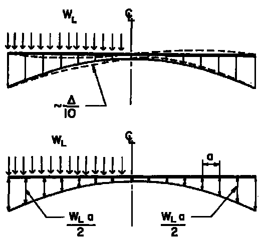
Resource : "Robert Maillart" by Max Bill



Deck-stiffened Arch



Structural behavior of unstiffened arches



Structural behavior of stiffened arches

Resource : David P. Billington

JICA Study Team 17

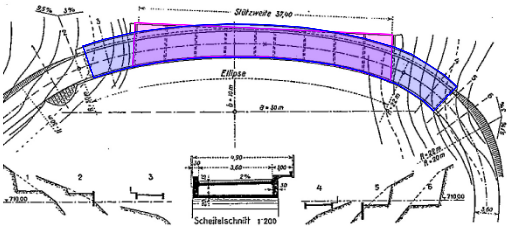
1. History of Concrete Bridges

1.4. Development of reinforced concrete bridges (cont.)

Works of Robert Maillart

- **Schwandbach Bridge (completed in 1933)**

Resource : David P. Billington



Resource : "Robert Maillart" by Max Bill

Resource : M. Ohyama, 1999

Arch bridge applied on curved alignment

JICA Study Team 18

1. History of Concrete Bridges

1.5. Development of prestressed concrete

In 1888, a patent for prestresing system (for slabs, planks and beams) by W. Döring **(Germany)**

… **However, no further practical application for 40 years**

- **Insufficient study on creep & shrinkage of concrete and relaxation of steel**
- **Materials (high strength steel & concrete) still to be developed**
- **Prestressing anchors and jacks still to be developed**

JICA Study Team 19

1. History of Concrete Bridges

1.5. Development of prestressed concrete

Beginning of practical application of prestressed concrete

- **Prestressed concrete was firstly developed in Germany and France, and then spread over the world.**

- From 1928 to 1936, a French engineer Eugène **Freyssinet** worked on the development of stressing systems with steel wires and strands, and patented prestressing jacks and anchors.

- In 1937, a German engineer **Franz Dischinger** built the world's 1st prestressed concrete bridge in Aue, using unbonded prestressing bars (dia. 70mm, tensile strength ~ 500 N/mm2).

- After Dischinger, his student Ulrich Finsterwalder invented Diwidag system (stressing system with steel bars smaller (dia. 26mm) and stronger (tensile strength ~ 900 N/mm2), and bonded to the concrete after stressing)

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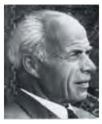
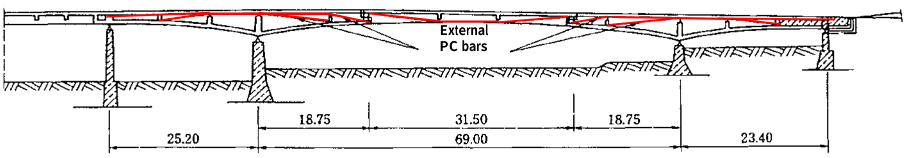
1. History of Concrete Bridges

1.5. Development of prestressed concrete



The world's 1st prestressed concrete bridge in Aue, Germany (1873)
by Frantz Dischinger



… However, the bridge resulted in large cracks and vertical deflection of 200mm, as almost 75% of the initial prestress had been lost through creep and shrinkage after 25 years.

JICA Study Team 21

1. History of Concrete Bridges

1.5. Development of prestressed concrete

Eugène **Freyssinet (1879 ~ 1962, France)**

- **A founder of prestressed concrete technologies, and the 1st president of FIP (International Federation for Prestressing, now changed to fib)**
- **Developed schemes both for pre-tensioned and post-tensioned concrete**
- **Preferred to use thin precast components**
- **Accepted only full-prestressing (= no tensile stress in the concrete under service load)**


Resource : structurae


Prougastel bridge, France
Resource : structurae (Photo by Philip Bourret)


Saint-Michel Bridge, France
Resource : structurae (photo by Nicolas Janberg)

JICA Study Team 22

1. History of Concrete Bridges

1.5. Development of prestressed concrete

Marne 5 bridges (1947 ~ 1950) by Eugène **Freyssinet**


Ussy bridge, France


Changis Bridge, France


Esbly bridge, France


Trilbardou bridge, France


Annet bridge, France

1

Technical Transfer on Bago River Bridge Construction Project

Superstructure 1 (Concrete Bridges)
JICA Study Team

October 2017

JICA Study Team 2

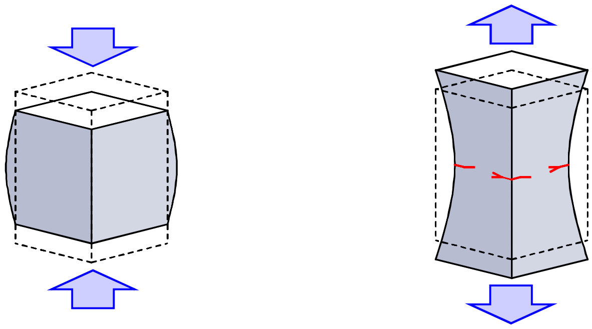
Agenda

1. **History of Concrete Bridges**
2. **What is "Prestressed Concrete"?**
3. **Planning of Prestressed Concrete Bridges**
4. **Structure Type of Prestressed Concrete Bridges**
5. **Basis of Design of Prestressed Concrete Bridges**

2. What is “Prestressed Concrete”?

2.1. Characteristics of concrete as a construction material

Strong against compression **Weak against tension**



… **How to resist against tension? →substitute concrete by steel**

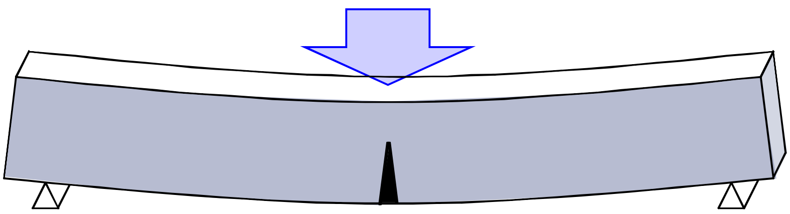
2. What is “Prestressed Concrete”?

2.1. Characteristics of concrete as a construction material

How to resist against tension in the concrete

Plain concrete beam

- **Cannot resist tension, as its tensile strength is approx. 1/10 of compressive strength.**



JICA Study Team 5

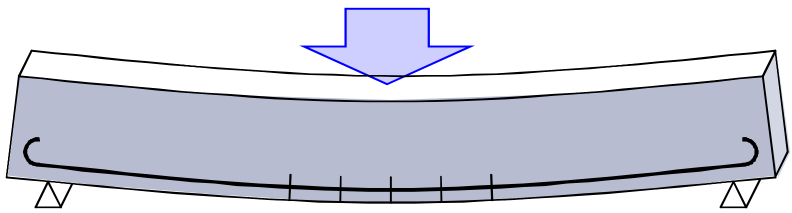
2. What is “Prestressed Concrete”?

2.1. Characteristics of concrete as a construction material

How to resist against tension in the concrete

Reinforced concrete beam

- Tension is carried by rebars.
- Some extent of cracks are inevitable.



JICA Study Team 6

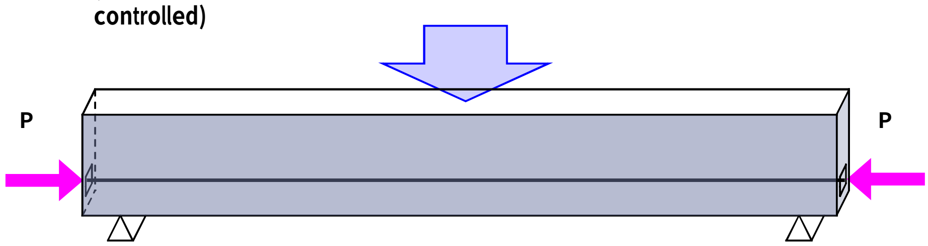
2. What is “Prestressed Concrete”?

2.1. Characteristics of concrete as a construction material

How to resist against tension in the concrete

Prestressed concrete beam

- Reinforced by prestressed tendons.
- Cracks can be controlled. (= state of stress can be controlled)



JICA Study Team 7

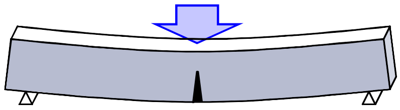
2. What is "Prestressed Concrete"?

2.1. Characteristics of concrete as a construction material

How to resist against tension in the concrete

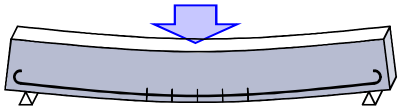
Plain concrete beam

- **Cannot resist tension, as its tensile strength is approx. 1/10 of compressive strength.**



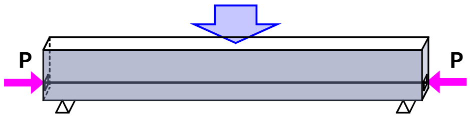
Reinforced concrete beam

- **Tension is carried by rebars.**
- **Some extent of cracks are inevitable.**



Prestressed concrete beam

- **Reinforced by prestressed tendons.**
- **Cracks can be controlled. (= state of stress can be controlled)**

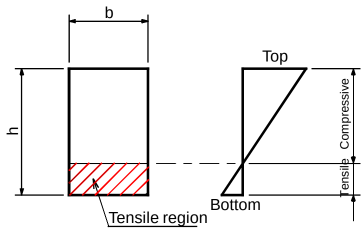


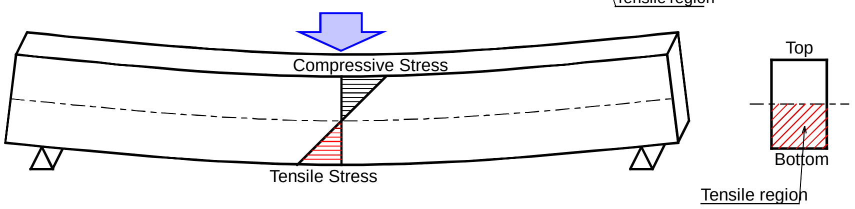
JICA Study Team 8

2. What is "Prestressed Concrete"?

2.2. Concept of prestressed concrete

As a flexural member, tensile side of concrete section shall be reinforced by some measures.





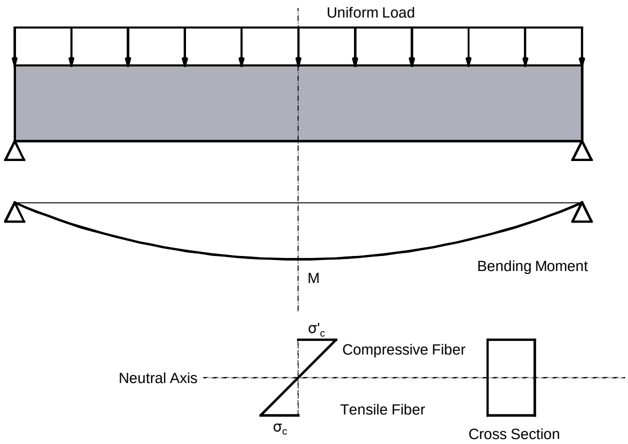
Reinforced concrete : Passive reinforcement
Prestressed concrete : Positive reinforcement

JICA Study Team 9

2. What is "Prestressed Concrete"?

2.2. Concept of prestressed concrete (cont.)

Bending moment and stress due to uniform load

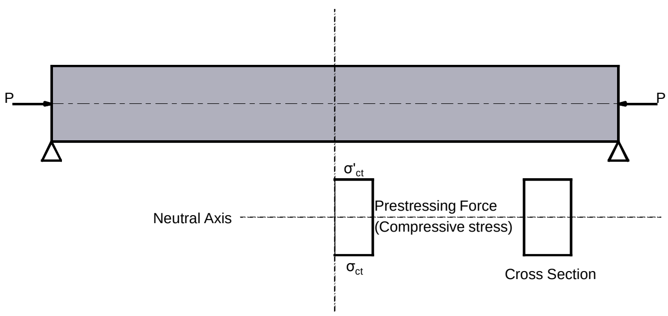


JICA Study Team 10

2. What is "Prestressed Concrete"?

2.2. Concept of prestressed concrete (cont.)

Stress by prestressing at centroid of the section

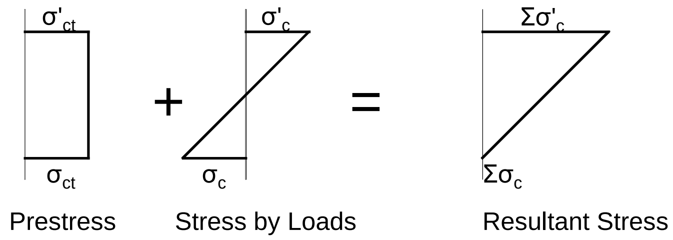


JICA Study Team 11

2. What is "Prestressed Concrete"?

2.2. Concept of prestressed concrete (cont.)

Resultant Stress

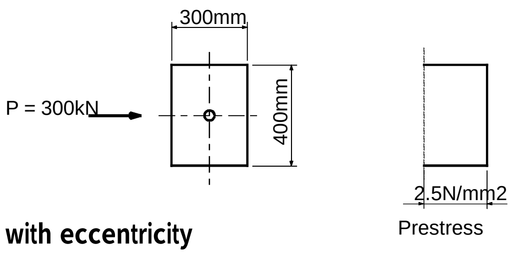


JICA Study Team 12

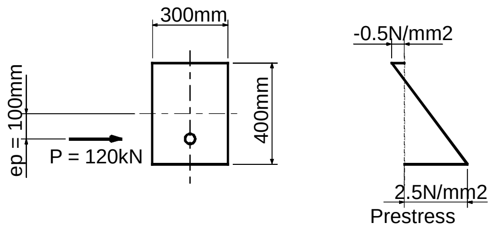
2. What is "Prestressed Concrete"?

2.2. Concept of prestressed concrete (cont.)

Prestressing at centroid of section



Prestressing with eccentricity

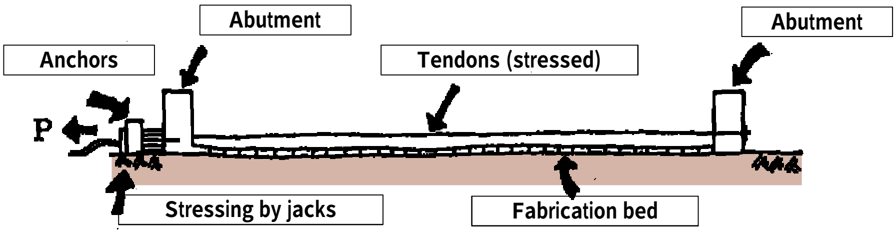


JICA Study Team 13

2. What is "Prestressed Concrete"?

2.3. Method of Prestressing

(1) Pre-tensioning



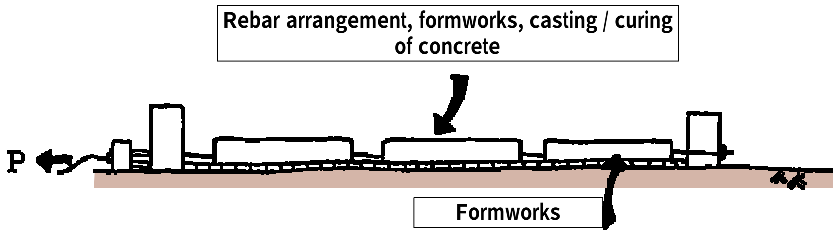
1) Stressing of Tendons

JICA Study Team 14

2. What is "Prestressed Concrete"?

2.3. Method of Prestressing

(1) Pre-tensioning



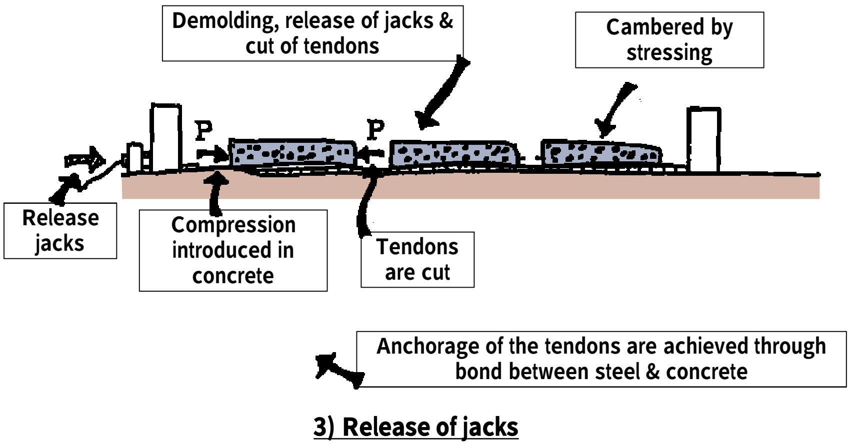
2) Casting & Curing of Concrete

JICA Study Team 15

2. What is “Prestressed Concrete”?

2.3. Method of Prestressing

(1) Pre-tensioning



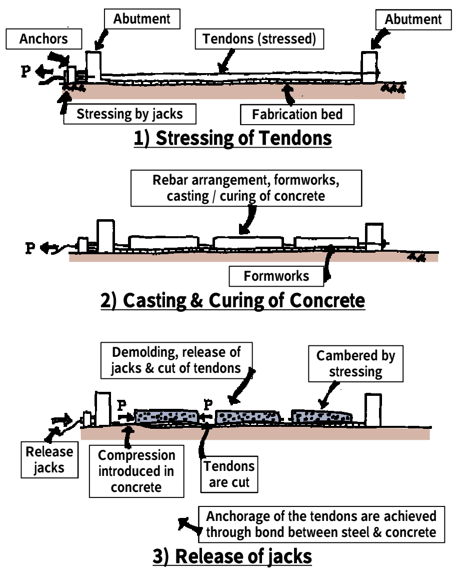
JICA Study Team 16

2. What is “Prestressed Concrete”?

2.3. Method of Prestressing

(1) Pre-tensioning

- Tendons are stressed before casting concrete
- Prestressing forces are kept by bond between steel and concrete
- Normally fabricated in factories

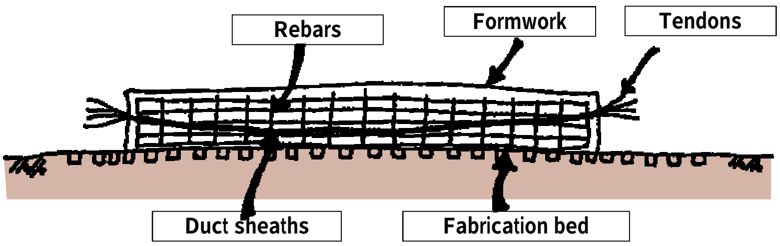


JICA Study Team 17

2. What is "Prestressed Concrete"?

2.3. Method of Prestressing

(2) Post-tensioning



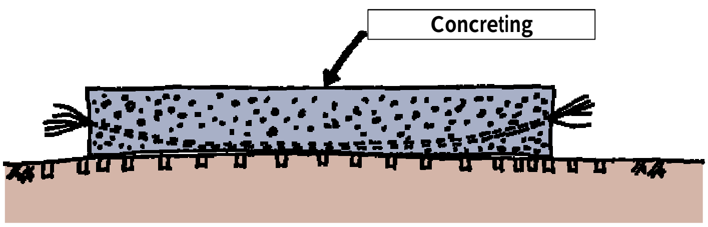
1) Arrangement of Rebars, Tendons & Formworks

JICA Study Team 18

2. What is "Prestressed Concrete"?

2.3. Method of Prestressing

(2) Post-tensioning



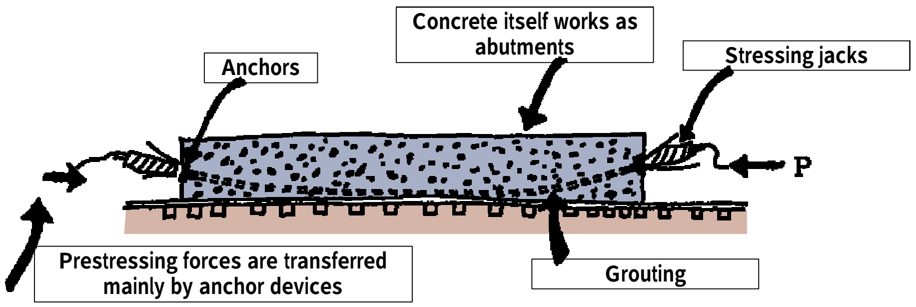
2) Casting of Concrete, Curing & Demolding

JICA Study Team 19

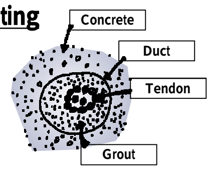
2. What is “Prestressed Concrete”?

2.3. Method of Prestressing

(2) Post-tensioning



3) Hardening of Concrete, Jacking of Tendons, & Grouting



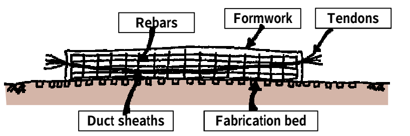
JICA Study Team 20

2. What is “Prestressed Concrete”?

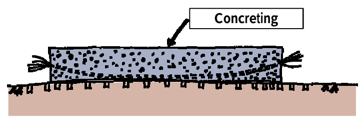
2.3. Method of Prestressing

(2) Post-tensioning

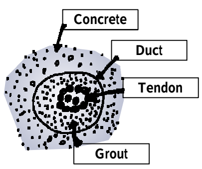
- Tendons are stressed after concrete has been cast / hardened
- Prestressing forces are kept mainly by anchors at the ends of tendons
- Suitable for construction on site

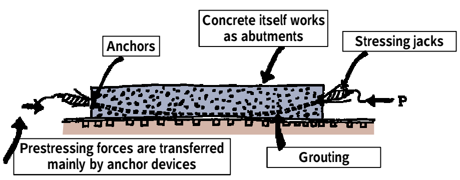


1) Arrangement of Rebars, Tendons & Formworks



2) Casting of Concrete, Curing & Demolding





3) Hardening of Concrete, Jacking of Tendons, & Grouting

JICA Study Team 21

2. What is “Prestressed Concrete”?

2.4. Classification by Degree of Prestressing

(1) Full prestressing
Concrete tensile stresses are eliminated under the action of design service loads, prestressing, and restraint deformations.

(2) Limited prestressing
Tensile stresses in the concrete must not exceed a specified permissible value.

(3) Partial prestressing
No restrictions on concrete tensile stresses under service conditions.

JICA Study Team 22

2. What is “Prestressed Concrete”?

2.5. Characteristics of Prestressed Concrete Structures

(1) Durability, impermeability than RC structures
- **No / limited cracks by prestressing**

(2) Lighter and slender than RC structures
- **Due to efficient use of cross section by controlling state of stress**

(3) Connection of precast elements by prestressing
- **Reduction of site work, mechanical erection, shortening of construction period**

(4) Applicable for segmental construction
- **Free cantilever, movable scaffolding, span-by-span erection etc.**

(5) Higher safety
- **Confirmation of safety at the time of prestressing**

(6) Higher capacity against fatigue
- **Smaller increase of tensile stress in steel**

(7) Smaller vibrations and noises

JICA Study Team 23

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures

(2) Architectural Buildings

(3) Storage Container Structures

(4) Marine Structures

JICA Study Team 24

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
1) Highway bridges

Manmunai Bridge, Sri Lanka

JICA Study Team 25

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
1) Highway bridges

Bridge Momoyama, Japan

JICA Study Team 26

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
1) Highway bridges

Miyagawa Bridge, Japan

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
1) Highway bridges

Usuyuki Bridge, Japan

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
1) Highway bridges

Incheon Grand Bridge, South Korea
(Viaducts: PC box girder, Approach bridges: PC rigid frame)

JICA Study Team 29

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
1) Highway bridges

Amerigo Vespucci Bridge, Italy

JICA Study Team 30

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
1) Highway bridges

Chillon Viaduct, Switzerland

JICA Study Team 31

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
1) Highway bridges

Sunniberg bridge, Switzerland

JICA Study Team 32

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
2) Railway bridges

Akkagawa Bridge, Japan

2. What is “Prestressed Concrete”?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
2) Railway bridges

Anegasaki Bridge, Japan

2. What is “Prestressed Concrete”?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
2) Railway bridges

Natorigawa Bridge, Japan

JICA Study Team 35

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
2) Railway bridges

Taiwan High Speed Rail Viaduct (Chiayi Station), Taiwan

JICA Study Team 36

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
2) Railway bridges

Narusegawa Bridge, Japan

JICA Study Team 37

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
2) Railway bridges

Contreras Viaduct, Italy

JICA Study Team 38

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
3) Others

- **pedestrian bridges, aqueduct bridges, monorails, MRTs, jetties … etc.**

Tsuru-no-hashi Bridge (pedestrian bridge), Japan

JICA Study Team 39

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
3) Others

- **pedestrian bridges, aqueduct bridges, monorails, MRTs, jetties … etc.**

Yume-tsuri-bashi Bridge (stress-ribbon bridge), Japan

JICA Study Team 40

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
3) Others

- **pedestrian bridges, aqueduct bridges, monorails, MRTs, jetties … etc.**

Haneda Monorail, Japan

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2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(a) Bridges
3) Others

- **pedestrian bridges, aqueduct bridges, monorails, MRTs, jetties … etc.**

Taipei MRT Viaduct (Jiantan Station), Taiwan

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2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(b) Others
1) PC rail sleepers, airport pavement

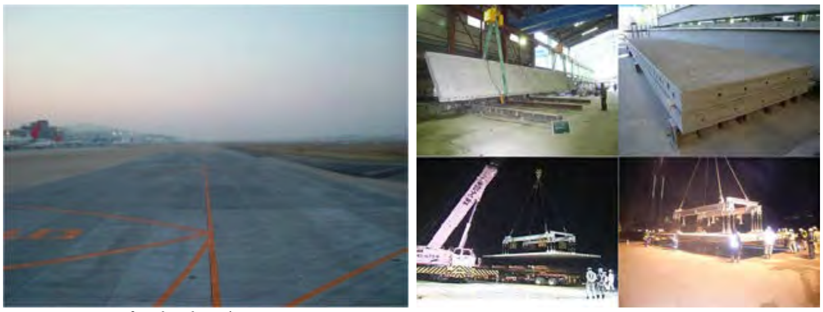
Various railway sleepers, Japan

JICA Study Team 43

2. What is “Prestressed Concrete”?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(b) Others
1) PC rail sleepers, airport pavement



Improvement of Fukuoka Airport Apron Pavement, Japan

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2. What is “Prestressed Concrete”?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(b) Others
2) Sheds / shelters (rock, snow)

Rebun Island Rock Shed, Japan

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2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(b) Others
2) Sheds / shelters (rock, snow)

Kuroishi Snow Shelter, Japan

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2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(b) Others
3) Earth anchors, artificial ground, culverts, sheet piles

Rock anchors at Ganter Bridge, Switzerland

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(b) Others
3) Earth anchors, artificial ground, culverts, sheet piles

Kakegawa Tsunami Shelter (Artificial Ground), Japan

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(b) Others
3) Earth anchors, artificial ground, culverts, sheet piles

A Portal Frame Culvert in Japan

JICA Study Team 49

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(1) Civil Engineering Structures
(b) Others
3) Earth anchors, artificial ground, culverts, sheet piles

PC sheet piles, Japan

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2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(2) Architectural Buildings

- **Schools, sports facilities, factories, warehouses, hangers, markets / freight centers, stadiums**

A School building, Japan

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2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(2) Architectural Buildings

- **Schools, sports facilities, factories, warehouses, hangers, markets / freight centers, stadiums**

A School Gymnasium, Japan

JICA Study Team 52

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(2) Architectural Buildings

- **Schools, sports facilities, factories, warehouses, hangers, markets / freight centers, stadiums**

A factory, Japan

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2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(2) Architectural Buildings

- **Schools, sports facilities, factories, warehouses, hangers, markets / freight centers, stadiums**

A Hanger in Leonardo da Vinci Airport, Italy

JICA Study Team 54

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(2) Architectural Buildings

- **Schools, sports facilities, factories, warehouses, hangers, markets / freight centers, stadiums**

Oarai Fish Market / Freight Center, Japan

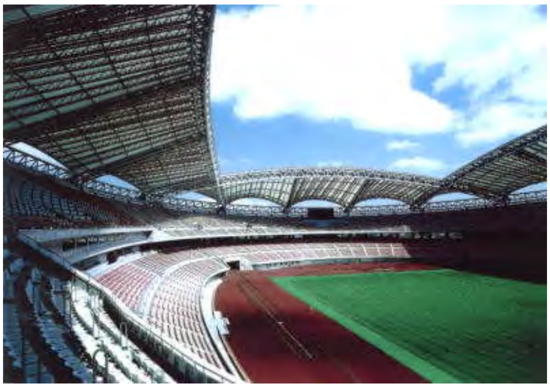
JICA Study Team 55

2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(2) Architectural Buildings

- **Schools, sports facilities, factories, warehouses, hangers, markets / freight centers, stadiums**



Niigata Stadium, Japan

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2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(3) Storage Container Structures

- **Water tanks, sewage treatment tanks, silos, POL tanks, gasholders, nuclear containment … etc.**

Water tanks, Japan

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2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(3) Storage Container Structures

- **Water tanks, sewage treatment tanks, silos, POL tanks, gasholders, nuclear containment … etc.**

Sewage treatment tanks, Japan

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2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(4) Marine Structures

- **Breakwaters, PC barges, artificial islands, concrete LNG storage barges … etc.**

Breakwaters in Jeju Port, South Corea

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2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(4) Marine Structures

- **Breakwaters, PC barges, artificial islands, concrete LNG storage barges … etc.**

Haneda Airport D Runway, Japan

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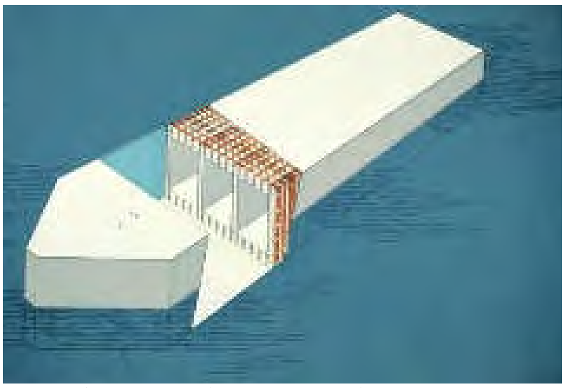
2. What is "Prestressed Concrete"?

2.6. Field of Application of Prestressed Concrete

(4) Marine Structures

- **Breakwaters, PC barges, artificial islands, concrete LNG storage barges … etc.**



LNG Platform Barge Project, Southeast Asia

Technical Transfer on Bago River Bridge Construction Project

Superstructure 1 (Concrete Bridges)
JICA Study Team

October 2017

Agenda

1. **History of Concrete Bridges**
2. **What is "Prestressed Concrete"?**
3. **Planning of Prestressed Concrete Bridges**
4. **Structure Type of Prestressed Concrete Bridges**
5. **Basis of Design of Prestressed Concrete Bridges**

3. Planning of Prestressed Concrete Bridges

3.1. Items to be considered in the planning of bridges

- **Purpose of usage of the bridge**
- **Natural conditions of the project site**
  - **Topography**
  - **Geological features**
  - **Meteorological conditions**
  - **Hydrological conditions … etc.**
- **Environmental conditions (natural and social)**
- **Aesthetics**
  - **Structural aesthetics of bridge itself**
  - **Visual harmony with surrounding landscape**

3. Planning of Prestressed Concrete Bridges

3.2. The elements to compose a bridge

- **Superstructure**
  - **Support the loads such as vehicle and pedestrians directly**
- **Substructure**
  - **Support the loads from superstructure and transfer the forces to foundation**
- **Foundation**
  - **Support the loads from substructure and transfer the forces to the ground**

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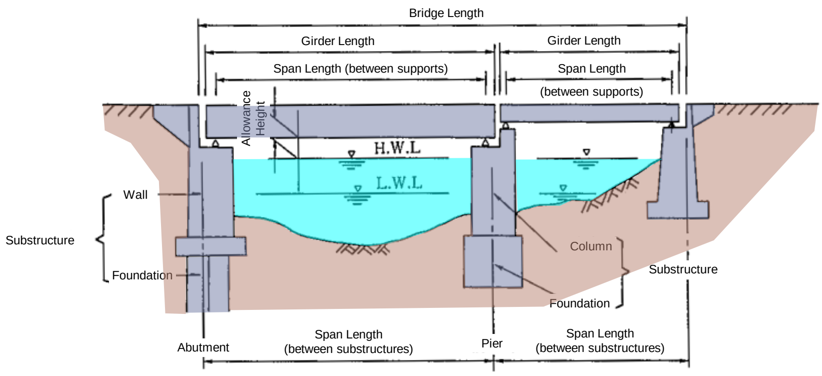
3. Planning of Prestressed Concrete Bridges

3.2. The elements to compose a bridge

Names of bridge elements



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3. Planning of Prestressed Concrete Bridges

3.3. Selection of bridge type in bridge planning

- **Economy**
- **Structural feature**
- **Workability / constructability**
- **Aesthetics**
- **Maintenance**
- **Drive confort / ride confort**

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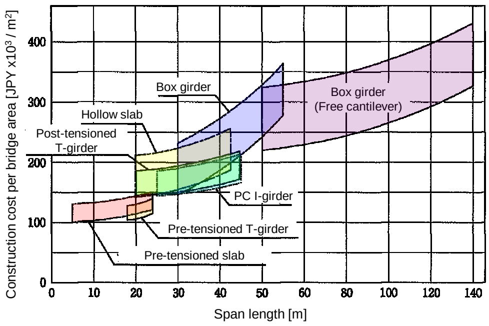
3. Planning of Prestressed Concrete Bridges

3.3. Selection of type in bridge planning

- **Economy**
  - **In general, longer maximum span →higher construction cost**
  - **Span length is controlled by the possible locations to place substructures.**
    - **Greatly depends on topographic conditions of the site**



Resource : "Manual for Planning of Highway Bridges", 2007, Japan Prestressed Concrete Contractors Association

Construction costs of superstructure by types and erection methods

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3. Planning of Prestressed Concrete Bridges

3.3. Selection of type in bridge planning

- **Structural features**
  - **Conditions from crossing obstacles**
    - **Large span is required when crossing rivers, canals, valleys … etc.**
    - **Navigational clearance shall be considered if vessel traffic is present.**
  - **Bridges crossing over roads & railways with small headroom**
    - **girder height might be limited**

3. Planning of Prestressed Concrete Bridges

3.3. Selection of type in bridge planning

- **Workability / constructability**
  - **Construction method**
    - **determined by topographic / gerlogical conditions, structural types ··· etc.**
    - **eg. Construction from the ground below, or construction from above ··· etc.**

3. Planning of Prestressed Concrete Bridges
3.3. Selection of type in bridge planning

- **Aesthetics**
  - **Geometric shape of the whole structure, shape of cross section, relationship with surrounding landscape ··· etc.**

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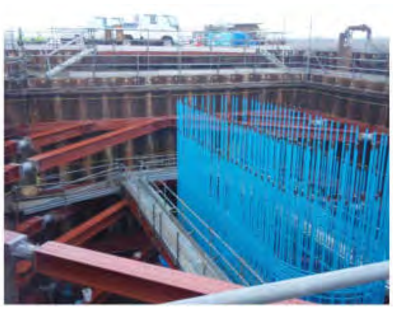
3. Planning of Prestressed Concrete Bridges
3.3. Selection of type in bridge planning

- **Maintenance**
  - **Relationship with environment (chloride damage … etc.)**
    - **Durable materials against deterioration, detailing … etc.**
  - **Fewer expansion joints / bearings**



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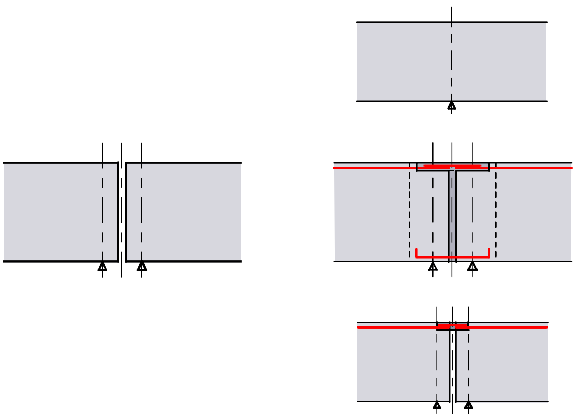
3. Planning of Prestressed Concrete Bridges
3.3. Selection of type in bridge planning

- **Drive comfort / ride comfort**
  - **Better ride comfort with fewer expansion joints**
    - **Making the deck continuous by continuous girder, spliced girders, link slab etc.**



3. Planning of Prestressed Concrete Bridges

3.4. Basics in planning of prestressed concrete bridges

(1) Structure types of prestressed concrete bridges

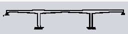
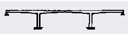
(2) General procedures of bridge planning

(3) Surveys to be carried out prior to bridge planning

3. Planning of Prestressed Concrete Bridges

3.4. Basics in planning of prestressed concrete bridges

(1) Structure types of prestressed concrete bridges

Structure type		Applicability	
		PCa	CIP
Simple girder bridge		✔	✔
Spliced girder bridge		✔	–
Continuous girder bridge		✔	✔
Continuous rigid frame bridge		✔	✔
Rigid frame bridge with hinge		*	✔
T frame bridge		*	✔
Cable stayed bridge		*	✔
Arch bridge		✔	✔
Truss bridge		✔	✔
Stress ribbon bridge		✔	✔

* : Applicability depends on the size of project etc.

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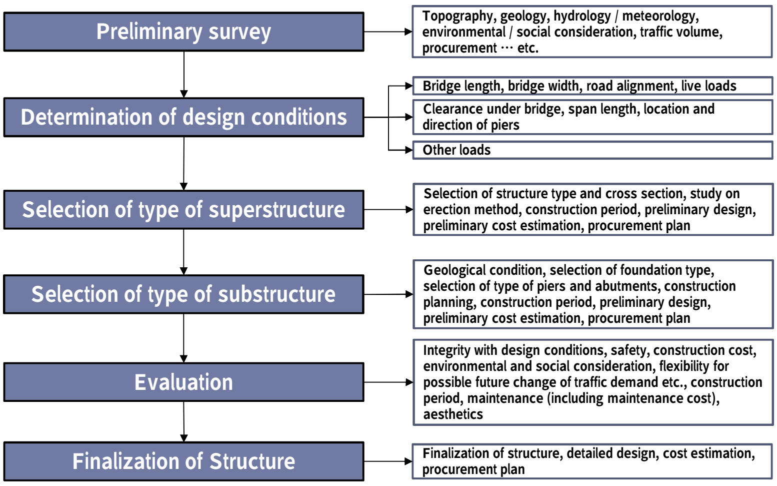
3. Planning of Prestressed Concrete Bridges

3.4. Basics in planning of prestressed concrete bridges

(2) General procedures of bridge planning



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3. Planning of Prestressed Concrete Bridges

3.4. Basics in planning of prestressed concrete bridges

(3) Surveys to be carried out prior to bridge planning

Item	Description
Topographic survey	Ground level, land use, faults, crossing obstacles etc.
Geological survey	Soil properties, bearing layer, groundwater level, risk of land slide etc.
Hydrological / meteorological survey	Water level, flow volume/velocity, conditions on use of river etc. Weather, climate (temperature), rainfall (rainy/dry seasons), snowfall, earthquake etc.
Environmental / social survey	Biota, air pollution, water contamination, noise, vibration, chloride damage, landscape etc. Land use, land owning, need for resettlement etc.
Traffic survey	Type of vehicles, loads, road width etc.
Construction condition	Access road, temporary roads, construction yards, neighboring projects etc.
Procurement	Construction materials / equipment (domestic / import), transportation, costs
Others	Electricity/water available for construction works, surrounding facilities, public utilities (need for relocation) etc.

3. Planning of Prestressed Concrete Bridges

3.5. Determination of design conditions

- Design conditions shall be determined taking into account the site conditions, relevant laws / regulations, design standards and specifications to be applied.
  - Standards on road geometry
  - Standards on river management
  - Standards on design & construction of bridges ··· etc.

3.5.1 Bridge length, bridge width, road alignment

- Mainly determined according to the basic plan of the road.
- Based on the laws and regulations relevant to road geometry, river management etc.
  - In Japan, "Government Ordinance on Road Design Standards", "Government Ordinance for Structural Standard for River Administration Facilities" etc.

3. Planning of Prestressed Concrete Bridges

3.5. Determination of design conditions

3.5.1 Bridge length, bridge width, road alignment

(1) Bridge length

- Bridge length is determined according to road plan, road alignment, location of bridge and abutments.
- The location of abutments are determined by the relationship with control points such as crossing obstacles (rivers, roads, railways, public utilities etc.), height of abutments etc.

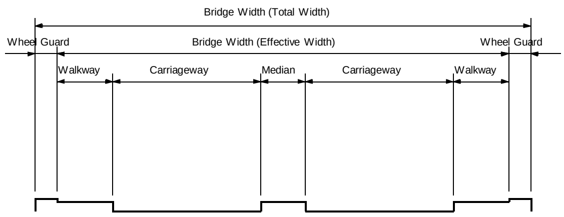
3. Planning of Prestressed Concrete Bridges

3.5. Determination of design conditions

3.5.1 Bridge length, bridge width, road alignment

(2) Bridge width

- **Bridge width is determined basically by the width composition of the road, based on the laws and regulations relevant to road geometry.**
- **Width composition depends on road classification, hence importance of the route (traffic demand etc.).**



3. Planning of Prestressed Concrete Bridges

3.5. Determination of design conditions

3.5.1 Bridge length, bridge width, road alignment

(3) Road alignment

- **Road alignment is determined by topographic features of the route etc., in accordance with the laws and regulations relevant to road geometry.**
  - **In Japan, “Government Ordinance on Road Design Standards” etc.**
- **Road alignment also depends on road classification, hence importance of the route (traffic demand etc.).**
- **Road alignment might include horizontal / vertical curve, variation of crossfall / superelevation etc.**

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3. Planning of Prestressed Concrete Bridges

3.5. Determination of design conditions

3.5.2 Span length, piers, clearance under bridge

(1) Span length

- **Center span: distance between center of piers**
- **Side span: distance between center of pier and parapet of abutment**
- **For river bridges, span length shall be determined to maintain smooth flow of water (also to avoid debris to stuck between piers at the time of flood)**
- **Other factors shall also be taken into account, such as relationship with center of flow, soil conditions, neighboring bridges, aesthetical consideration, construction method etc.**

JICA Study Team 22

3. Planning of Prestressed Concrete Bridges

3.5. Determination of design conditions

3.5.2 Span length, piers, clearance under bridge

(2) Piers

- **Pier thickness is determined firstly by structural requirement.**
- **For river bridges, pier thickness shall also be determined to maintain smooth flow of water. It is desirable to choose direction and shape of cross section (oval etc.) so as not to disturb river flow.**
- **Visual appearance (including relationship with surrounding landscape) is also important.**

JICA Study Team 23

3. Planning of Prestressed Concrete Bridges

3.5. Determination of design conditions

3.5.2 Span length, piers, clearance under bridge

(3) Clearance under bridge

- For river bridges, "design high water level" + "allowance height" shall be taken into account. Navigational clearance shall also be considered If vessel traffic under bridge is expected.
- Clearance for roads and railways under bridge shall be considered if necessary.

JICA Study Team 24

3. Planning of Prestressed Concrete Bridges

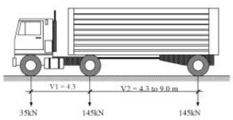
3.5. Determination of design conditions

3.5.3 Live loads

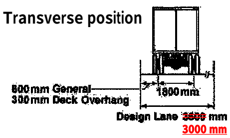
(1) Vehicular live load

1. AASHTO HL-93

(1)-1 Design truck (HS20-44)

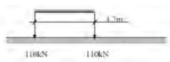


Transverse position



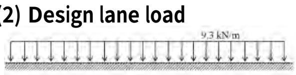
In Bago Bridge, Design Lane width is assumed to be 3000mm to be on the safer side.

(1)-2 Design tandem

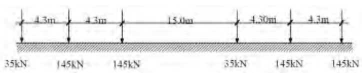


Transverse position of design tandem is same as design truck.

(2) Design lane load



(3) Two design trucks for negative moment



JICA Study Team 25

3. Planning of Prestressed Concrete Bridges

3.5. Determination of design conditions

3.5.3 Live loads

(1) Vehicular live load

1. AASHTO HL-93 (cont.)

Types of combination
1) (1)-1 + (2)
2) (1)-2 + (2)
3) (3) x 0.9 + (2) x 0.9

Where,
(1)-1 : Design truck (HS20-44)
(1)-2 : Design tandem
(2) : Design lane load
(3) : Two design trucks for negative moment

Multiple presence factor

Number of Loaded Lanes	Multiple Presence Factors, *m*
1	1.20
2	1.00
3	0.85
>3	0.65

Note: Nominal lane width shall be 3.0m.

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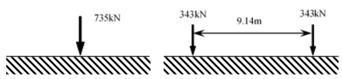
3. Planning of Prestressed Concrete Bridges

3.5. Determination of design conditions

3.5.3 Live loads

(1) Vehicular live load (cont.)

2. Special vehicular load (75t and 35t x 2 concentrated loads)



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3. Planning of Prestressed Concrete Bridges

3.5. Determination of design conditions

3.5.3 Live loads

(2) Pedestrian live load – N/A for Bago river bridge

In JRA Specifications,	3.0 ~ 3.5 kN/m2	for main girders
	5.0 kN/m2	for deck slabs and floor systems
In AASHTO LRFD,	3.6 x 10-3 MPa	for sidewalks of highway bridges
	4.1 x 10-3 MPa	for pedestrian/bicycle bridges

(3) Railway live load – N/A for Bago river bridge

1

Technical Transfer on Bago River Bridge Construction Project

Superstructure 1 (Concrete Bridges)
JICA Study Team

October 2017

JICA Study Team 2

Agenda

1. **History of Concrete Bridges**
2. **What is "Prestressed Concrete"?**
3. **Planning of Prestressed Concrete Bridges**
4. **Structure Type of Prestressed Concrete Bridges**
5. **Basis of Design of Prestressed Concrete Bridges**

4. Structure Type of Prestressed Concrete Bridges

4.1. Selection of Structure type

Applicable structure type of bridge is studied based on the design condition determined according to various survey.

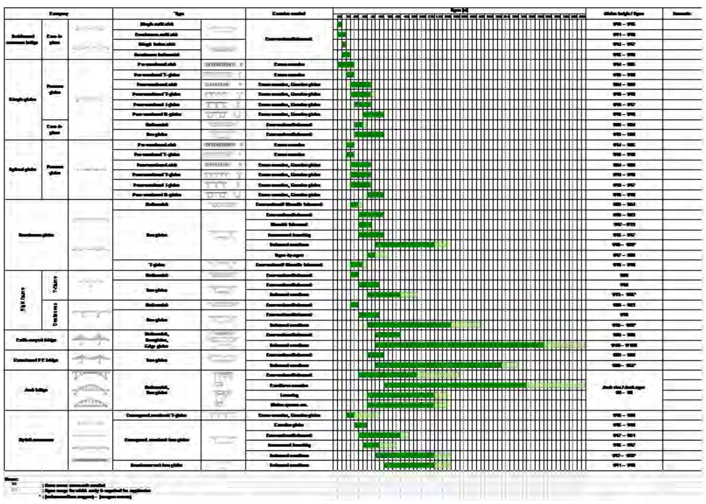
In general, the followings are determined according to maximum span length.

- **Structure type**
- **Shape of cross section**
- **Construction method ··· etc.**

4. Structure Type of Prestressed Concrete Bridges

4.1. Selection of Structure type

(1) Structure types and applicable span lengths



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4. Structure Type of Prestressed Concrete Bridges

4.1. Selection of Structure type

(2) Ratio of girder depth to span length h/L (for reference)

	Cross section, structure type, construction method etc.			h/L
PCa	Slab beam (JIS A5313 standard beam)			1/18 ~ 1/28
	Precast T-girder			1/16 ~ 1/20
	Precast I-girder			1/14 ~ 1/18
CIP	Hollow slab			1/20 ~ 1/25
	Double-T (Triple-T)			1/16 ~ 1/18
	Box girder	Conventional falsework, uniform girder height		1/20 ~ 1/22
		Free cantilever, uniform girder height		1/16 ~ 1/18
		Incremental launching, uniform girder height		1/16 ~ 1/18
		Continuous girder (haunched girder)	At pier	1/16 ~ 1/20
			At span center	1/30 ~ 1/40
		Hinged rigid frame (haunched girder)	At pier	1/15 ~ 1/18
			At center	1/40 ~ 1/60

JICA Study Team 6

4. Structure Type of Prestressed Concrete Bridges

4.2. Characteristics of typical structure types

General procedure of bridge planning

- **Selection of possible span arrangement**

↓

- **Selection of structure type (considering erection method)**
- **Selection of girder cross section**
- **Study on construction method ··· etc.**

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4. Structure Type of Prestressed Concrete Bridges

4.2. Characteristics of typical structure types

(1) Simple girder type

(a) Precast girder bridges

1) Pre-tensioned slab / T-girder

a) General features

- Normally applied to spans L = 5 ~ 24m (JIS A 5313)
- Easy erection.
- Most widely used.
- Low superstructure cost.
- Structurally simple and clear.

b) Points of consideration

- Short applicable span.
- Inferior in ride comfort due to expansion joints.
- Maintenance of expansion joints required.
- Unseating prevention connectors required against earthquake.

Pre-tensioned hollow slab

Pre-tensioned T-girder

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4. Structure Type of Prestressed Concrete Bridges

4.2. Characteristics of typical structure types

(1) Simple girder type

(a) Precast girder bridges

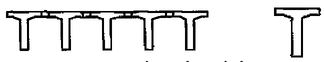
2) Post-tensioned T-girder

a) General features

- Normally applied to spans L = 20 ~ 45m (Japanese Standard Design of MLIT).
- Easy erection.
- Widely used.
- Low superstructure cost.
- Structurally simple and clear.
- Segmental construction can be applied if fabrication yard cannot be prepared.

b) Points of consideration

- Short applicable span.
- Inferior in ride comfort due to expansion joints.
- Maintenance of expansion joints required.
- Unseating prevention connectors required against earthquake.



Post-tensioned T-girder

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4. Structure Type of Prestressed Concrete Bridges

4.2. Characteristics of typical structure types

(1) Simple girder type

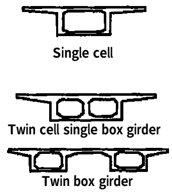
(b) Cast-in-place girder bridges

a) General features

- Box or hollow slab are normally used for cross section.
- Hollow slab : normally applied to L = 20 ~ 30m
- Box girder : normally applied to L = 30 ~ 60m
- Suitable to complicated alignment.
- Constructed by conventional falsework.

b) Points of consideration

- No standardized design.
- Inferior in ride comfort due to expansion joints.
- Maintenance of expansion joints required.
- Unseating prevention connectors required against earthquake.



Types of box cross section


Cross section of hollow slab

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4. Structure Type of Prestressed Concrete Bridges

4.2. Characteristics of typical structure types

(2) Spliced girder type

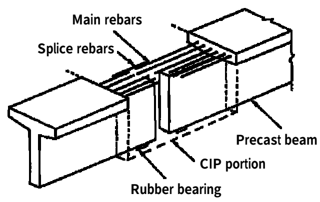
Aimed to improve ride comfort and durability by splicing girders at intermediate support and omitting expansion joints, while maintaining benefits of precast girders

a) General features

- Same benefits with simple girders.
- Applicable to all types of precast girders.
- Good ride comfort as well as continuous girder.
- Easier maintenance due to elimination of expansion joints and unseating prevention connectors.

b) Points of consideration

- Rubber bearings shall be used at intermediate supports.
- Substructures shall be designed with similar consideration to continuous girders.



Detail of Girder Splicing

4. Structure Type of Prestressed Concrete Bridges

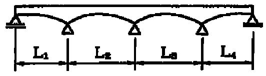
4.2. Characteristics of typical structure types

(3) Continuous girder type

(a) Continuous girder bridges

a) General features

- Most normal type in cast-in-place PC bridges.
- Normally applied to spans L = 20 ~ 120m.
- Good ride comfort and low vibration / noise due to elimination of expansion joints.
- Various erection methods and cross section shapes can be used.
- Maximum continuous length reaches up to approx. 500m when elastomeric rubber bearings are used to distribute horizontal forces to each substructure. (The maximum length also depends on effect of earthquake.)



Continuous girder

b) Points of consideration

- Bearings are required at supports.
- Periodic maintenance is required when steel bearings are used.

4. Structure Type of Prestressed Concrete Bridges

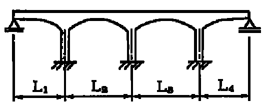
4.2. Characteristics of typical structure types

(3) Continuous girder type

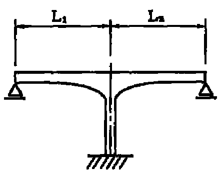
(b) Continuous rigid frame bridges

a) General features

- Similar features with continuous girder bridges.
- Superior in construction cost, maintenance and distribution of horizontal forces to each substructure as bearings are not installed at intermediate supports.
- In case of T-frame bridge, applicable span length corresponds to the side span of continuous rigid frame bridges.



Continuous rigid frame



T-frame

b) Points of consideration

- Difficulty in application when piers are very low (e.g H < 10m etc.) due to the effect of restraint forces by creep, shrinkage and temperature.

4. Structure Type of Prestressed Concrete Bridges

4.2. Characteristics of typical structure types

(3) Continuous girder type

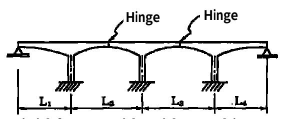
(c) Rigid frame bridges with midspan hinges

a) General features

- Longitudinal seismic forces are carried by each piers. Restraint forces are released by hinges at midspan.
- In general, haunched box girder is used, and constructed by free cantilever method.
- Economical than monolithic connections since redistribution of sectional forces is small.
- Applied to the spans L = 60 ~ 180m.
- Girder erection can be started from any piers, and construction period can be shortened.

b) Points of consideration

- Disadvantages with regard to serviceability (discontinuities in roadway grade at midspan).
- Inferior in durability and ride comfort when expansion joint is used.



Rigid frame with midspan hinges

4. Structure Type of Prestressed Concrete Bridges

4.3. Categorization by Erection Method

Condition \ Erection method		Precast: Precast girder: Erection girder	Precast: Precast girder: Crane erection	Precast: Precast segment: All-staging	Precast: Precast segment: Span-by-Span erection	Precast: Precast segment: Erection girder	Precast: Precast segment: Free cantilever by derrick crane	Cast-in-Place: Conventional falsework: prefabricated falsework	Cast-in-Place: Conventional falsework: column-type falsework	Cast-in-Place: Movable falsework: Hanger type	Cast-in-Place: Movable falsework: Support-type	Cast-in-Place: Cantilever erection: Free cantilever by form traveller	Cast-in-Place: Cantilever erection: Erection girder	Cast-in-Place: Incremental launching: Concentrated jacks	Cast-in-Place: Incremental launching: Distributed jacks
Span length	20~40m	◎	◎	◎	◎	△	△	◎		◎		△		◎	
	40~60m	○	※	○	○	※	※	◎		○		○		◎	
	60~80m	△	△	※	※	◎	◎	○		※		◎		※	
	80~100m	△	△	△	※	○	◎	※		△		◎		△	
	>100m	△	△	△	※	※	◎	※		△		◎	○	△	
Construction condition	Variation of girder depth	○	○	○	※	◎	◎	○		※	○	◎		△	
	Horizontal curve	○	○	○	○	○	◎	◎		○	◎	◎	○	○	
	Widening of main girder	○	○	※	※	※	※	◎		※		◎	○	※	
	Space under girder	◎	○	※	◎	◎	◎	△	○	◎	※	◎		◎	
	Rapid construction	○	○	○	◎	◎	◎	※		○		○		○	
	Advantage for multiple spans	◎	◎	※	◎	◎	◎	※		◎		○		◎	
	Safetey under girder	○	○	○	○	○	○	○		○		○		◎	
	Advantage for weather condition	※	※	○	◎	◎	◎	※		◎	※	◎		◎	
	Transportation of material & equipment w/o using under girder	◎	△	△	◎	◎	※	△		◎	△	※	◎	◎	
	Construction of high bridge	◎	※	△	◎	◎	◎	※	※	◎	△	◎		◎	

Legend
◎: Most applicable
○: Applicable
△: Not applicable
※: Careful study required for application

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4. Structure Type of Prestressed Concrete Bridges

4.3. Categorization by Erection Method

Cast-in-place (by All-staging)

- **Most conventional method for cast-in-place construction.**
- **The ground under bridge shall have sufficient capacity to support the loads during construction.**

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4. Structure Type of Prestressed Concrete Bridges

4.3. Categorization by Erection Method

Precast Girders (Erection by Cranes)

- **Common method for erection of precast girders.**
- **Erection height is limited.**

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4. Structure Type of Prestressed Concrete Bridges

4.3. Categorization by Erection Method

Precast Girders (by Erection girders)

- **Superstructure can be erected without using space under bridge.**
- **Erection height is not limited.**

Hung below erection girder

Slid above erection girder

Supported by 2 beams aside

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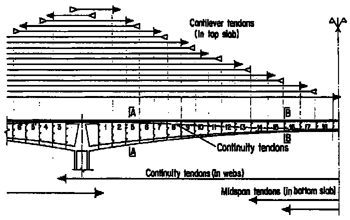
4. Structure Type of Prestressed Concrete Bridges

4.3. Categorization by Erection Method

Cantilever erection (by form travelers or erection girder)

- **Superstructure can be erected without using space under bridge.**
- **Tendon arrangement can be efficient as the arrangement of cantilever tendon closely balances the moment diagram.**
- **Both CIP and precast are applicable.**



Typical tendon arrangement for free cantilever erection

Free Cantilever Method (FCM) with form travelers

Cantilever erection with erection girder (P & Z Method)

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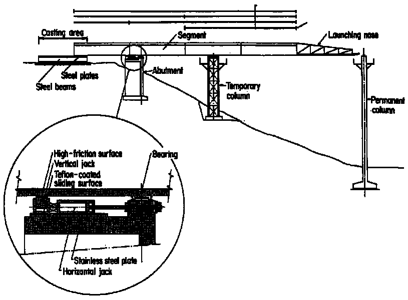
4. Structure Type of Prestressed Concrete Bridges
4.3. Categorization by Erection Method

Incremental launching erection

- **Superstructure can be erected without using space under bridge.**
- **Erection height is not limited.**
- **Horizontal alignment must be straight or of constant curvature**



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4. Structure Type of Prestressed Concrete Bridges
4.3. Categorization by Erection Method

Movable falsework erection

- **Superstructure can be erected without using space under bridge.**
- **Erection height is not limited.**
- **Having advantages in projects of large size**

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4. Structure Type of Prestressed Concrete Bridges

4.3. Categorization by Erection Method

Span-by-span erection

- Superstructure can be erected without using space under bridge.
- Erection height is not limited.
- Horizontal alignment must be straight or of slight curvature
- Having advantages in projects of large size
- Construction period can be shortened in combination with application of precast segments.

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4. Structure Type of Prestressed Concrete Bridges

4.4. Construction Using Precast Segments

General Characteristics of Precast Segment Method

[**Advantages**]

- Shorter construction period than cast-in-place construction due to separation of segment fabrication work and erection work
- Stable quality due to concentrated control and mechanized fabrication of segments such as formworks etc.
- Upskilling effect due to regular repetition of identical fabrication / erection work, and laborsaving due to mechanization
- Lower loss of prestress by smaller creep / shrinkage deformation of members after erection, due to storage periods of segments after fabrication

[**Disadvantages**]

- No longitudinal tensile stress permitted, as the reinforcements is discontinuous at the joints between segments
- Normally economical only for long bridges, due to the high cost of fabrication / erection equipment

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4. Structure Type of Prestressed Concrete Bridges

4.4. Construction Using Precast Segments

Manufacture of Precast Segments

[**Long-line casting**]

- **All segments to make up either half or a full cantilever are manufactured on a fixed bed with the formwork moving along the bed for the successive casting operations**

[**Short-line casting**]

- **Segments are manufactured in a step-by-step procedure with the forms maintained at a stationary position**

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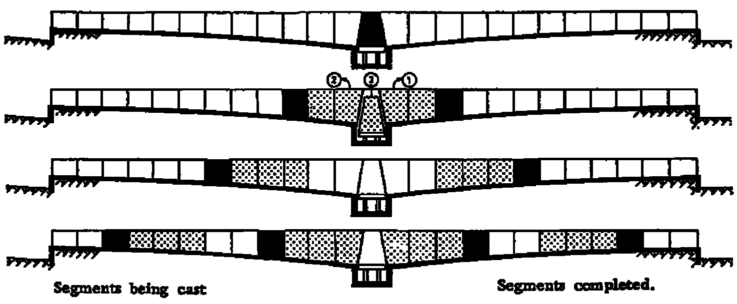
4. Structure Type of Prestressed Concrete Bridges

4.4. Construction Using Precast Segments

Manufacture of Precast Segments

Typical long-line precast bed



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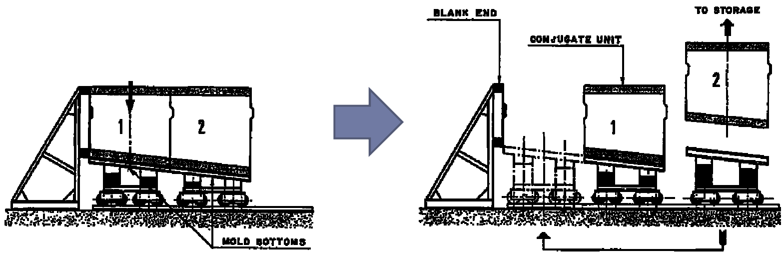
4. Structure Type of Prestressed Concrete Bridges

4.4. Construction Using Precast Segments

Manufacture of Precast Segments

Typical short-line precasting operation



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4. Structure Type of Prestressed Concrete Bridges

4.4. Construction Using Precast Segments

Characteristics of Long-line and Short-line method

	Long-line casting	Short-line casting
Accommodation to complicated alignment, variety of cross section	• Easily applicable, as the bed is prepared for final shape of the girder	• Fabrication is complicated when girder height etc. varies
Fabrication equipment	• Simple and inexpensive equipment	• Large and expensive equipment • Laborsaving is possible by mechanizing equipment
Fabrication cycle	• Long fabrication cycle	• Many segments can be fabricated in short period due to short cycle (1 segment / day)
Fabrication yards	• Large yard is required due to the long fabrication bed	• Smaller fabrication yard
Suitability	Bridges with varying cross section, or small bridges with few segments	Large / long bridges with many segments of unified cross section

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4. Structure Type of Prestressed Concrete Bridges

4.4. Construction Using Precast Segments

Transfer of Precast Segments

- In large projects with large or many segments, loading / unloading facilities such as gantry crane or transfer crane shall be equipped.
- These cranes are used to transfer the segments from fabrication yard to stock yard.
- From stock yard to construction site, the segments are normally transported by trailers etc.

Storage of Precast Segments

- The ground of stock yards shall have sufficient bearing capacity, and the soil shall be improved, if necessary, to avoid settlement.
- Segments are normally placed on buffer material (plywood etc.) supported by H-beam etc.

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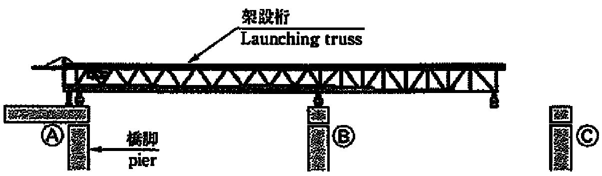
4. Structure Type of Prestressed Concrete Bridges

4.5. Span-by-Span Erection

Procedure of Span-by-span erection

[Step-1]

Placing the pier segments and installing the overhead truss on them.



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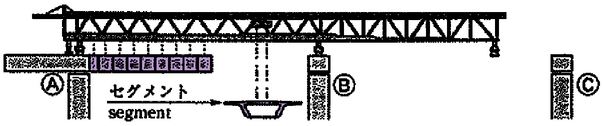
4. Structure Type of Prestressed Concrete Bridges

4.5. Span-by-Span Erection

Procedure of Span-by-span erection

[Step-2]

Lifting all segments of one span to be assembled.



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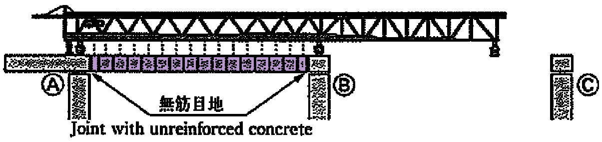
4. Structure Type of Prestressed Concrete Bridges

4.5. Span-by-Span Erection

Procedure of Span-by-span erection

[Step-3]

Placing and curing concrete at key segments (unreinforced closure joints).



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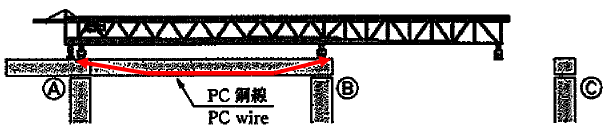
4. Structure Type of Prestressed Concrete Bridges

4.5. Span-by-Span Erection

Procedure of Span-by-span erection

[**Step-4**]

Post-tensioning the entire span.



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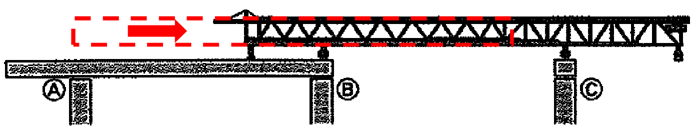
4. Structure Type of Prestressed Concrete Bridges

4.5. Span-by-Span Erection

Procedure of Span-by-span erection

[**Step-5**]

Launching the overhead truss forward and repeat new cycle.



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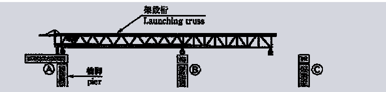
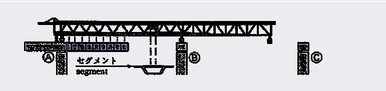
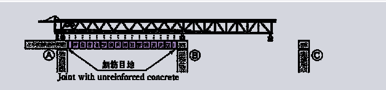
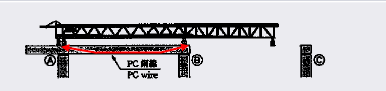
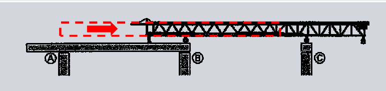
4. Structure Type of Prestressed Concrete Bridges

4.5. Span-by-Span Erection

Procedure of Span-by-span erection

Step	Schematic View
[Step-1] Placing the pier segments and installing the overhead truss on them.	
[Step-2] Lifting all segments of one span to be assembled.	
[Step-3] Placing and curing concrete at key segments (unreinforced closure joints).	
[Step-4] Post-tensioning the entire span.	
[Step-5] Launching the overhead truss forward and repeat new cycle.	

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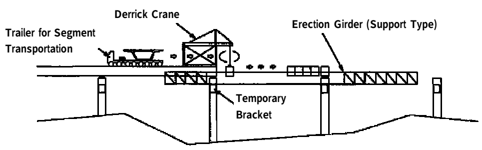
4. Structure Type of Prestressed Concrete Bridges

4.5. Span-by-Span Erection

Type of Erection Girders for SBS Method

Support Type



- Applicability depends on
  - alignment (shall be basically straight or slight curvature)
  - shape and height of piers (temporary bracket are required to support erection girder) ··· etc.
- Segments can be transported on completed superstructure, without using space under girder.

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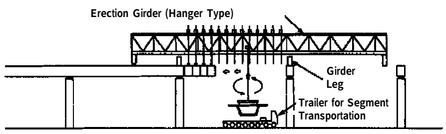
4. Structure Type of Prestressed Concrete Bridges

4.5. Span-by-Span Erection

Type of Erection Girders for SBS Method

Hanger Type



- Higher flexibility on application to
  - Curved alignment
  - Change of bridge width ··· etc.
- Segments are basically transported from under the bridge (In this case, access to the space under the bridge is necessary).
- Transportation on completed girder (without using space under bridge) is also possible if special type of erection girder is used.

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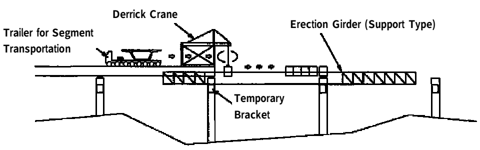
4. Structure Type of Prestressed Concrete Bridges

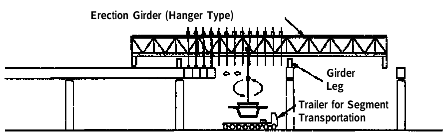
4.5. Span-by-Span Erection

Type of Erection Girders for SBS Method

Support Type



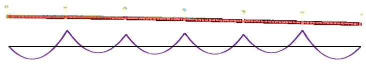
Hanger Type



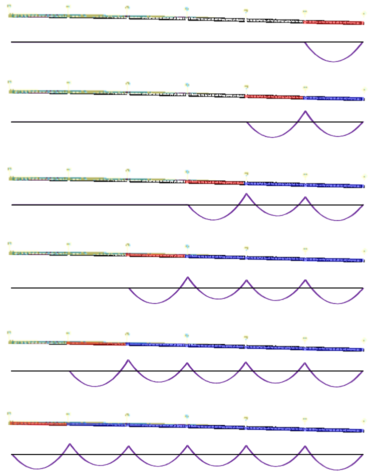
JICA Study Team 37

4. Structure Type of Prestressed Concrete Bridges

4.5. Span-by-Span Erection



Bending moment due to self weight assuming all spans cast at once



Transition of bending moment according to progress of erection

JICA Study Team 38

4. Structure Type of Prestressed Concrete Bridges

4.5. Span-by-Span Erection

Points of Consideration on Planning

[**Segment Length**]

In case of insufficient fabrication / stock yard for segments adjacent to construction site:

- **Segments must be transported via public road from factory or distant fabrication yards**
- **Segments length must thus be determined from the viewpoints of transportation (max. ~ 3 m), as well as economy and structural aspects etc. (Too short segments are not reasonable.)**

[**Pier Segments**]

For pier segments, weight reduction must be studied:

- **Splitting of segment, casting diaphragms in place after installation … etc.**

[**Prestressing of Deck Slabs**]

- **Both post-tensioning and pre-tensioning can be applied for deck slab prestressing.**
- **Pre-tensioning method**
  - **Possible to save on-site work and advantageous for projects with many segments**
  - **On the other hand, difficulties on geometry control of segments (matching at joints between segments etc.).**
- **Post-tensioning method**
  - **Needs more labor work than pre-tensioning method**
  - **However, geometry control of segments is easier than pre-tensioning.**

1

Technical Transfer on Bago River Bridge Construction Project

Superstructure 1 (Concrete Bridges)
JICA Study Team

October 2017

JICA Study Team 2

Agenda

1. **History of Concrete Bridge**
2. **What is "Prestressed Concrete"?**
3. **Planning of Prestressed Concrete Bridges**
4. **Structure Type of Prestressed Concrete Bridges**
5. **Basis of Design of Prestressed Concrete Bridges**

JICA Study Team 3

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.1. General

In this section, basic points in the design of prestressed concrete bridges are described.

- The description is basically based on PC box girder bridges using precast segments erected by Span-by-Span (SBS) Method (Same type as Bago River Bridge (approach section)).
- Reference design standards are "Specifications for Highway Bridges" by Japan Road Association ("JRA Specifications") and "AASHTO LRFD Bridge Design Specifications" for HL-93 live loads.

JICA Study Team 4

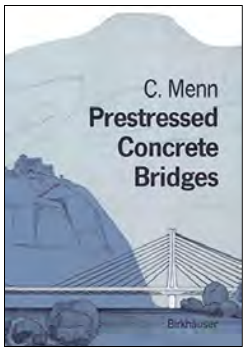
5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.1. General (cont.)

- This lecture is generally based on "Design of Prestressed Concrete Bridges for Beginners (「やさしいPC橋の設計」)" from Japan.
- There are some more reference books / documents useful for studying design and planning of prestressed concrete bridges in more detail.

"Design of Prestressed Concrete Bridges for Beginners"
by Japan Prestressed Concrete Contractors Association



A book on planning and design of prestressed concrete bridges based on practical experiences

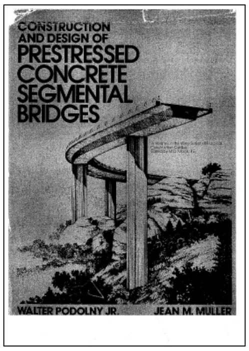
JICA Study Team 5

5. Basis of Design of Prestressed Concrete Bridges

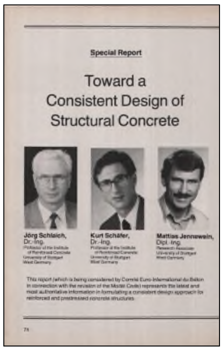
5.1. Outline

5.1.1. General (cont.)

- Some more reference books / documents useful for studying design and planning of prestressed concrete bridges in more detail (cont.).



A book on planning, design and construction of prestressed concrete segmental bridges (both CIP and precast) based on practical experiences



An issue in PCI Journal describing "Strut-and-Tie model" useful for design of "D-regions" ("D" stands for discontinuity, disturbance or detail) of RC / PC structures, as an expanded concept of truss model.

JICA Study Team 6

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(1) Procedure of Detailed Design

[Assumption of Shape/Dimension and Calculation of Sectional Forces]

- Confirmation of design conditions (structural standards, site conditions, material properties ··· etc.).
- Assumption of member shape / dimensions based on the design condition.
- Calculation of sectional forces based on the above-assumed members.

[Check of Stresses under Service Loads]

- JRA Specifications is based basically on allowable stress method.
- Member elements (reinforcement, PC tendons and concrete) are checked to satisfy specified allowable values under most critical actions (bending moment, shear etc.) due to specified combinations of service loads.

[Check of Safety against Failure]

- Member elements are also checked for safety of resistance against failure under most critical actions due to specified combinations of ultimate loads as well.

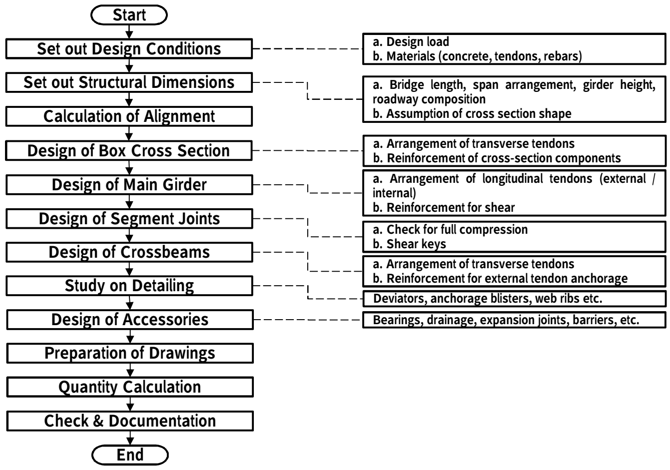
JICA Study Team 7

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(1) Procedure of Detailed Design



JICA Study Team 8

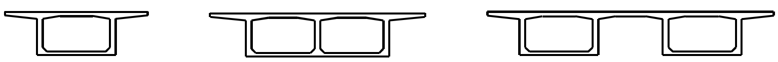
5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(2) Determination of Cross Section

- Cross section of girder is determined according to the given conditions (span arrangements, bridge width etc.)
  - Girder Height
  - Box width (number of boxes / cells, ratio of box width to bridge width)



- In general, the shape of cross section is selected to most efficiently resist against bending moment, as flexure (= bending) is normally one of the most dominant factors for girders.

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(2) Determination of Cross Section

1) Girder Height

- **Desirable ratio of girder height (H) to span length (L) normally depends on loads, type of cross section, structure type, erection method ··· etc.**
- **Desirable ratio of H/L for box girder bridges by SBS erection**
  = 1/17 ~ 1/20 (for highway bridges)
- **In the case of Bago River Bridge,**
  L = 50.0m, H = 2.7m, H/L = 1/18.5

Category		Type		Erection method	Span [m] (10 20 30 40 50 60 70 80 90 100 110 120 130 140 150)	Girder depth / Span	Remarks
Continuous girder		Hollowslab		Conventional / Movable falsework		1/20 – 1/24	
		Box girder		Conventional falsework		1/18 – 1/22	
				Movable falsework		1/17 – 1/22	
				Incremental launching		1/15 – 1/17	
				Balanced cantilever		1/18 – 1/36*	
				Span-by-span		1/17 ~ 1/20	
		T-girder		Conventional / Movable falsework		1/13 – 1/18	

Notes:
: Span range commonly applied
: Span range for which study is required for application
* : (at intermediate support) – (at span center)

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(2) Determination of Cross Section

2) Box Width

- **Ratio of box width B to bridge width D (= deck slab width) is determined taking into account the balance of bending moment in deck slab.**
- **In JRA Specifications, common deck span lengths are as follows:**

Category	Structure	Span length
Simple and Continuous Slab	RC	0 ≦L ≦4.0
	PC	0 ≦L ≦6.0
Cantilever Slab	RC	0 ≦L ≦1.5
	PC	0 ≦L ≦3.0

- **Desirable ratio of B/D is as follows:**

Type of Cross Section		Deck Structure	Desk Slab Width: D [m] (5 10 15)	Ratio of Box Width to Deck Slab Width: B / D	Remarks
1 cell box		RC		055 ~ 0.65	
		PC		0.50 ~ 0.60	
2 cells box		RC		0.64 ~ 0.72	
		PC		0.64 ~ 0.72	

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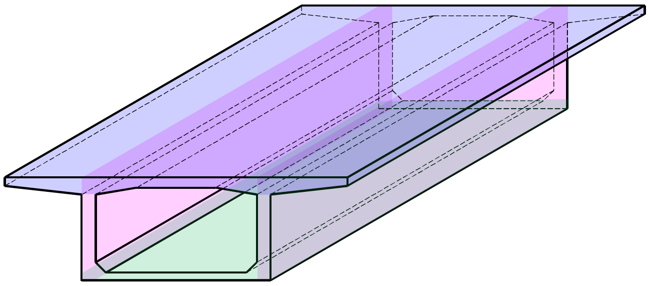
5. Basis of Design of Prestressed Concrete Bridges
5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts
(2) Determination of Cross Section

3) Structural Function of Cross-Section Components

- Cross-section of box girder is composed of deck slab, webs and bottom slab.



JICA Study Team 12

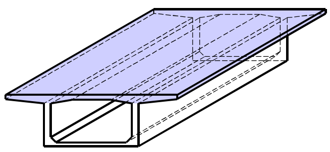
5. Basis of Design of Prestressed Concrete Bridges
5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts
(2) Determination of Cross Section

3) Structural Function of Cross-Section Components

(a) Deck Slab

	Structural Function	Structural Response
Transverse	as a slab, to carry its self-weight & live load to the webs	transverse bending, longitudinal bending & vertical shear
	as a frame component, to resist distortion of the section	transverse bending & vertical shear
Longitudinal	as a tension or compression chord, to resist bending of the entire cross-section about its horizontal axis	longitudinal axial force & in-plane shear
	as a shear wall, to resist torsion of the entire cross-section	longitudinal axial force & in-plane shear
	as a web, to resist bending of the entire cross-section about its vertical axis (lateral bending)	longitudinal axial force & in-plane shear



Reference value of deck slab thickness
- 270mm (at box center)
- 450mm (at webs)
- 250mm (at the tip of cantilever, depending on the transverse tendons)
- Installation of longitudinal internal tendons shall be taken into account if necessary.

JICA Study Team 13

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

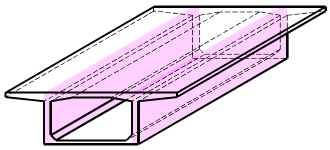
5.1.2. Procedure of Design Calculation and Basic Concepts

(2) Determination of Cross Section

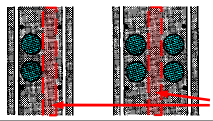
3) Structural Function of Cross-Section Components

(b) Webs

	Structural Function	Structural Response
Longitudinal	as a web, to resist bending of the entire cross-section about its horizontal axis	vertical shear & longitudinal axial force (+ vertical axial forces)
Longitudinal	as a shear wall, to resist torsion of the entire cross-section	longitudinal axial force & vertical shear
Longitudinal	as a tension or compression chord, to resist bending of the entire cross-section about its vertical axis	longitudinal axial force & in-plane shear
Transverse	as a frame component, to provide rotational restraint to the deck slab and (when applicable) bottom slab, as well as to resist distortion of the section	transverse bending & vertical shear



Minimum web thickness (for reference)
- 300mm ~ (with no or 1 row of internal tendons)
- 350mm ~ (with 2 rows of internal tendons)



Space for internal vibrators

JICA Study Team 14

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

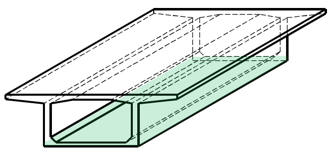
5.1.2. Procedure of Design Calculation and Basic Concepts

(2) Determination of Cross Section

3) Structural Function of Cross-Section Components

(c) Bottom Slab

	Structural Function	Structural response
Transverse	as a slab, to carry its self-weight & any superimposed loads to the webs	primarily transverse bending, as well as vertical shear
Transverse	as a frame component, to resist distortion of the section	transverse bending & vertical shear
Longitudinal	as a tension or compression chord, to resist bending of the entire cross-section about its horizontal axis	longitudinal axial force & in-plane shear
Longitudinal	as a shear wall, to resist torsion of the entire cross-section	longitudinal axial force & in-plane shear
Longitudinal	as a web, to resist bending of the entire cross-section about its vertical axis (lateral bending)	longitudinal axial force & in-plane shear



Minimum bottom slab thickness
- 200mm (without internal tendons)
- 250mm (with internal tendons)
- Thickness of bottom slabs at intermediate supports are determined considering compressive stress.
- When tendons are anchored at bottom slab, thickness shall be carefully studied.

JICA Study Team 15

5. Basis of Design of Prestressed Concrete Bridges

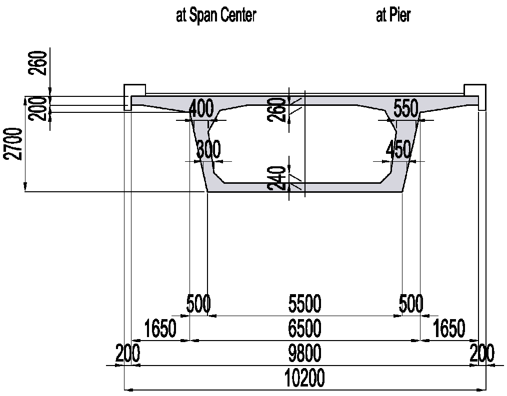
5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(2) Determination of Cross Section

3) Thickness of Cross-Section Components

In case of Bago River Approach Bridge (Standard section, for reference)



JICA Study Team 16

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(3) Flexure and Axial Force

- **In RC members, some extent of cracks are allowed as long as they are not harmful in the viewpoints of durability and serviceability under service load state.**
- **On the other hand, cracks are not allowed under service load state in PC members, excluding exceptional loads such as collision or earthquake etc., while tensile stress within allowable value are acceptable.**
- **For concrete members subjected to flexure and axial force, both of the following shall be checked basically:**
  - **Serviceability under service load state (stresses shall be within allowable value.)**
  - **Safety against failure under ultimate load state (ultimate bending moment at a cross section shall be smaller than the flexural resistance of the section.)**
- **In order to prevent brittle failure and to maintain ductile behavior of the structure, tensile reinforcement provided in concrete members subjected to flexure and axial force must be larger than "ultimate reinforcement ratio of equilibrium" (See also (5) 2) (a)).**

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(4) Shear

- **Behavior of RC and PC members against shear are complicated compared to behavior against flexure and axial force.**
- **In general, failure due to shear shows brittle behavior.**
- **Shear failure thus shall not take place prior to flexural failure. RC and PC members shall hence be designed with sufficient shear reinforcement, in order to maintain their ductility.**

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(5) Check of Stress

1) Service Load State

(a) Allowable Stress

- **In the design according to JRA Specifications, stresses are checked for concrete, reinforcing steel and prestressing steel.**
- **In prestressed concrete bridges, high strength materials are used for concrete and steel, in order to fully utilize the capacity of prestressing steel.**

5. Basis of Design of Prestressed Concrete Bridges
5.1. Outline

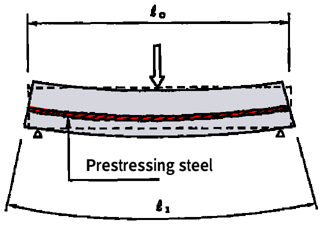
5.1.2. Procedure of Design Calculation and Basic Concepts

(5) Check of Stress

1) Service Load State

(b) Stress of Prestressing Steel

- When loads act on a girder and stress occurs, strain is produced in concrete.
- The concrete strain causes same strain in prestressing steel, which is bonded to the concrete, and stress in the prestressing steel changes as well. This stress of prestressing steel after change must be verified to be within its allowable value.



$\Delta\ell = \ell_1 - \ell_0$

Prestressing steel is elongated as the concrete fiber at the same height of the steel is elongated by $\Delta\ell$.
This causes stress increase in the prestressing steel.

5. Basis of Design of Prestressed Concrete Bridges
5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(5) Check of Stress

1) Service Load State

(c) Reinforcement

- In PC box girders, amount of prestressing force is determined according to the tensile stress in the girder induced by loads, and resultant stress of girder cross sections are verified.
- Reinforcement for detailing consideration, such as minimum reinforcement, is specified which is not determined by calculation.
- Minimum reinforcement is specified aiming to:
  - control shrinkage / thermal cracks within harmless range
  - prevent sudden failure of concrete members by actions larger than design assumptions.

JICA Study Team 21

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(5) Check of Stress

2) Ultimate Load State

(a) Bending

- In prestressed concrete, structural behavior changes after cracking. Check for safety under ultimate load is thus required.
- Failure at ultimate state occurs by
  - Crushing of concrete
  - Breaking of steel (after yielding)
  - Or both of the above two at the same time (= ultimate reinforcement ratio of equilibrium)
- As the failure by crushing of concrete occurs suddenly, such failure behavior is brittle. In order to prevent such brittle failure and maintain ductile behavior of the structure, tensile reinforcement to be provided must be larger than "ultimate reinforcement ratio of equilibrium", to induce failure by breaking of steel, not by crushing of concrete.

JICA Study Team 22

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

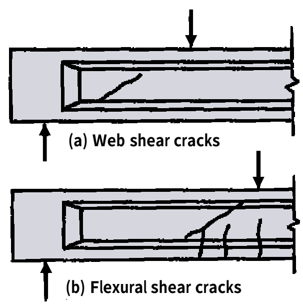
5.1.2. Procedure of Design Calculation and Basic Concepts

(5) Check of Stress

2) Ultimate Load State

b) Shear

- As concrete is weak against tension, reinforcement by prestressing or mild steel is required to resist the tension.
- Tensile stress in concrete is induced also by shear, as well as bending
  →"Diagonal Tensile Stress"
- Shear reinforcement such as stirrups are arranged in order to resist the tensile stress due shear
  - To adequately distribute cracks
  - To increase shear resistance
  - To prevent brittle failure



Type of cracks in PC members

JICA Study Team 23

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(6) Design Loads

- **In JRA Specifications, design loads are categorized in 3 types:**
  - **Principal Load : The loads that shall be considered to act at all times when designing the major structural parts of a bridge.**
  - **Secondary load (Subordinate load) : The loads that do not always or frequently act but shall always be considered in combination of loads when designing the major structural parts of a bridge.**
  - **Special load : the loads that shall be specially considered when designing the major structural parts of a bridge, depending on the conditions such as bridge type, structure type, site condition etc.**

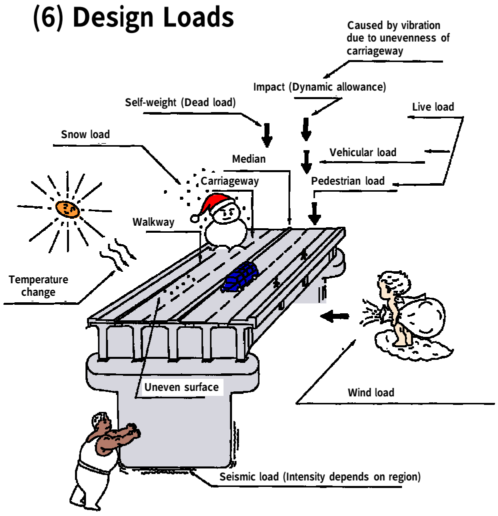
JICA Study Team 24

5. Basis of Design of Prestressed Concrete Bridges

5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts

(6) Design Loads



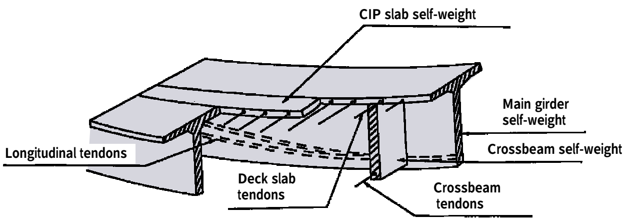
The following loads shall be considered in the design:

Principal load (*P*)	1. Dead load (*D*)
	2. Live load (*L*)
	3. Impact (*I*)
	4. Prestress force (*PS*)
	5. Influence of concrete creep (*CR*)
	6. Influence of drying shrinkage of concrete (*SH*)
	7. Earth pressure (*E*)
	8. Hydraulic pressure (*HP*)
	9. Buoyancy or uplift (*U*)
Subordinate load (*S*)	10. Wind load (*W*)
	11. Influence of temperature change (*T*)
	12. Influence of earthquakes (*EQ*)
Special load equivalent to principal load (*PP*)	13. Snow load (*SW*)
	14. Influence of ground displacement (*GD*)
	15. Influence of support displacement(*SD*)
	16. Wave pressure (*WP*)
	17. Centrifugal load (*CF*)
Special load equivalent to subordinate load (*PA*)	18. Braking load (*BK*)
	19. Erection load (*ER*)
	20. Collision load (*CO*)
	21. Others

JICA Study Team 25

5. Basis of Design of Prestressed Concrete Bridges
5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts
(6) Design Loads
Type of Loads
1) Self-Weight (Dead Load)



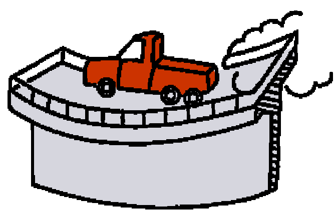
Girder self-weight, CIP slab, crossbeam

JICA Study Team 26

5. Basis of Design of Prestressed Concrete Bridges
5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts
(6) Design Loads
Type of Loads
2) Superimposed Dead Loads, Live Loads

- Superimposed dead loads include pavement, barriers (railings), wheelguards etc.
- Live loads for highway bridges includes vehicular live loads, pedestrian / bicycle loads etc.



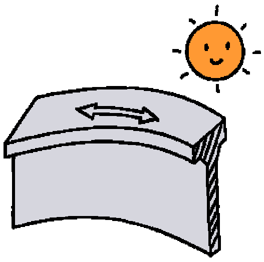
Live load, pavement, barriers, wheelguards

JICA Study Team 27

5. Basis of Design of Prestressed Concrete Bridges
5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts
(6) Design Loads
Type of Loads
3) Temperature Loads

- Concrete structure extends / shortens when it is warmed / cooled due to temperature rise / fall.
- Temperature difference between members / cross-sectional components must be taken into account in some type of structures.
- In statically indeterminate structures, temperature change induces redundant forces.



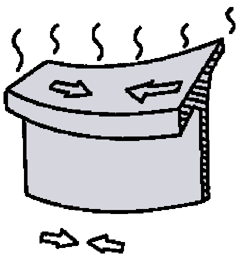
Temperature change: T [°C]

JICA Study Team 28

5. Basis of Design of Prestressed Concrete Bridges
5.1. Outline

5.1.2. Procedure of Design Calculation and Basic Concepts
(6) Design Loads
Type of Loads
4) Shrinkage

- Shrinkage in concrete is induced by
  - Decrease in volume by chemical reaction between water and cement (hydration). The amount of decrease by the hydration is approximately 10%.
  - Drying of water in excess of the amount used for above-mentioned hydration. The amount of decrease by drying depends on the amount of excess water etc.
- Shrinkage is a time-dependent long-term effect as well as creep.
- In statically indeterminate structures, shrinkage induces redundant forces.



Shrinkage: SH

JICA Study Team 29

5. Basis of Design of Prestressed Concrete Bridges
5.1. Outline

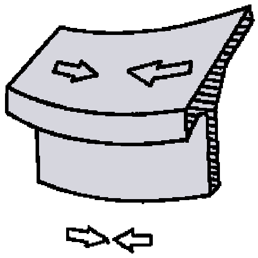
5.1.2. Procedure of Design Calculation and Basic Concepts

(6) Design Loads

Type of Loads

5) Creep

- Concrete undergoes time-dependent elasto-plastic deformations under sustained stress due to *creep*.
- In statically indeterminate structures, creep induces redundant forces.



Creep: CR

JICA Study Team 30

5. Basis of Design of Prestressed Concrete Bridges
5.1. Outline

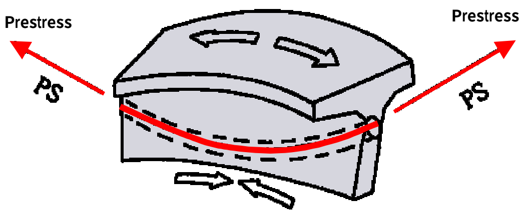
5.1.2. Procedure of Design Calculation and Basic Concepts

(6) Design Loads

Type of Loads

6) Prestress

- In prestressed concrete bridges, external loads are resisted by prestressing force (within allowable tensile stress of concrete).
- In statically indeterminate structures, prestressing force induces redundant forces (secondary prestress).



Prestressing force: PS

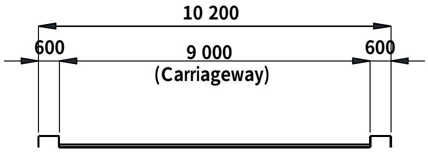
JICA Study Team 31

5. Basis of Design of Prestressed Concrete Bridges

5.2. Design Condition

5.2.1. Design Condition

- Bridge Category : Prestressed concrete highway bridge
- Bridge type : Continuous PC box girder bridge
- Erection Method : Span-by-span (SBS) erection using precast elements
- Bridge length : 200 m
- Span arrangement : 50 m x 4 spans
- Bridge width :



- Skew angle : Beginning point 90deg, End point 90deg

JICA Study Team 32

5. Basis of Design of Prestressed Concrete Bridges

5.2. Design Condition

5.2.1. Design Condition

- Design Live Loads : AASHTO HL-93,
  Special Vehicular load (75t x 1 concentrated load)
  (35t x 2 concentrated loads)
- Design Standards : "Specifications for Highway Bridges", JRA
  "AASHTO LRFD Design Specifications"
  (for HL-93 load)
- Impact factor : $i = 10 / (25 + \ell)$ for main girder
  $i = 20 / (50 + \ell)$ for deck slab
  (where, ℓ = span length)
- Horizontal alignment: Straight
- Crossfall : Level (simplified for example)
- Profile : Level (simplified for example)
- Load combination under ultimate loads:
  1) 1.3 x [Dead loads] + 2.5 x [Live loads + Impact]
  2) 1.0 x [Dead loads] + 2.5 x [Live loads + Impact]
  3) 1.7 x [Dead loads + Live loads + Impact]

JICA Study Team 33

5. Basis of Design of Prestressed Concrete Bridges

5.2. Design Condition

5.2.2. Material Properties and Allowable Stress

(1) Concrete

- Specified characteristic strength — 50.0 N/mm2 (cylinder strength)
- Modulus of elasticity — 3.30E+04 N/mm2
- Shear modulus — 1.43E+04 N/mm2
- Coefficient of thermal expansion — 1.00E–05 / °C

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5. Basis of Design of Prestressed Concrete Bridges

5.2. Design Condition

5.2.2. Material Properties and Allowable Stress

(1) Concrete (cont.)

Table 3.2.2 Allowable compressive stress (N/mm^2) for prestressed concrete structure

Stress type \ Design standard strength of concrete			30	40	50	60
Immediately after prestressing	Bending compressive stress	1) Rectangular section	15.0	19.0	21.0	23.0
		2) T-shaped or box-shaped section	14.0	18.0	20.0	22.0
	3) Axial compressive stress		11.0	14.5	16.0	17.0
Others	Bending compressive stress	4) Rectangular section	12.0	15.0	17.0	19.0
		5) T-shaped or box-shaped section	11.0	14.0	16.0	18.0
	6) Axial compressive stress		8.5	11.0	13.5	15.0

Table 3.2.5 Allowable diagonal tensile stress (N/mm^2) for prestressed concrete structure

Stress type \ Design standard strength of concrete		30	40	50	60
Principal loads other than live load and impact	1) Case where shear force alone or torsional moment alone is to be considered	0.8	1.0	1.2	1.3
	2) Case where both shear force and torsional moment are to be considered	1.1	1.3	1.5	1.6
Combination of loads not considering collision load or the effects of earthquakes	3) Case where shear force alone or torsional moment alone is to be considered	1.7	2.0	2.3	2.5
	4) Case where both shear force and torsional moment are to be considered	2.2	2.5	2.8	3.0

Table 3.2.3 Allowable tensile stress (N/mm^2) for prestressed concrete structure

Stress type \ Design standard strength of concrete			30	40	50	60
Bending tensile stress	1) Immediately after prestressing		1.2	1.5	1.8	2.0
	2) Principal loads other than live load and impact		0	0	0	0
	Principal loads and special loads corresponding to "principal load"	3) Floor slab	0	0	0	0
		4) Segment joint of precast segment bridges	0	0	0	0
		5) Other cases	1.2	1.5	1.8	2.0
6) Axial tensile stress			0	0	0	0

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5. Basis of Design of Prestressed Concrete Bridges
5.2. Design Condition

5.2.2. Material Properties and Allowable Stress

(2) Prestressing Steel (cont.)

[External tendons (longitudinal)]

- **Tendon type** **SWPR7BL 19S15.2 (Low relaxation, ECF)**
- **Tensile strength** **1850.0 N/mm2**
- **Yield strength** **1600.0 N/mm2**
- **Modulus of elasticity** **2.00E+05 N/mm2**

ECF (Epoxy Coated & Filled) strands

[Internal tendons (longitudinal)]

- **Tendon type** **SWPR7BL 12S15.2 (Low relaxation)**
- **Tensile strength** **1850.0 N/mm2**
- **Yield strength** **1600.0 N/mm2**
- **Modulus of elasticity** **2.00E+05 N/mm2**

Bare strands

JICA Study Team 36

5. Basis of Design of Prestressed Concrete Bridges
5.2. Design Condition

5.2.2. Material Properties and Allowable Stress

(2) Prestressing Steel (cont.)

[Deck slab tendons (transverse)]

- **Tendon type** **SWPR7BL 3S12.7 (Low relaxation)**
- **Tensile strength** **1850.0 N/mm2**
- **Yield strength** **1600.0 N/mm2**
- **Modulus of elasticity** **2.00E+05 N/mm2**

[Cross beam tendons (strands)]

- **Tendon type** **SWPR7BL 4S15.2 (Low relaxation)**
- **Tensile strength** **1850.0 N/mm2**
- **Yield strength** **1600.0 N/mm2**
- **Modulus of elasticity** **2.00E+05 N/mm2**

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5. Basis of Design of Prestressed Concrete Bridges

5.2. Design Condition

5.2.2. Material Properties and Allowable Stress

(2) Prestressing Steel (cont.)

[Cross beam tendons (PT bars)]

- **Tendon type** **SBPR930/1080, φ32mm**
- **Tensile strength** **1080.0 N/mm2**
- **Yield strength** **930.0 N/mm2**
- **Modulus of elasticity** **2.00E+05 N/mm2**

PT bars

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5. Basis of Design of Prestressed Concrete Bridges

5.2. Design Condition

5.2.2. Material Properties and Allowable Stress

(2) Prestressing Steel (cont.)

- **In JRA specifications, allowable stress of tendons are specified at the following states, based on specified tensile strength and yield strength.**
  - **During prestressing**
  - **Immediately after prestressing**
  - **Under design load**

Table 3.4.1 Allowable tensile stress of PC tendon

Stress state	Allowable tensile stress	Remarks
1) During prestressing	The value of 0.80 σ_{pu} or 0.90 σ_{py}, whichever is smaller	σ_{pu}: Tensile strength (N/mm^2) of PC tendon σ_{py}: Yield point (N/mm^2) of PC tendon
2) Immediately after prestressing	The value of 0.70 σ_{pu} or 0.85 σ_{py}, whichever is smaller	
3) Under design load	The value of 0.60 σ_{pu} or 0.75 σ_{py}, whichever is smaller	

5. Basis of Design of Prestressed Concrete Bridges

5.2. Design Condition

5.2.2. Material Properties and Allowable Stress

(2) Prestressing Steel (cont.)

Table C. 3.4.1 Allowable tensile stress (N/mm²) of PC tendon

PC tendon type \ Allowable tensile stress				During prestressing	Immediately after prestressing	Under design load
Steel wire	SWPR1AN SWPR1AL SWPD1N SWPD1L		5 mm	1260	1120	960
			7 mm	1170	1050	900
			8 mm	1125	1015	870
			9 mm	1080	980	840
	SWPR1BN SWPR1BL		5 mm	1350	1190	1020
			7 mm	1260	1120	960
			8 mm	1215	1085	930
Steel strand	SWPR2N SWPR2L		2.9 mm (2-strand wire)	1530	1365	1170
	SWPR7AN (7-strand wire) SWPR7AL (7-strand wire)			1305	1190	1020
	SWPR7BN (7-strand wire) SWPR7BL (7-strand wire)			1440	1295	1110
	SWPR19N SWPR19L (19-strand wire)		17.8 mm	1440	1295	1110
			19.3 mm	1440	1295	1110
			20.3 mm	1440	1260	1080
			21.8 mm	1440	1260	1080
			28.6 mm	1350	1260	1080
Steel bar	Round bar Type A	2	SBPR785/1030	706	667	588
	Round bar Type B	1	SBPR930/1080	837	756	648
		2	SBPR930/1180	837	790	697

5. Basis of Design of Prestressed Concrete Bridges

5.2. Design Condition

5.2.2. Material Properties and Allowable Stress

(3) Reinforcing Steel

- Reinforcement type (class) SD345
- Yield strength 345.0 N/mm2
- Modulus of elasticity 2.00E+05 N/mm2

Table 3.3.1 Allowable stress (N/mm²) of reinforcement

Stress and member type \ Reinforcement type			SR235	SD295A SD295B	SD345
Tensile stress	1) Principal loads other than live load and impact		80	100	100
	2) Reference value of allowable stress to be used when collision load or the effects of earthquakes are not considered in the combination of loads	General members	140	180	180
		Floor slab and slab bridges with a span of 10 m or less	140	140	140
	3) Reference value of allowable stress to be used when collision load or the effects of earthquakes are considered in the combination of loads		140	180	200
	4) Reference value of allowable stress to be used when calculating the lap joint length or bond length of reinforcement		140	180	200
5) Compressive stress			140	180	200

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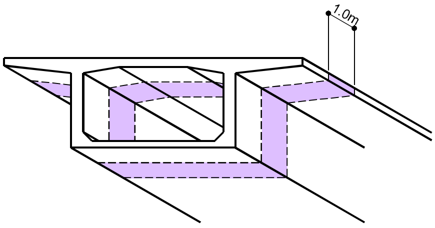
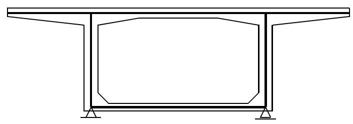
5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.1. General

- **Cross section of box girder is designed as transverse box frame composed of deck slab, webs and bottom slab.**
  - **Girder element is cut out in longitudinal unit length (1m).**
  - **The element is substituted by a box frame model supported at the bottom of the webs.**
  - **The cross-section components (deck slab, webs, and bottom slab) are designed as transverse plate elements.**
  - **Deck slab is designed as PC structure, while webs and bottom slab are designed as RC structure.**





Example of Analysis Model

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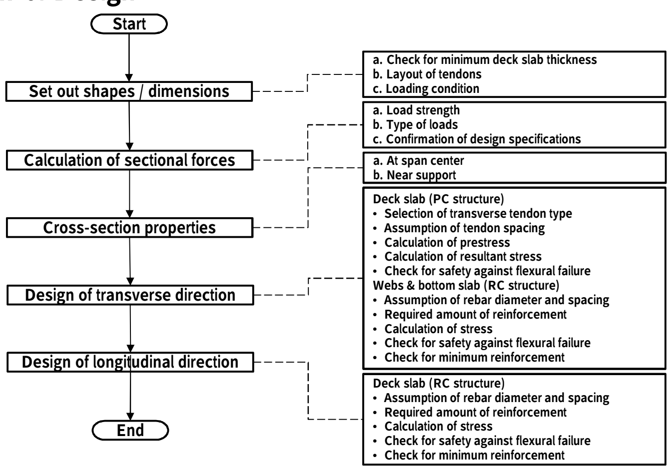
5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.1. General

(1) Flow of Design



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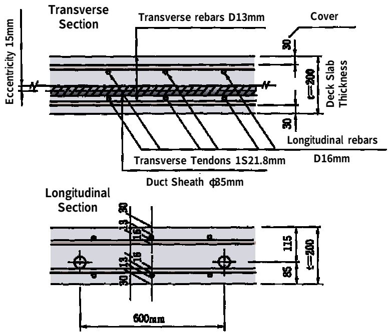
5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.1. General

(2) Thickness of Deck Slab

- **Deck slab thickness shall be determined to be safe, durable and easy to construct.**
- **In JRA Specifications, minimum thickness of deck slab is specified in Part III Clause 7.3.1 [Reinforced concrete (RC) slab] & 7.3.2 [Prestressed concrete (PC) slab].**
- **Thickness of deck slab is determined considering**
  - **Type and arrangement of transverse tendons**
  - **Dimension of anchors of transverse tendons**
  - **Arrangement of longitudinal internal tendons**
  - **Concrete cover ⋯ etc., as well as minimum thickness**



Arrangement of transverse tendons and reinforcement at span center of PC deck slab (Example)

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5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.1. General

(2) Thickness of Deck Slab (cont.)

[RC slab] (in JRA Specifications)

(3) The minimum total thickness of a slab in the roadway shall be 160 mm or the value shown in Table 7.3.1, whichever is greater. The minimum total thickness of a cantilever slab in Table 7.3.1 is referred to as the thickness at the front face of the supporting girder web.

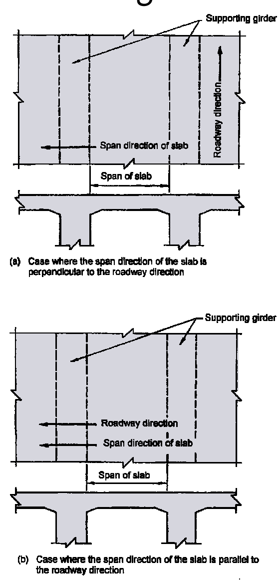
However, when the traffic of large automobiles is heavy, or in other similar cases, it is desirable to design with an increased slab thickness instead of the minimum total slab thickness stipulated in Table 7.3.1.

Table 7.3.1 Minimum total slab thickness in roadway portion

(mm)

Slab type \ Direction of span of slab (see note)		Perpendicular to the roadway direction	Parallel to the Roadway direction
Simple slab		40 *l* + 110	65 *l* + 130
Continuous slab		30 *l* + 110	50 *l* + 130
Cantilever slab	*l* ≦ 0.25	280 *l* + 160	240 *l* + 130
	l > 0.25	80 *l* + 210	

where *l* : Span length of slab for T-load stipulated in Section 7.4 (m)
Note: For the span direction of a slab, see Figure 7.3.1.



Span direction of deck slab

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5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.1. General

(2) Thickness of Deck Slab (cont.)

[PC slab] (in JRA Specifications)

(3) The minimum total slab thickness in the roadway portion shall be in accordance with the following provisions. The minimum total thickness of a cantilever slab means the thickness at the front face of the web of the supporting girder.

1) The total slab thickness in the roadway portion shall not be below 160 mm in any part.

2) The thickness of a cantilever slab at the slab end shall be in accordance with Provision 1) as well as being 50% or more of the minimum total thickness of the cantilever slab in Table 7.3.1.

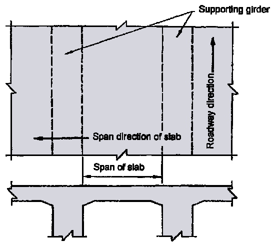
3) When the floor slab is prestressed only in one direction, the minimum total thickness in the roadway portion shall be in accordance with Provisions 1) and 2) as well as being the value in Table 7.3.2.

Table 7.3.2 Minimum total thickness in roadway portion when the slab is prestressed only in one direction

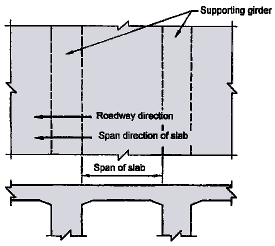
(mm)

Direction of span of slab (see note) / Prestressing direction	Perpendicular to the roadway direction	Parallel to the roadway direction
Parallel to direction of slab span	90% of the value in Table 7.3.1 when the direction of slab span is perpendicular to the roadway direction	65% of the value in Table 7.3.1 when the direction of slab span is parallel to the roadway direction
Perpendicular to the direction of slab span	The value in Table 7.3.1 when the direction of slab span is perpendicular to the roadway direction	The value in Table 7.3.1 when the direction of slab span is parallel to the roadway direction

Note: For the direction of slab span, see Figure 7.3.1.



(a) Case where the span direction of the slab is perpendicular to the roadway direction



(b) Case where the span direction of the slab is parallel to the roadway direction

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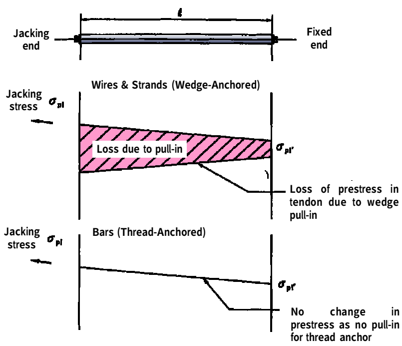
5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.1. General

(3) Tendons for Transverse Prestressing of Deck Slab

- In general, strands, wires and bars are used for transverse deck prestressing.
- Type of tendons for transverse deck prestressing is determined from the viewpoints of economy, ease of construction, prestressing force (capacity), transportation etc.
- Although strands are popularly used, PT bars are used for narrow decks for its advantage in no loss of prestress due to pull-in for short tendons.
- In Japan, high-capacity single strand system has been developed and is commonly used, while multi-strand system is widely used in other countries.



5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.1. General

(4) Direction of Deck Span and Vehicle Traffic

- **The span length of slabs shall be determined considering the stress transfer from the slabs to their supporting girders and the position of wheel loads.**

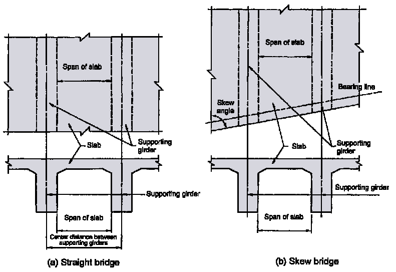


Figure 7.4.1 Span of simple slab and continuous slab

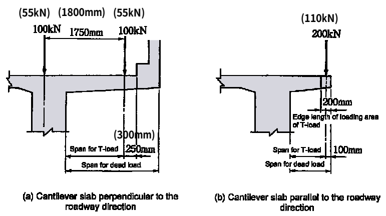


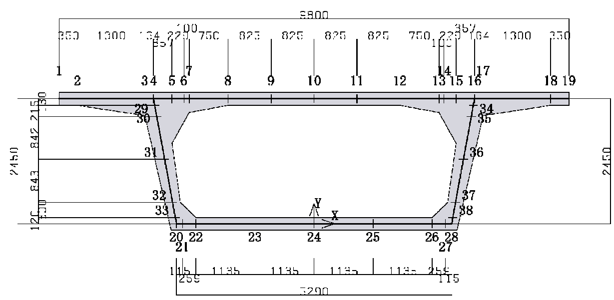
Figure 7.4.2 Span of cantilever slab

Note:
- Values in () are for Tandem Loads in AASHTO LRFD Design Specifications

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.2. Analysis Model



5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.3. Calculation of Bending Moment

(1) Calculation Method

- **Design bending moment is calculated per unit width in longitudinal direction, considering load strength, position of loads, distance to design section etc.**
- **In JRA Specifications, check of deck slab for shear can be omitted according to Part III clause 7.2(2).**
  - **Prestressed concrete slabs satisfying clause 7.3 "Slab thickness", 7.4 "Design Bending Moment of Slab" and 7.5 "Structural Details"**
  - **Reinforced concrete slabs using a concrete with a design standard strength of 24N/mm2 or larger**

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.3. Calculation of Bending Moment

(2) Design Bending Moment

1) Design Concept

- **In JRA Specifications, design bending moment for deck slab due to live load (T-load) is defined as the functions of deck span length.**

Table 7.4.1 Design bending moment per unit width (1 m) of slab due to T-loads (including impact)

(kN·m/m)

Slab type	Bending moment type	Constr-uction	Direction of slab span (see note) / Direction of bending moment / Applicable range	Perpendicular to the roadway direction		Parallel to the roadway direction	
				Parallel to span	Perpendicular to span	Parallel to span	Perpendicular to span
Simple slab	Span bending moment	RC	$0 \leqq l \leqq 4$	$+(0.12l + 0.07)P$	$+(0.10l + 0.04)P$	$+(0.22l + 0.08)P$	$+(0.06l + 0.06)P$
		PC	$0 \leqq l \leqq 6$				
Continuous slab	Span bending moment	RC	$0 \leqq l \leqq 4$	+ (80% of Simple slab)	+ (80% of Simple slab)	+ (80% of Simple slab)	+ (80% of Simple slab)
		PC	$0 \leqq l \leqq 6$				
	Support bending moment	RC	$0 \leqq l \leqq 4$	$-(0.15l + 0.125)P$	-	+ (80% of Simple slab)	-
		PC	$0 \leqq l \leqq 6$				
Cantilever slab	Support bending moment	RC	$0 \leqq l \leqq 1.5$	$-\frac{P \cdot l}{1.30l + 0.25}$	-	$-(0.71l + 0.22)P$	-
		PC	$0 \leqq l \leqq 1.5$				
			$1.5 < l \leqq 3.0$	$-(0.6l - 0.22)P$			
	End bending Bnding moment around esge	RC	$0 \leqq l \leqq 1.5$	-	$+(0.15l + 0.13)P$	-	$+(0.16l + 0.07)P$
		PC	$0 \leqq l \leqq 3.0$				

RC: Reinforced concrete slab
PC: Prestressed concrete slab
l: Slab span against T-load stipulated in Section 7.4.3 (m)
P: One-sided load of T-load shown in Section 2.2.2 of the Volume of Common (100 kN)
(Note) For the direction of the slab span, see Figure 7.3.1.

Table 7.4.2 Increase coefficient of bending moment parallel to the span of a simple slab and continuous slab when the direction of the slab span is perpendicular to the roadway direction

Span length l (m)	$l \leqq 2.5$	$2.5 < l \leqq 4.0$	$4.0 < l \leqq 6.0$
Increase coefficient	1.0	$1.0 + (l - 2.5) / 12$	$1.125 + (l - 4.0) / 26$

Table 7.4.3 Increase coefficient of bending moment parallel to the span of a cantilever slab when the direction of the slab span is perpendicular to the roadway direction

Span length l (m)	$l \leqq 1.5$	$1.5 < l \leqq 3.0$
Increase coefficient	1.0	$1.0 + (l - 1.5) / 25$

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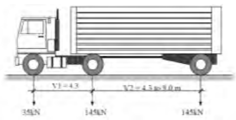
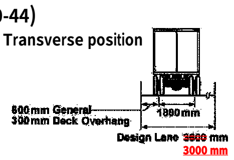
5. Basis of Design of Prestressed Concrete Bridges
5.3. Design of Box Cross Section

5.3.3. Calculation of Bending Moment
(2) Design Bending Moment
1) Design Concept (cont.)
- **In the case of Bago River Bridge, design live load is HL-93 from AASHTO LRFD Specifications.**
- **Design bending moment of deck slab is thus obtained using "influence surfaces" published by Pucher 1977.**

(1)-1 Design truck (HS20-44)



Transverse position



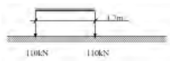
In Bago Bridge, Design Lane width is assumed to be 3000mm to be on the safer side.

Multiple presence factor

Number of Loaded Lanes	Multiple Presence Factors, m
1	1.20
2	1.00
3	0.85
>3	0.65

Nominal lane width shall be 3.0m.

(1)-2 Design tandem



Transverse position of design tandem is same as design truck.

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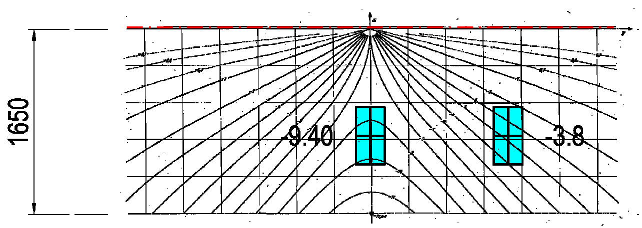
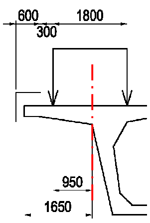
5. Basis of Design of Prestressed Concrete Bridges
5.3. Design of Box Cross Section

5.3.3. Calculation of Bending Moment
(2) Design Bending Moment
1) Design Concept (cont.)

Influence surface (for cantilever slab)
- Design tandem load is considered.





Tandem Load	=	55.0 kN/wheel
Multiple Presence Factor	=	1.2
Impact = 20 / (50 + 0.95)	=	0.393
Coefficient (1.0 x 1.1)	=	1.1
Influence Value	=	-13.2
Bending Moment	=	-53.1 kNm/m

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5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

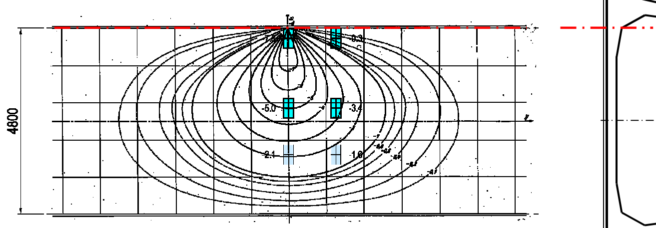
5.3.3. Calculation of Bending Moment

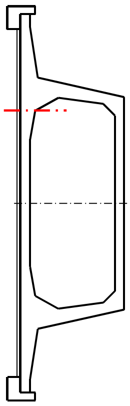
(2) Design Bending Moment

1) Design Concept (cont.)

Influence surface (for box slab at support)

- Design tandem load is considered.





		1 Tandem	2 Tandems
Tandem Load	=	55.0	55.0 kN/wheel
Multiple Presence Factor	=	1.2	1.0
Impact = 20 / (50 + 4.8)	=	0.365	0.365
Coefficient (1.0 x 1.1)	=	1.1	1.1
Influence Value	=	-16.5	-20.2
Bending Moment	=	-65.1	-66.4 kNm/m

JICA Study Team 54

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

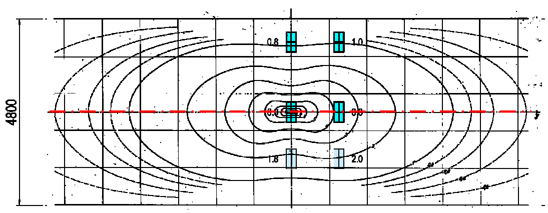
5.3.3. Calculation of Bending Moment

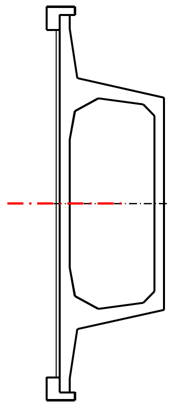
(2) Design Bending Moment

1) Design Concept (cont.)

Influence surface (for box slab at span center)

- Design tandem load is considered.





		1 Tandem	2 Tandems
Tandem Load	=	55.0	55.0 kN/wheel
Multiple Presence Factor	=	1.2	1.0
Impact = 20 / (50 + 4.8)	=	0.365	0.365
Coefficient (0.8 x 1.1)	=	0.88	0.88
Influence Value	=	13.6	17.4
Bending Moment	=	42.9	45.7 kNm/m

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.3. Calculation of Bending Moment

(2) Design Bending Moment

2) Loading

★ Practice : Calculate design bending moment at cantilever slab.

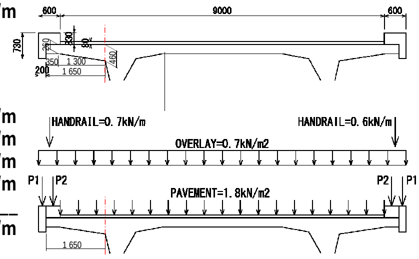
(a) Self-Weight (Dead Load)

- Calculated from member properties.
- M_{d0} = __________ kNm/m

(b) Superimposed Dead Load

- Pavement __________ kNm/m
- Handrail __________ kNm/m
- Wheelguard __________ kNm/m
- Overlay __________ kNm/m

- Total : M_{d1} = __________ kNm/m



P1 = 0.730 x 0.200 x 24.5 = 3.577 kN/m

P2 = 0.400 x 0.330 x 24.5 = 3.234 kN/m

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

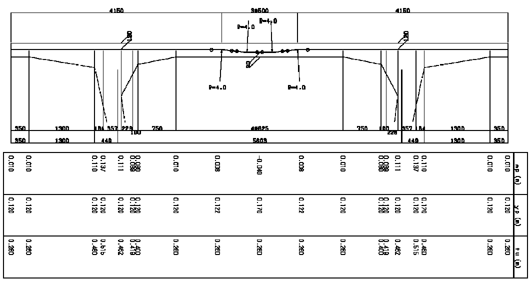
5.3.3. Calculation of Bending Moment

(2) Design Bending Moment

2) Loading

(c) Prestress

- Tendon Arrangement



JICA Study Team 57

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.3. Calculation of Bending Moment

(2) Design Bending Moment

2) Loading

(d) Temperature Gradient

- +5°C is considered for deck slab only.

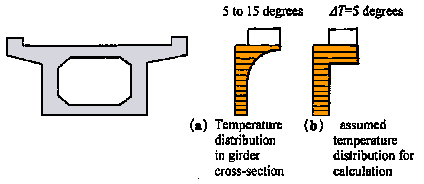


Fig. C. 2.2.25 Temperature difference between slab and girder

JICA Study Team 58

5. Basis of Design of Prestressed Concrete Bridges

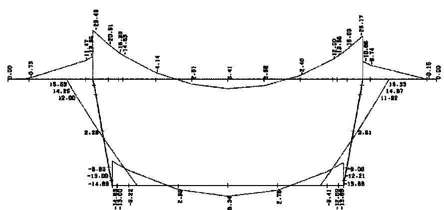
5.3. Design of Box Cross Section

5.3.3. Calculation of Bending Moment

(2) Design Bending Moment

3) Bending Moment

(a) Self-Weight (Dead Load)



5. Basis of Design of Prestressed Concrete Bridges

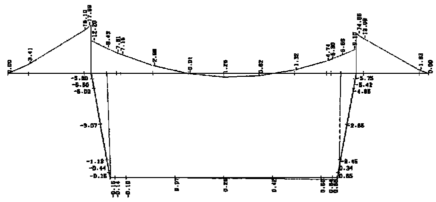
5.3. Design of Box Cross Section

5.3.3. Calculation of Bending Moment

(2) Design Bending Moment

3) Bending Moment

(b) Superimposed Dead Load



5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

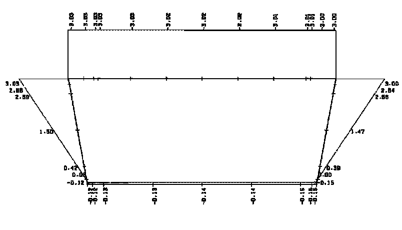
5.3.3. Calculation of Bending Moment

(2) Design Bending Moment

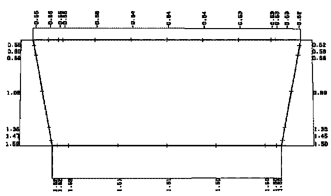
3) Bending Moment

(c) Prestress

Due to eccentricity



Due to eccentricity + elastic shortening



JICA Study Team 61

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

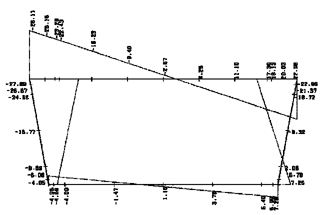
5.3.3. Calculation of Bending Moment

(2) Design Bending Moment

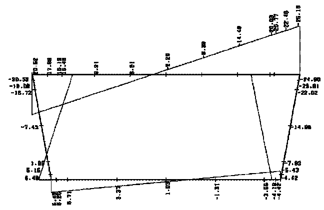
3) Bending Moment

(d) Live load

Loaded on left cantilever slab



Loaded on right cantilever slab



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5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

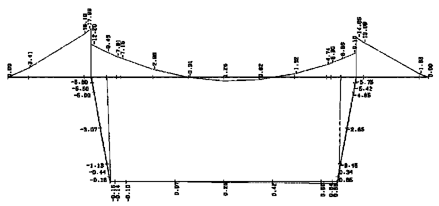
5.3.3. Calculation of Bending Moment

(2) Design Bending Moment

3) Bending Moment

(d) Live Load (cont.)

Loaded on box slab



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5. Basis of Design of Prestressed Concrete Bridges

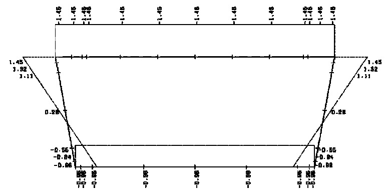
5.3. Design of Box Cross Section

5.3.3. Calculation of Bending Moment

(2) Design Bending Moment

3) Bending Moment

(e) Temperature Gradient



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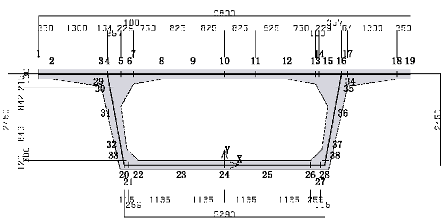
5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.4. Cross-Sectional Properties



A : Cross-sectional area
I: Moment of Inertia
X, Y : dimension of member

MEMBER	A (m2)	I (m4)	X (m)	Y (m)	MAT	MEMBER	A (m2)	I (m4)	X (m)	Y (m)	MAT
1- 2	0.260	0.00146	0.4800	0.0000	1	21- 22	0.290	0.00221	0.2590	0.0000	1
2- 3	0.360	0.00479	1.3000	0.0000	1	22- 23	0.240	0.00115	1.1352	0.0000	1
3 4	50.000	50.00000	0.1638	0.0000	1	23 24	0.240	0.00115	1.1352	0.0000	1
4- 5	50.000	50.00000	0.3567	0.0000	1	24- 25	0.240	0.00115	1.1352	0.0000	1
5- 6	50.000	50.00000	0.2290	0.0000	1	25- 26	0.240	0.00115	1.1352	0.0000	1
6- 7	0.417	0.00606	0.1000	0.0000	1	26- 27	0.290	0.00221	0.2590	0.0000	1
7- 8	0.330	0.00340	0.7500	0.0000	1	27- 28	50.000	50.00000	0.1155	0.0000	1
8 9	0.260	0.00146	0.8252	0.0000	1	4 29	50.000	50.00000	0.0234	0.1300	1
9- 10	0.260	0.00146	0.8252	0.0000	1	29- 30	0.438	0.00701	0.0387	0.2150	1
10- 11	0.260	0.00146	0.8252	0.0000	1	30- 31	0.402	0.00556	0.1517	0.8425	1
11- 12	0.260	0.00146	0.8252	0.0000	1	31- 32	0.318	0.00287	0.1517	0.8425	1
12- 13	0.330	0.00340	0.7500	0.0000	1	32- 33	0.320	0.00293	0.0540	0.3000	1
13- 14	0.417	0.00606	0.1000	0.0000	1	33- 20	50.000	50.00000	0.0216	0.1200	1
14- 15	50.000	50.00000	0.2290	0.0000	1	16- 34	50.000	50.00000	0.0234	0.1300	1
15- 16	50.000	50.00000	0.3567	0.0000	1	34- 35	0.438	0.00701	0.0387	0.2150	1
16- 17	50.000	50.00000	0.1638	0.0000	1	35- 36	0.402	0.00556	0.1517	0.8425	1
17- 18	0.460	0.00811	1.3000	0.0000	1	36- 37	0.318	0.00287	0.1517	0.8425	1
18 19	0.360	0.00479	0.2200	0.0000	1	37 38	0.320	0.00293	0.0540	0.3000	1
20- 21	50.000	50.00000	0.1155	0.0000	1	38- 28	50.000	50.00000	0.0216	0.1200	1

	Shape	A : Cross sectional area	y : Centroid	I : Moment of inertia around x	W: Modulus of section around x	r : Radius of rotation around x
Rectangle		$A = bh$	$y_0 = h/2$	$I = bh^3/12$	$W = bh^2/6$	$r = h/\sqrt{12}$
Triangle		$A = bh/2$	$y_1 = 2h/3$ $y_2 = h/3$	$I = bh^3/36$	$W_1 = I/y_1 = bh^2/24$ $W_2 = I/y_2 = bh^2/12$	$r = h/\sqrt{18}$
Circle		$A = \pi d^2 / 4$	$y_0 = d/2$	$I = \pi d^4/64$	$W = \pi d^3/32$	$r = d/4$

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(1) Basis

1) Full Prestressing

- **As deck slab is subject to vehicle wheel loads of significant frequency, deck slab is designed as full-prestressed member, in order to maintain serviceability & durability by avoiding deterioration such as corrosion of steels due to penetration of hazardous factors from cracks, such as rain water, incoming sea salt, deicing chemicals etc.**

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

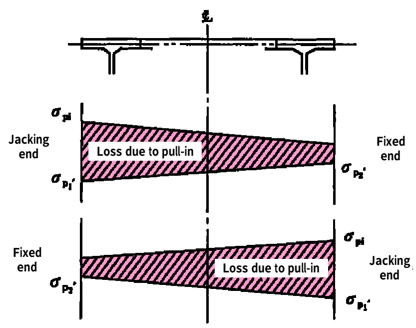
5.3.5. Calculation in Transverse Direction

(1) Basis

2) Method of Prestressing

- **Deck slab tendons are normally jacked one side alternately, in order to prestress the deck slab evenly.**

$$\sigma_{pt} = \frac{\sigma_{p1'} + \sigma_{p2'}}{2}$$



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5. Basis of Design of Prestressed Concrete Bridges

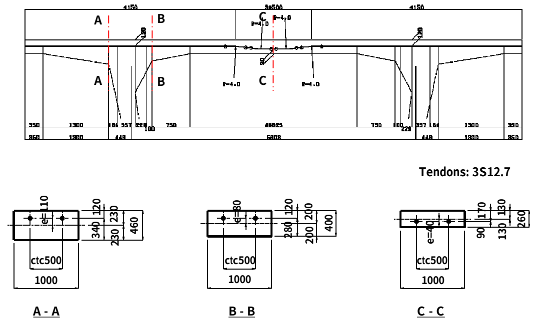
5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(1) Basis

3) Eccentricity of Tendons

- **Tendons are normally arranged with some eccentricities at support and at span center, in order to compensate tensile stresses induced by bending moment due to loads efficiently.**



JICA Study Team 68

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(1) Basis

4) Points of Consideration on Tendon Arrangement

- **The followings shall be taken into account in the determination of tendon arrangement:**
  - **The deck slab shall be evenly prestressed.**
  - **Size of anchor devices and distribution width of prestress shall be considered.**
  - **Prestress at each section shall not be excessively large nor small.**

JICA Study Team 69

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(2) Stress due to Bending by Loads

- **Stress due to bending is obtained by dividing bending moment by modulus of section.**

$$\sigma_{c'} = \frac{M}{Z_{c'}}$$ for top fiber of cross section

$$\sigma_c = \frac{M}{Z_c}$$ for bottom fiber of cross section

where M : Bending moment by loads

$\sigma_{c'}$ / σ_c : Stress due to bending at top / bottom fiber of the section (positive when compressive, negative when tensile)

$Z_{c'}$ / Z_c : Modulus of section at top / bottom fiber of the section (positive / negative for top / bottom fiber of the section)

JICA Study Team 70

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(2) Stress due to Bending by Loads

★ Practice: Calculate stress due to bending by loads.

				Sec.3
Moment due to each load				
Self-weight			kNm/m	
Superimposed dead load			kNm/m	
Secondary prestress	immediately after anchor-set		kNm/m	0.00
Secondary prestress	at service load state		kNm/m	0.00
Live load	Max.		kNm/m	
Live load	Min.		kNm/m	-54.00
Temperature gradient Δ5°C			kNm/m	
Load combination				
Immediately after anchor set			kNm/m	
Permanent load			kNm/m	
Service loads	Max.		kNm/m	
Service loads	Min		kNm/m	
Service loads + Temperature gradient	Max.		kNm/m	
Service loads + Temperature gradient	Min		kNm/m	
Stress due to load				
Section modulus	$Z = I / y_c$		m^3/m	
Immediately after anchor set		top	N/mm^2	
Immediately after anchor set		bottom	N/mm^2	
Permanent load		top	N/mm^2	
Permanent load		bottom	N/mm^2	
Service loads	Max.	top	N/mm^2	
Service loads	Max.	bottom	N/mm^2	
Service loads	Min.	top	N/mm^2	
Service loads	Min.	bottom	N/mm^2	
Service loads + Temperature gradient	Max.	top	N/mm^2	
Service loads + Temperature gradient	Max.	bottom	N/mm^2	
Service loads + Temperature gradient	Min.	top	N/mm^2	
Service loads + Temperature gradient	Min.	bottom	N/mm^2	

JICA Study Team 71

5. Basis of Design of Prestressed Concrete Bridges
5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

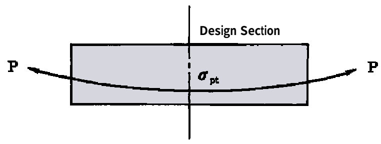
(3) Calculation of Prestressing

1) Concept of Prestressing

Prestress varies due to the state of construction. For example, prestressing force is decreased by various factors such as

- Friction
- pull-in of wedges
- elastic deformation of concrete
- Loss due to creep and shrinkage of concrete
- Loss due to relaxation of steel

Such factors shall be taken into account when determining required prestressing force.



Concept of Prestressing

JICA Study Team 72

5. Basis of Design of Prestressed Concrete Bridges
5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(3) Calculation of Prestressing

2) Loss of Prestress

1. Loss due to friction
   - Friction in the jack and anchorage, and friction in the duct cause loss of prestress from jacking point to a design section.
2. Loss due to pull-in of wedges
   - At the setting of anchorages, tendons are pulled in with wedges by some extent. This causes the reduction of prestressing force.
3. Loss due to elastic deformation of concrete
   - Concrete is shortened by prestressing force. When multiple tendons are used, the prestress of formerly jacked tendons is decreased due to the elastic shortening of the concrete by newly jacked tendons.
4. Loss due to creep and shrinkage of concrete
   - Long-term effects such as creep and shrinkage cause shortening of concrete.
5. Loss due to relaxation of steel
   - When prestressing steel is kept with uniform tensile strain, its tensile stress will be decreased with time.

JICA Study Team 73

5. Basis of Design of Prestressed Concrete Bridges

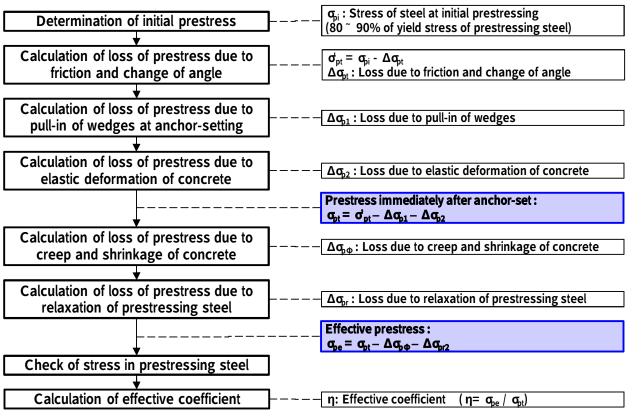
5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(3) Calculation of Prestressing

3) Calculation of Prestressing

Flow of calculation



JICA Study Team 74

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

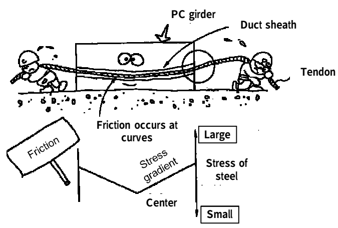
5.3.5. Calculation in Transverse Direction

(3) Calculation of Prestressing

3) Calculation of Prestressing

(a) Immediately after prestressing

➢ **Loss due to friction**



$$\sigma_{pt1} = \sigma_{pi} \cdot e^{-(\mu\alpha+\lambda\ell)}$$

where

σ_{pt1}	: Tensile stress of prestressing steel at a design section
σ_{pi}	: Initial prestress at the jacking end $\sigma_{pi} < \sigma_{pai}$ = 1440 N/mm² (allowable value)
λ	: Wobble friction coefficient [/m] (0.004 for bare steel strands)
ℓ	: Distance from jacking end to the design section [m]
μ	: Friction coefficient due to curvature of tendon [/rad] (0.30 for bare steel strands)
α	: Change of angle of tendon [rad]

JICA Study Team 75

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

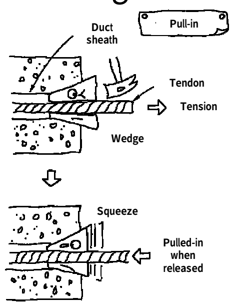
5.3.5. Calculation in Transverse Direction

(3) Calculation of Prestressing

3) Calculation of Prestressing

(a) Immediately after prestressing

- **Loss due to pull-in of anchor wedges**



$$\Delta\sigma_{p1} \cdot \ell = \Delta\ell \cdot E_p$$

where
- $\Delta\sigma_{p1}$: Loss of prestress due to pull-in of anchor wedges
- ℓ : Length of tendon [m]
- $\Delta\ell$: Amount of pull-in [mm] (Depends on system and type of anchor devices)
- E_p : Modulus of elasticity of prestressing steel [N/mm²] (2.0×10^5 N/mm²)

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5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

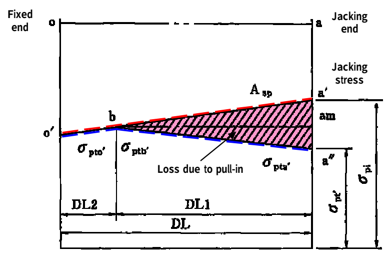
5.3.5. Calculation in Transverse Direction

(3) Calculation of Prestressing

3) Calculation of Prestressing

(a) Immediately after prestressing

- **Loss due to pull-in of anchor wedges (cont.)**
  - Distribution of prestress in the steel can be obtained by graphical method.
  - Assuming that friction at jacking and at pull-in are the same, the distribution of prestress is as shown in right.
  - The line a'-b-c' and a"-b-c' shows the stress just before anchoring and just after anchoring (wedge is pulled-in) respectively.
  - The lines a'-b and a"-b are symmetrical about the horizontal line am-b.



$\Delta\ell$: Amount of pull-in [mm]
E_p : Modulus of elasticity of steel [N/mm²]
A_{sp} : Area of triangle a'-b-a"

Find the point b on the line a'-c' which gives $A_{sp} = \Delta\ell \cdot E_p$, and the line ba" is determined, which gives the stress in steel considering loss due to pull-in.

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5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

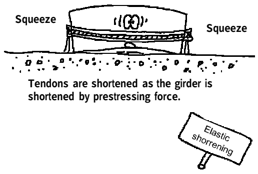
5.3.5. Calculation in Transverse Direction

(3) Calculation of Prestressing

3) Calculation of Prestressing

(a) Immediately after prestressing

- **Loss due to elastic deformation of concrete**



(a) In the pretensioning method

$$\Delta\sigma_p = n \cdot \sigma_{cpg}$$

(b) In the post-tensioning method

$$\Delta\sigma_p = \frac{1}{2} n \cdot \sigma_{cpg} \cdot \frac{N-1}{N}$$

where

$\Delta\sigma_p$: Loss of tensile stress of PC steel (N/mm^2)

n : Ratio of Young's modulus $n = \frac{E_p}{E_c}$

E_p : Young's modulus of PC steel (N/mm^2)

E_c : Young's modulus of concrete at the time of tensioning (N/mm^2)

σ_{cpg} : Stress in concrete due to PC steel tensioning at the centroid of the PC steel (N/mm^2)

N : Number of times of PC steel tensioning (number of PC steel bars)

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5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(3) Calculation of Prestressing

3) Calculation of Prestressing

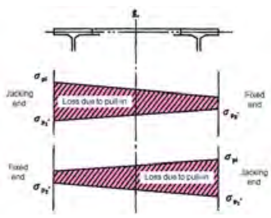
(a) Immediately after prestressing

- **Prestress immediately after prestressing (after anchor-set)**
  - **As the transvers tendons for deck slabs are jacked at one side alternately, the value of prestress immediately after anchor-set are averaged for design use.**

$$\sigma_{pt} = \frac{\sigma_{pi'} + \sigma_{pt2}}{2}$$

where $\sigma_{pi'}$: Tensile stress of prestressing steel at jacking end

σ_{pt2} : Tensile stress of prestressing steel at fixed end



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5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

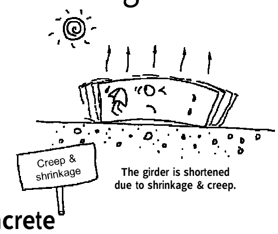
5.3.5. Calculation in Transverse Direction

(3) Calculation of Prestressing

3) Calculation of Prestressing

(b) Effective Prestress

- **Loss of prestress due to creep and shrinkage of concrete**



$$\Delta\sigma_{p\varphi} = \frac{n \cdot \varphi \cdot \sigma_{cp} + E_p \cdot \varepsilon_s}{1 + n \cdot \frac{\sigma_{cpt}}{\sigma_{pt}}\left(1 + \frac{\varphi}{2}\right)}$$

where	$\Delta\sigma_{p\phi}$	: Loss of prestress due to creep and shrinkage
	ϕ	: Creep coefficient of concrete
	ε_s	: Shrinkage coefficient
	n	: Ratio of modulus of elasticity E_p / E_c
	E_p	: Modulus of elasticity of prestressing steel
	E_c	: Modulus of elasticity of concrete
	σ_{cp}	: Concrete stress at the centroid of tendons due to long-term load (prestress immediately after anchor-set, self-weight and superimposed dead load)
	σ_{pt}	: Tensile stress in prestressing steel immediately after anchor-set
	σ_{cpt}	: Prestress in concrete at the centroid of tendons immediately after anchor-set

JICA Study Team 80

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(3) Calculation of Prestressing

3) Calculation of Prestressing

(b) Effective Prestress

- **Loss of prestress due to relaxation of steel**

$$\Delta\sigma_{p\gamma} = \gamma \cdot \sigma_{pt}$$

where	$\Delta\sigma_{p\gamma}$	: Loss of prestress in steel tensile stress due to relaxation of steel
	γ	: Relaxation coefficient of prestressing steel
	σ_{pt}	: Tensile stress in prestressing steel immediately after anchor-set
	σ_{cpt}	: Prestress in concrete at the centroid of tendons immediately after anchor-set

JICA Study Team 81

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(3) Calculation of Prestressing

3) Calculation of Prestressing

(b) Effective Prestress

- **Effective prestress in prestressing steel**

$$\sigma_{pe} = \sigma_{pt} - \Delta\sigma_{p\varphi} - \Delta\sigma_{pr}$$

where
σ_{pe} : Effective prestress
σ_{pt} : Tensile stress in prestressing steel immediately after anchor-set
$\Delta\sigma_{p\phi}$: Loss of prestress due to creep and shrinkage of concrete
$\Delta\sigma_{pr}$: Loss of prestress due to relaxation of prestressing steel

- **Effective coefficient**

$$\eta = \sigma_{pe} / \sigma_{pt}$$

where η : Effective coefficient
where σ_{pe} : Effective prestress
σ_{pt} : Tensile stress in prestressing steel immediately after anchor-set

JICA Study Team 82

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(3) Calculation of Prestressing

4) Stress in Concrete due to Prestressing

(a) Immediately after prestressing (after anchor-set)

$$\sigma_{ct'} = P_t / A + P_t \cdot e_p / Z_{c'}$$
$$\sigma_{ct} = P_t / A + P_t \cdot e_p / Z_c$$
$$\sigma_{cpt} = P_t / A + P_t \cdot e_p / Z_e$$

where
$\sigma_{ct'}$, σ_{ct} σ_{cpt} : Concrete stresses at the top, at bottom and at tendon centroid of the cross section
P_t : Prestressing force immediately after anchor set
Pt = $\sigma_{pt} \cdot N_p \cdot A_p \cdot \sin \alpha$
A : Cross-sectional area of concrete at a design section
e_p : Eccentricity of tendon at the design section
$Z_{c'}$, Z_c : Modulus of section at top and bottom fiber of the design section

JICA Study Team 83

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(3) Calculation of Prestressing

4) Stress in Concrete due to Prestressing

(b) due to effective prestress

$$\sigma_{ce'} = \eta \cdot \sigma_{ct'}$$
$$\sigma_{ce} = \eta \cdot \sigma_{ct}$$

where

$\sigma_{ct'}$, σ_{ct}	: Concrete stresses at the top and the bottom of the cross section immediately after anchor-set
$\sigma_{ce'}$, σ_{ce}	: Concrete stresses at the top and the bottom of the cross section due to effective prestress
η	: Effective coefficient

JICA Study Team 84

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.5. Calculation in Transverse Direction

(4) Resultant Stress

(a) Immediately after anchor-set

$\sigma_{ci'} = \sigma_{cd0'} + \sigma_{ct'}$, $\qquad \sigma_{ci} = \sigma_{cd0} + \sigma_{ct}$

(b) At service load state

$\sigma_{cs'} = \sigma_{c'} + \sigma_{ce'}$, $\qquad \sigma_{cs} = \sigma_{c} + \sigma_{ce}$

where

σ_{cti}, σ_{ci}	: Resultant stress at the top and the bottom of the cross section immediately after anchor-set
σ_{cd0}, σ_{cd0}	: Concrete stress at the top and the bottom of the cross section due to self-weight
$\sigma_{ct'}$, σ_{ct}	: Concrete stresses at the top and the bottom of the cross section immediately after anchor-set
σ_{cs}, σ_{cs}	: Resultant stress at the top and the bottom of the cross section at service load state
σ_{c}, σ_{c}	: Concrete stress at the top and the bottom of the cross section due to service loads
$\sigma_{ce'}$, σ_{ce}	: Concrete stresses at the top and the bottom of the cross section due to effective prestress

- Resultant stress shall be checked to satisfy allowable stress.

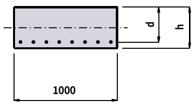
5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.6. Calculation in Longitudinal Direction

- In general, deck slab of box girder bridge in the longitudinal direction is designed for live load (wheel load).
- In the case of PC box girder bridges using precast segments by SBS erection, deck slab is not designed in the longitudinal direction, as the longitudinal reinforcing steels are discontinuous at the joints between segments.
- For reference, required area of reinforcement for RC deck slab in longitudinal direction can be calculated using the following equation:

$$A_{sreq} = \frac{M}{\sigma_{sa} \cdot j \cdot d}$$



where

- A_{sreq} : Required area of reinforcing steel
- σ_{sa} : Allowable tensile stress of reinforcing steel
- j : Internal lever arm between resultant compressive force and resultant tensile force (7/8 = 0.875 can be used for pure flexure with empirical adequacy)
- d : Distance from the extreme compressive fiber to the centroid of tension reinforcement

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(1) Basis

- In concrete structure, safety against failure is not always obtained even though the member is designed to satisfy allowable stress.
- Check for resistance under ultimate load state is thus required as well as to satisfy allowable stress under service load state.

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(2) Calculation in Transverse Direction

1) Reinforcement provided > ultimate reinforcement of equilibrium

(a) Ultimate reinforcement ratio of equilibrium

$$P_b = [(0.68 \cdot \varepsilon_{cu})/(\varepsilon_{cu} + \varepsilon_{sy})] \cdot \sigma_{ck}/\sigma_{sy}$$

where

P_b	: Ultimate reinforcement ration of equilibrium
ε_u	: Ultimate compressive strain of concrete $\varepsilon_u = 0.0035$
ε_y	: Yield strain of tensile steel $\varepsilon_y = 0.00973$ for wires, strands and PT-bars class1
E_s	: Modulus of elasticity of tensile steel $E_s = 2.0 \times 10^5$ N/mm^2 for prestressing steel
σ_{sy}	: Yield stress of tensile steel 0.93 σ_{pu} for wires, strands and PT-bars class1
σ_{ck}	: Specified characteristic strength of concrete $\sigma_{ck} = 50$ N/mm^2 (cylinder strength)
σ_{pu}	: Tensile strength of prestressing steel σ_{pu} = 1850.0 N/mm2 for SWPR7BL strands

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(2) Calculation in Transverse Direction

1) Reinforcement provided > ultimate reinforcement of equilibrium

(b) Ratio of tensile reinforcement

$$P = A_s/b \cdot d$$

where

P	: Ratio of tensile reinforcement
A_s	: Area of tensile reinforcement [mm^2]
b	: Effective width of compression flange [mm]
d	: Distance from extreme compression fiber to centroid of tensile reinforcement [mm]

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(2) Calculation in Transverse Direction

1) Reinforcement provided > ultimate reinforcement of equilibrium

(c) Check for strain level of tensile reinforcement

- If $P_b > P$, tensile reinforcement has been yielded at the time of failure of the member.
- In this case, tensile force in the tensile reinforcement and compressive force in concrete are given by

$$T = \sigma_{sy} \cdot A_s = 0.93\ \sigma_{pu} \cdot A_s$$
$$C = 0.68 \cdot \sigma_{ck} \cdot b \cdot x$$

where

σ_{pu} : Tensile strength of prestressing steel
A_s : Area of tensile reinforcement [mm²]
T : Tensile force in reinforcement
C : Compressive force in concrete
σ_{ck} : Specified characteristic strength of concrete

- As $C = T$,

$$x = \sigma_{sy} \cdot A_s / 0.68 \cdot \sigma_{ck} \cdot b$$

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(2) Calculation in Transverse Direction

1) Reinforcement provided > ultimate reinforcement of equilibrium

(d) Flexural resistance

$$M_u = 0.68 \cdot \sigma_{ck} \cdot b \cdot x \cdot (d - 0.4\,x)$$

(e) Bending moment at ultimate load state

$$M_1 = 1.3\ M_d + 2.5\ M_\ell$$
$$M_2 = 1.7\ (M_d + M_\ell)$$

where

M_d : Bending moment due to dead loads
M_ℓ : Bending moment due to live loads (including impact)

(f) Safety ratio against flexural failure

- It is checked that $M_u > M_1$, $M_u > M_2$

$$F_1 = M_u / M_1, \qquad F_2 = M_u / M_2$$

where

F_1, F_2 : Safety ratio against flexural failure for M_1 and M_2

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(2) Calculation in Transverse Direction

2) Reinforcement provided < ultimate reinforcement of equilibrium

$$P_b = [(0.68 \cdot \varepsilon_{cu})/(\varepsilon_{cu} + \varepsilon_{sy})] \cdot \sigma_{ck}/\sigma_{sy}$$

where

P_b : Ultimate reinforcement ration of equilibrium

ε_u : Ultimate compressive strain of concrete
ε_u = 0.0035

ε_y : Yield strain of tensile steel
ε_y = 0.00973 for wires, strands and PT-bars class1

E_s : Modulus of elasticity of tensile steel
$E_s = 2.0 \times 10^5$ N/mm² for prestressing steel

σ_{sy} : Yield stress of tensile steel
0.93 σ_{pu} for wires, strands and PT-bars class1

σ_{ck} : Specified characteristic strength of concrete
σ_{ck} = 50 N/mm² (cylinder strength)

σ_{pu} : Tensile strength of prestressing steel
σ_{pu} = 1850.0 N/mm2 for SWPR7BL strands

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(2) Calculation in Transverse Direction

2) Reinforcement provided < ultimate reinforcement of equilibrium

(b) Ratio of tensile reinforcement

$$P = A_s/b \cdot d$$

where

P : Ratio of tensile reinforcement

A_s : Area of tensile reinforcement [mm²]

b : Effective width of compression flange [mm]

d : Distance from extreme compression fiber to centroid of tensile reinforcement [mm]

JICA Study Team 93

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(2) Calculation in Transverse Direction

2) Reinforcement provided < ultimate reinforcement of equilibrium

(c) Check for strain level of tensile reinforcement

- If $P_b < P$, tensile reinforcement has not been yielded at the time of failure of the member.
- In this case, assuming the strain of tensile reinforcement as

  $\varepsilon_s = \varepsilon_1 = 0.84 \cdot \sigma_{pu} / E_s$
- Neutral axis x can be assumed as

  $x = 0.0035 / (\varepsilon_1 - \varepsilon_{pe} + 0.0035) \cdot d$
- Compressive force in concrete is

  $C = 0.68 \cdot \sigma_{ck} \cdot b \cdot x$
- Tensile force in tensile reinforcement is

  $T = \varepsilon_1 \cdot E_s \cdot A_s$

  where

  x : Distance from extreme compression fiber to neutral axis
  ε_1 : Strain of tensile reinforcement $= 0.84 \cdot \sigma_{pu} / E_s$
  σ_{pu} : Tensile strength of prestressing steel
  E_s : Modulus of elasticity of prestressing steel
  A_s : Area of prestressing steel

JICA Study Team 94

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(2) Calculation in Transverse Direction

2) Reinforcement provided < ultimate reinforcement of equilibrium

(c) Check for strain level of tensile reinforcement (cont.)

- If $C > T$, tensile reinforcement (prestressing steel) is in region II.

  $D = (0.93\ \sigma_{pu} - 0.84\ \sigma_{pu}) / (0.015 - \varepsilon_1)$

$$x = \frac{\beta + \sqrt{\beta^2 + 4\alpha_\gamma}}{2\alpha}$$

where

$\alpha = 0.68 \cdot \sigma_{ck} \cdot b$
$\beta = (\varepsilon_{pe} - \varepsilon_u - \varepsilon_1) \cdot A_s \cdot D + \varepsilon_1 \cdot A_s \cdot E_s$
$\gamma = \varepsilon_1 \cdot A_s \cdot D \cdot d$

$$T = \left| D \cdot (\varepsilon_s - \varepsilon_1) + \varepsilon_1 \cdot E_s \right| \cdot \Sigma A_s$$

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(2) Calculation in Transverse Direction

2) Reinforcement provided < ultimate reinforcement of equilibrium

(d) Flexural resistance

$M_u = T \cdot (d - 0.4\ x)$

(e) Bending moment at ultimate load state

$M_1 = 1.3\ M_d + 2.5\ M_\ell$

$M_2 = 1.7\ (M_d + M_\ell)$

where

M_d : Bending moment due to dead loads

M_ℓ : Bending moment due to live loads (including impact)

(f) Safety ratio against flexural failure

- It is checked that $M_u > M_1$, $M_u > M_2$

$F_1 = M_u \,/\, M_1$, $F_2 = M_u \,/\, M_2$

where

F_1, F_2 : Safety ratio against flexural failure for M_1 and M_2

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(3) Calculation in Longitudinal Direction

(a) Ultimate reinforcement ratio of equilibrium

$P_b = [(0.68 \cdot \varepsilon_{cu})/(\varepsilon_{cu} + \varepsilon_{sy})] \cdot \sigma_{ck}/\sigma_{sy}$

where

P_b : Ultimate reinforcement ration of equilibrium

ε_u : Ultimate compressive strain of concrete

$\varepsilon_u = 0.0035$

ε_y : Yield strain of tensile steel

$\varepsilon_y = \sigma_{sy} / E_s = 345.0 / (2.0 \times 10^5) = 0.00148$ for reinforcing steel SD345

E_s : Modulus of elasticity of tensile steel

$E_s = 2.0 \times 10^5$ N/mm² for reinforcing steel

σ_{sy} : Yield stress of tensile steel

$\sigma_{sy} = 345.0$ N/mm² for reinforcing steel SD345

σ_{ck} : Specified characteristic strength of concrete

$\sigma_{ck} = 50$ N/mm² (cylinder strength)

★ Practice : Calculate ultimate reinforcement ration of equilibrium.

P_b = = ________

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(3) Calculation in Longitudinal Direction

(b) Ratio of tensile reinforcement

$$P = A_S / b \cdot d$$

where

P	: Ratio of tensile reinforcement
A_s	: Area of tensile reinforcement [mm²]
b	: Effective width of compression flange [mm]
d	: Distance from extreme compression fiber to centroid of tensile reinforcement [mm]

★ Practice : Calculate ratio of tensile reinforcement.

Assuming b = 1000mm
d = 200mm

When reinforcement is D16 ctc125

A_s = = ________ mm²

P = = ________

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(3) Calculation in Longitudinal Direction

(c) Check for strain level of tensile reinforcement

- If $P_b > P$, tensile reinforcement has been yielded at the time of failure of the member.
- In this case, tensile force in the tensile reinforcement and compressive force in concrete are given by

$$T = \sigma_{sy} \cdot A_s$$
$$C = 0.68 \cdot \sigma_{ck} \cdot b \cdot x$$

where

σ_{sy}	: Tensile strength of reinforcing steel
A_s	: Area of tensile reinforcement [mm²]
T	: Tensile force in reinforcement
C	: Compressive force in concrete
σ_{ck}	: Specified characteristic strength of concrete

- As $C = T$,

$$x = \sigma_{sy} \cdot A_s / 0.68 \cdot \sigma_{ck} \cdot b$$

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.7. Safety against Bending Failure

(3) Calculation in Longitudinal Direction

(d) Flexural resistance

$$M_u = 0.68 \cdot \sigma_{ck} \cdot b \cdot x \cdot (d - 0.4\,x)$$

(e) Bending moment at ultimate load state

$$M_1 = 1.3\,M_d + 2.5\,M_\ell$$

$$M_2 = 1.7\,(M_d + M_\ell)$$

where

M_d : Bending moment due to dead loads

M_ℓ : Bending moment due to live loads (including impact)

(f) Safety ratio against flexural failure

- It is checked that $M_u > M_1$, $M_u > M_2$

$$F_1 = M_u / M_1, \qquad F_2 = M_u / M_2$$

where

F_1, F_2 : Safety ratio against flexural failure for M_1 and M_2

5. Basis of Design of Prestressed Concrete Bridges

5.3. Design of Box Cross Section

5.3.8. Check for Minimum Reinforcement

- **Minimum reinforcement shall be bonded steel of more than 0.15 % of cross-sectional area of concrete**

$$A_{smin} = 0.0015 \cdot A_c$$

where

A_{smin} : Minimum reinforcement required for a concrete section

A_c : Area of the concrete cross section

JICA Study Team 101

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.1. General

- In the design of main girder, the followings shall be checked.
  - Sufficient safety against possible loads during service
  - Capability to fulfill its function for the purpose of long-term use
  - Economy for construction and maintenance
- The shape of cross section, amount of prestress … etc. shall be determined to be most effective against various actions on the structure, considering the characteristics of member cross section, material properties etc.
- The cross section shall be checked for safety as well.

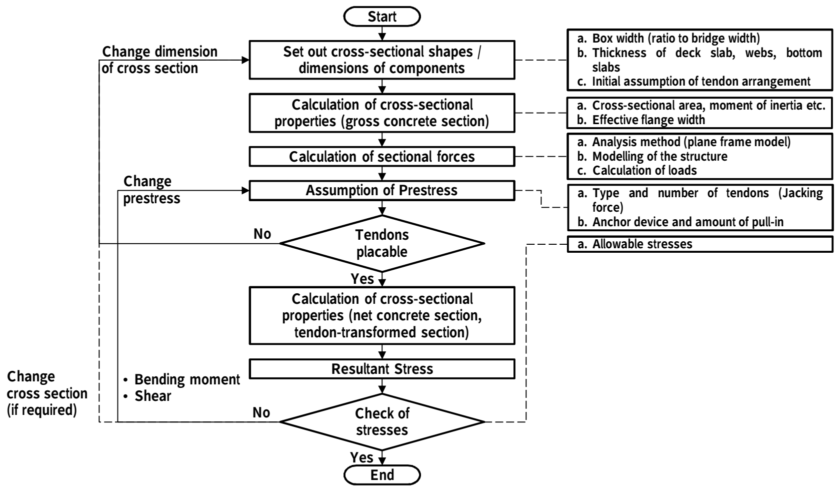
JICA Study Team 102

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.1. General

(1) Flow of Design



JICA Study Team 103

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.1. General

(2) Preliminary Study

1) Shape of Box Girder

a) Girder Height

L = 50.0m, H = 2.7m,

H/L = 1/18.5

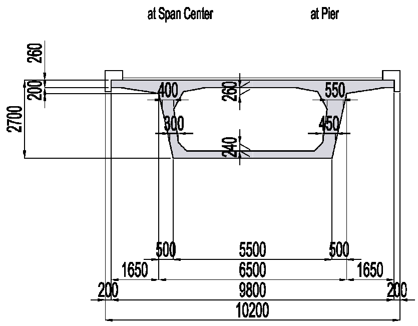
(Desirable ratio of girder height H to span length L: H/L = 1/17~ 1/20)

b) Box Width

D = 9.8m, B = 6.5m,

B/D = 0.66

(Desirable ratio of box width B to deck slab width D: B/D = 0.50 ~ 0.60 for PC box.
The box width for Bago Bridge has been determined considering the widening of bridge.)



JICA Study Team 104

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.1. General

(2) Preliminary Study

2) Number of Tendons and Prestressing Force

- Number of tendons and prestressing force are determined considering minimum number to be arranged, member dimensions etc. as well as structural requirement (to obtain desirable state of stress at each section etc.)
  - In the case of Bago River Bridge, 2 internal tendons at least (1 tendon / web) are arranged in order to obtain adequate deformability of the girder at ultimate load state, as the girder is composed of precast segments and not connected by reinforcing steels in the longitudinal direction.

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.1. General

(2) Preliminary Study

3) Analysis of Sectional Forces

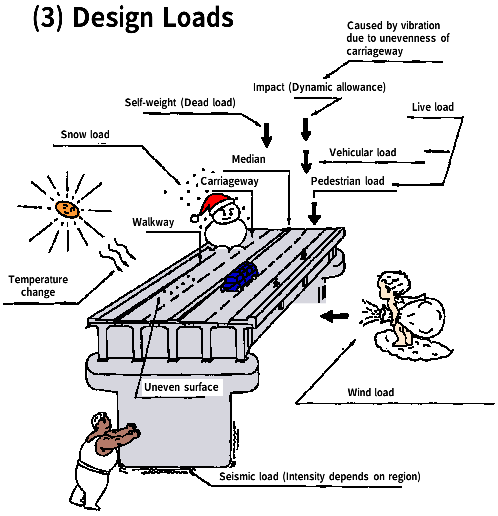
- **In general, PC box girders with single box and straight alignment are analyzed using plane frame model (2-dimensional).**
- **In case of curved box girders, 3-dimensional frame model are sometimes used. Application of 3-D or 2-D models depends of extent of curvature of the bridge.**

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.1. General

(3) Design Loads



The following loads shall be considered in the design:

Principal load (*P*)	1. Dead load (*D*)
	2. Live load (*L*)
	3. Impact (*I*)
	4. Prestress force (*PS*)
	5. Influence of concrete creep (*CR*)
	6. Influence of drying shrinkage of concrete (*SH*)
	7. Earth pressure (*E*)
	8. Hydraulic pressure (*HP*)
	9. Buoyancy or uplift (*U*)
Subordinate load (*S*)	10. Wind load (*W*)
	11. Influence of temperature change (*T*)
	12. Influence of earthquakes (*EQ*)
Special load equivalent to principal load (*PP*)	13. Snow load (*SW*)
	14. Influence of ground displacement (*GD*)
	15. Influence of support displacement(*SD*)
	16. Wave pressure (*WP*)
	17. Centrifugal load (*CF*)
Special load equivalent to subordinate load (*PA*)	18. Braking load (*BK*)
	19. Erection load (*ER*)
	20. Collision load (*CO*)
	21. Others

JICA Study Team 107

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.1. General

(4) Material Properties

(1) CONCRETE

Specified compressive strength	50.0 N/mm2
Young's modulus	3.30E+04 N/mm2
Shear modulus	1.43E+04 N/mm2
Coefficient of thermal expansion	1.00E-05 / ℃

(2) REINFORCEMENT

Reinforcement type	SD345
Yeild strength	345.0 N/mm2
Young's modulus	2.00E+05 N/mm2

(3) PRESTRESSING TENDON

(External cable for longitudinal)

Tendon type	SWPR7BL, 19S15.2, Low relaxation
Tensile strength	1850.0 N/mm2
Yeild strength	1600.0 N/mm2
Young's modulus	2.00E+05 N/mm2

(Internal cable for longitudinal)

Tendon type	SWPR7BL, 12S15.2, Low relaxation
Tensile strength	1850.0 N/mm2
Yeild strength	1600.0 N/mm2
Young's modulus	2.00E+05 N/mm2

JICA Study Team 108

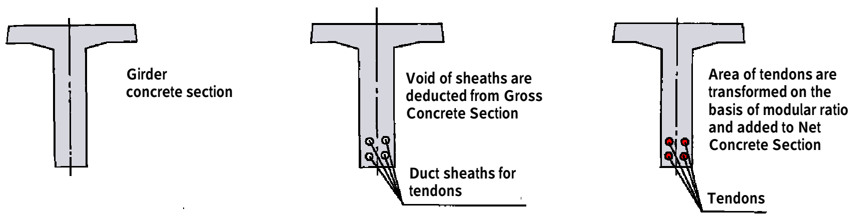
5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(1) General

1) State of Cross Section



Gross Concrete Section   Net Concrete Section   Tendon Transformed Section

5. Basis of Design of Prestressed Concrete Bridges

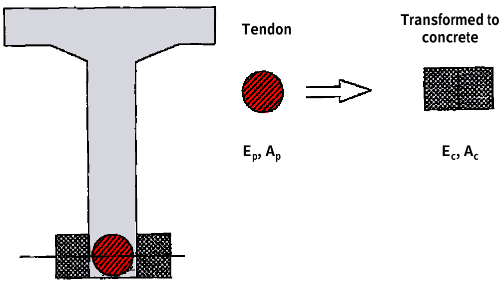
5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(1) General

1) State of Cross Section (cont.)

(a) Tendon transformed section



5. Basis of Design of Prestressed Concrete Bridges

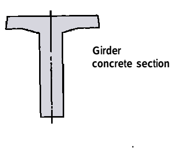
5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

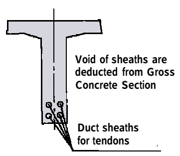
(1) General

2) State of Cross Section used in Analysis of Sectional Forces and in Calculation of Stress

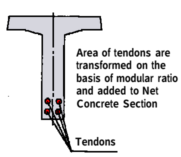
- Sectional Forces : Gross Concrete Section
- Stresses
  - Self-weight and prestressing force : Net Concrete Section
    - Tendons are not bonded to concrete section yet.
  - Superimposed dead load, live load and other loads : Tendon Transformed Section
    - Tendons are bonded to concrete section by grouting.



Gross Concrete Section



Net Concrete Section



Tendon Transformed Section

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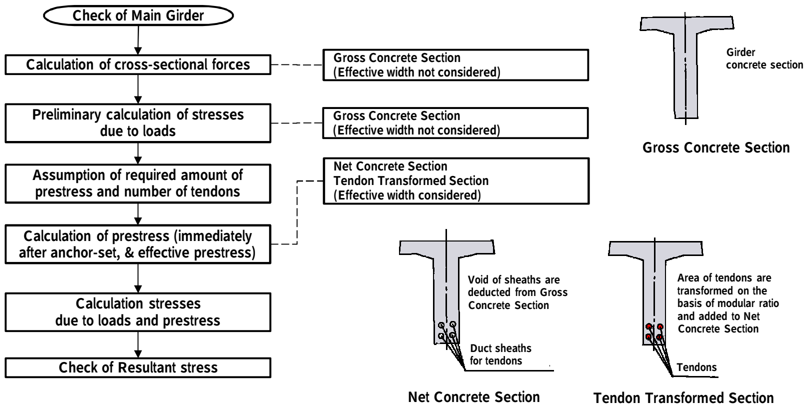
5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(1) General

3) Design Steps and State of Cross-Sectional Properties to be used



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5. Basis of Design of Prestressed Concrete Bridges

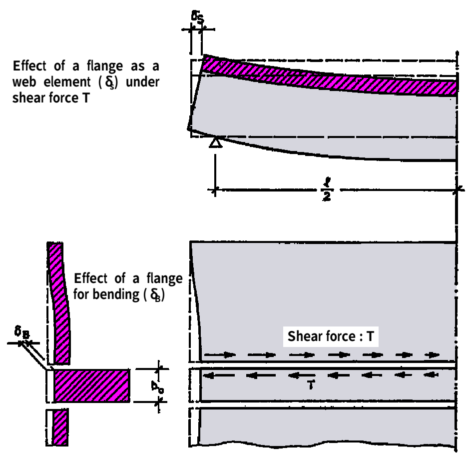
5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(1) General

4) Effective Flange Width

- **For members subjected to flexure and/or axial force, effective flange width shall be considered in order to take shear lag into account.**



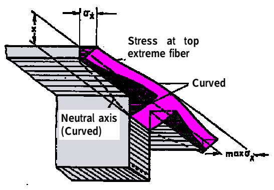
5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

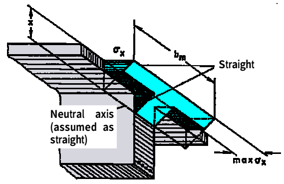
5.4.2. Calculation of Cross-Sectional Properties

(1) General

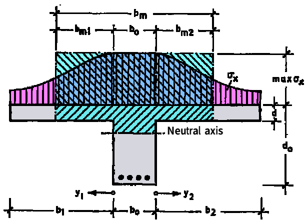
4) Effective Flange Width (cont.)



Actual distribution of compressive stress and variation of neutral axis



Assumption of effective flange width and idealized stress distribution



Comparison of actual extreme fiber stress and idealized stress considering effective flange width

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(2) Calculation of Cross-Sectional Properties

1) Effective Flange Width

(3) Half effective width of a compressive flange under a bending moment shall be calculated by Equation 4.2.1.

1) Main girder and cross beam at a support (directly supported beam)

$$\lambda = \frac{l}{8} + b_s$$

for a continuous slab and simple slab: $\lambda \leqq l_b / 2$

for a cantilever slab: $\lambda \leqq l_c$

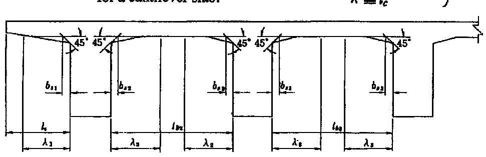
2) Intermediate cross beam (indirectly supported beam) .... (4.2.1)

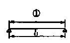
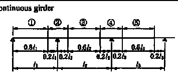
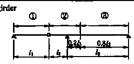
$$\lambda = \frac{n-1}{6}(l_b + b_w) + b_s$$

for a continuous slab and simple slab: $\lambda \leqq l_t / 2$

for a cantilever slab: $\lambda \leqq l_c$

where
λ: Half of the effective width of compressive flange (mm)
l: Span length for calculation of effective width (mm) (Value in Table 4.2.1)
b_s: Effective width of haunch (mm)
l_b: Clearance between main girders (mm)
l_c: Length of overhanging of cantilever slab (mm)
l_t: Clearance between cross beams (mm)
n: Number of main girders
b_w: Web thickness of main girder (mm)



Girder type	Segment	Span length (l) for calculation of effective width
Simple girder 	①	l_1
Continuous girder 	①	$0.8\, l_1$
	②	$0.2\,(l_1 + l_2)$
	③	$0.6\, l_2$
	④	$0.2\,(l_2 + l_3)$
	⑤	$0.6\, l_3$
Gerber girder 	①	l_1
	②	$2\, l_2$
	③	$0.8\, l_3$

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(2) Calculation of Cross-Sectional Properties

1) Effective Flange Width (cont.)

(4) Half effective width of a compressive flange under an axial force shall be calculated by Equation 4.2.2.

1) Main girder and cross beam at support (directly supported beam)

Continuous slab and simple slab: $\lambda \leqq l_b / 2$

Cantilever slab: $\lambda \leqq l_c$

2) Intermediate beam (indirectly supported beam)

Continuous slab and simple slab: $\lambda \leqq l_i / 2$

Cantilever beam: $\lambda \leqq l_c$

.... (4.2.2)

where λ: Half effective width of compressive flange (mm)

l_b: Clearance between main girders (mm)

l_c: Length of overhanging of cantilever slab (mm)

l_i: Clearance between cross beams (mm)

(5) Ducts in a prestressed concrete structure shall not be included in the effective section.

5. Basis of Design of Prestressed Concrete Bridges

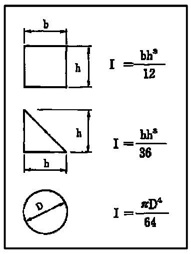
5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(2) Calculation of Cross-Sectional Properties

2) Calculation of Cross-Sectional Properties

- **To obtain cross-sectional properties, cross section is divided into several simple elements as shown in the example below.**



Sectional area : $A = \sum_{i=1}^{n} A_i$

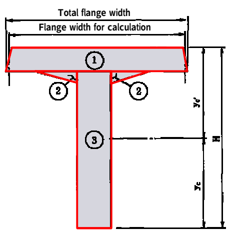
Centroid of section : $y_c' = \frac{\sum_{i=1}^{n}(A_i \cdot y')}{A}$

Distance from centroid to bottom of the section :

$$y_c = H - y_c'$$

Moment of inertia : $I = \sum_{i=1}^{n}(A_i \cdot y'^2) + \sum_{i=1}^{n} I_{ci} - \sum_{i=1}^{n} A_i \cdot y_c'^2$

Section Modulus : $Z_c' = \frac{I}{y_c'}$ **for top,** $Z_c = \frac{I}{y_c}$ **for bottom fiber**



where

y' : Distance from top of section to centroid of each element

y_c' : Distance from top of section to centroid of section

A_i : Area of each element

I_{ci} : Moment of inertia of each element

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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(2) Calculation of Cross-Sectional Properties

3) Eccentricity of Tendons

- **Eccentricity of tendons means the distance from centroid of the section to the centroid of tendons.**

Eccentricity of tendons : $e_p = \sum_{i=1}^{n} A_i$

where

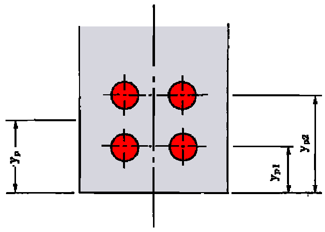
M : Number of tendons at each layer (k : Number of layers)

N : Total number of tendons

y_p : Distance from bottom of section to centroid of tendons

$$y_p = \frac{\sum_{i=1}^{n}(M \cdot y_{pi})}{N}$$

I_{ci} : Moment of inertia of each element



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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(2) Calculation of Cross-Sectional Properties

4) Cross Sections for Check

- **Check of stress etc. shall be carried out for all the critical cross sections. (eg. Span center, at support ··· etc.)**
- **Cross-sectional properties shall be calculated for standard section as well as for the sections in which the thickness of elements (slabs, webs) varies (near support etc.)**

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5. Basis of Design of Prestressed Concrete Bridges

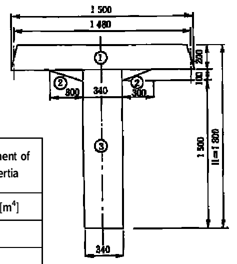
5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(3) Cross-Sectional Properties

★ Practice: Calculate cross-sectional properties

➢ **Gross concrete section**



Element No.	Shape	Nos.	Dimension: Width b [m]	Dimension: Height h [m]	Cross-sectional area A [m²]	Distance from top of section to centroid y' [m]	A・y' [m³]	A・y'² [m⁴]	Moment of Inertia I_0 [m⁴]
①	□	1							
②	▽	2							
③	□	1							
Total									

Cross-sectional area : $A_c = \sum A$

Centroid of section : $y_c' = \frac{\sum(A \cdot y')}{\sum A}$

From bottom to centroid of section : $y_c = -(H - y_c')$

Moment of inertia : $I_c = \sum(A \cdot y'^2) + \sum I_0 - \sum A \cdot y_c'^2$

Section modulus

at top fiber : $Z_c' = \frac{I_c}{y_c'}$

at bottom fiber : $Z_c = \frac{I_c}{y_c}$

JICA Study Team 120

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

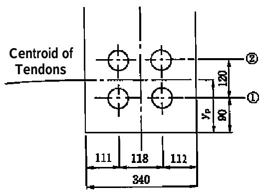
5.4.2. Calculation of Cross-Sectional Properties

(3) Cross-Sectional Properties

★ Practice: Calculate cross-sectional properties

➢ **Net concrete section**

Element No.	Shape	Nos.	Dimension: Diameter D [m]	Cross-sectional area A [m²]	Distance from top of section to centroid y' [m]	A・y' [m³]	A・y'² [m⁴]	Moment of Inertia I_0 [m⁴]
Gross section		1						
Ducts ①	○	2						
Ducts ②	○	2						
Total								



Diameter of ducts : D = 0.068mm

Cross-sectional area : $A_{c0} = \sum A$

Centroid of section : $y_{c0}' = \frac{\sum(A \cdot y')}{\sum A}$

From bottom to centroid of section : $y_{c0} = -(H - y_{c0}')$

Eccentricity of tendons : $e_{pc0} = y_{c0} - y_p$

Moment of inertia : $I_{c0} = \sum(A \cdot y'^2) + \sum I_0 + \sum A \cdot y_{c0}'^2$

Section modulus

at top fiber : $Z_{c0}' = \frac{I_c}{y_{c0}'}$, at bottom fiber : $Z_{c0} = \frac{I_{c0}}{y_{c0}}$, at centroid of tendons : $Z_{e0} = \frac{I_{c0}}{e_{pc0}}$

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(3) Cross-Sectional Properties

★ Practice: Calculate cross-sectional properties

➢ **Tendon-transformed section**

Element No.	Shape	Nos.	Cross-sectional area A [m²]	Distance from top of section to centroid y' [m]	A・y' [m³]	A・y'² [m⁴]	Moment of Inertia I_0 [m⁴]
Net section		1					
Tendons ①		2					
Tendons ②		2					
Total							

Modulus Ratio:
$n_P = E_P/E_c = 2.0\text{x}10^5/3.1\text{x}10^4 = 6.452$
Area of a tendon: $A_p = 1184.52$ mm²
Equivalent section of tendon (transformed to Concrete) :
$A_{cp} = n_p \cdot A_p$

Cross-sectional area : $A_{c1} = \sum A$

Centroid of section : $y_{c1}' = \frac{\sum(A \cdot y')}{\sum A}$

From bottom to centroid of section : $y_{c1} = -(H - y_{c1}')$

Eccentricity of tendons : $e_{pc1} = y_{c1} - y_p$

Moment of inertia : $I_{c1} = \sum(A \cdot y'^2) + \sum I_0 - \sum A \cdot y_{c1}'^2$

Section modulus

at top fiber : $Z_{c1}' = \frac{I_c}{y_{c1}'}$, at bottom fiber : $Z_{c1} = \frac{I_{c1}}{y_{c1}}$, at centroid of tendons : $Z_{e1} = \frac{I_{c1}}{e_{pc1}}$

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(3) Cross-Sectional Properties

4) Summary

★ Practice : Tabulate cross sectional properties.

		unit	symbol	Gross concrete section	Net concrete section	Tendon-transformed section
Cross-sectional area		m²	A			
Distance from top to centroid		m	y'			
Distance from bottom to centroid		m	y			
Eccentricity of tendons ①		m	$e_{p①}$			
Eccentricity of tendons ②		m	$e_{p②}$			
Eccentricity of All tendons		m	e_p			
Moment of inertia		m⁴	I			
Section modulus	at top	m³	Z'			
	at bottom	m³	Z'			
	tendons centroid	m³	Z_e			

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5. Basis of Design of Prestressed Concrete Bridges

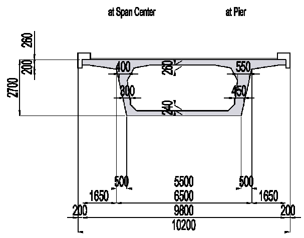
5.4. Design of Main Girder

5.4.2. Calculation of Cross-Sectional Properties

(3) Cross-Sectional Properties

4) Summary

(a) Cross-sectional properties for box section



at span center

		unit	symbol	Gross concrete section	Net concrete section	Tendon-transformed section
Cross-sectional area		m^2	A	6.303	6.252	6.352
Distance from top to centroid		m	y'	1.001	0.988	1.013
Distance from bottom to centroid		m	y	-1.699	-1.712	-1.687
Eccentricity of All tendons		m	e_p		-1.592	-1.567
Moment of inertia		m^4	I	6.4367	6.3103	6.5594
Section modulus	at top	m^3	Z'	6.430	6.385	6.473
	at bottom	m^3	Z'	-3.789	-3.687	-3.889
	tendons centroid	m^3	Z_e		-3.964	-4.187

at support

		unit	symbol	Gross concrete section	Net concrete section	Tendon-transformed section
Cross-sectional area		m^2	A	6.963	6.963	6.963
Distance from top to centroid		m	y'		1.035	1.038
Distance from bottom to centroid		m	y		-1.665	-1.662
Eccentricity of All tendons		m	e_p			
Moment of inertia		m^4	I	6.7799	6.7799	6.7799
Section modulus	at top	m^3	Z'		6.551	6.551
	at bottom	m^3	Z'		-4.072	-4.072
	tendons centroid	m^3	Z_e			

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5. Basis of Design of Prestressed Concrete Bridges

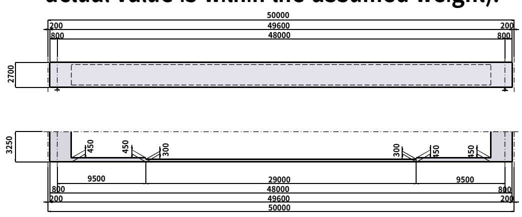
5.4. Design of Main Girder

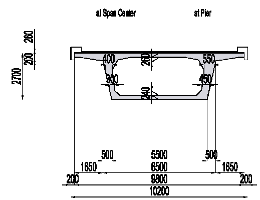
5.4.3. Calculation of Sectional Forces

(1) Loads

1) Self Weight

- **Self-weight of main girder is calculated as**
  [cross-sectional area of member] x [unit weight of prestressed concrete]
- **Crossbeams are normally loaded on the nodes at supports as concentrated loads.**
- **Anchor blisters for internal tendons are normally loaded as uniform load (xx kN/m.) based on assumption (Final confirmation required whether actual value is within the assumed weight).**





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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

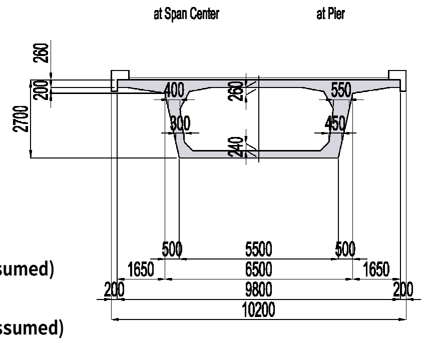
5.4.3. Calculation of Sectional Forces

(1) Loads

1) Self Weight

★ Practice: Calculate the strength of self-weight

- **At span center**
  - A = 6.303 m^2
  - unit weight = 24.5 kN/m^3
  - w = ________kN/m
- **At pier**
  - A = 6.963 m^2
  - unit weight = 24.5 kN/m^3
  - w = ________kN/m
- **Deviators, ribs, anchor blisters**
  - w = 8.0 kN/m (assumed)
- **Crossbeams at supports**
  - P = 700.0 kN/EA (assumed)



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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

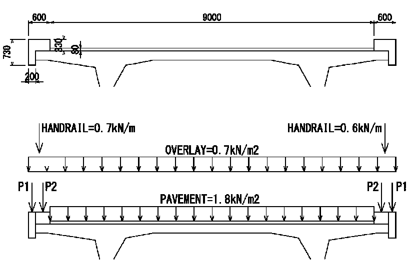
5.4.3. Calculation of Sectional Forces

(1) Loads

2) Superimposed Dead Load

★ Practice: Calculate the strength of superimposed dead load

Pavement : w = ________ kN/m
Wheelguards: (per each) ________ kN/m
w x 2 = ________ kN/m
Handrails : w = ________ kN/m
Overlay : w = ________ kN/m
____
Total w = ________ kN/m



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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.3. Calculation of Sectional Forces

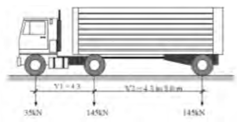
(1) Loads

3) Live Load

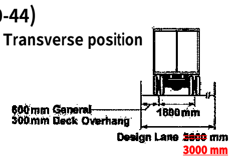
★ Practice : Calculate strength of live load.

- Impact (dynamic allowance): i = 10 / (25 + L) = ________
  (assume L = 48.0m)
- Design truck: P = (35 + 145 + 145) x 3 lanes x m x (1 + i) = ________kN
- Design lane load : w = 9.3 x 3 lanes x m x (1 + i) = ________kN

(1)-1 Design truck (HS20-44)



Transverse position



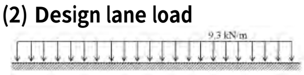
In Bago Bridge, Design Lane width is assumed to be 3000mm to be on the safer side.

Multiple presence factor

Number of Loaded Lanes	Multiple Presence Factors, m
1	1.20
2	1.00
3	0.85
>3	0.65

Nominal lane width shall be 3.0m.

(2) Design lane load



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5. Basis of Design of Prestressed Concrete Bridges

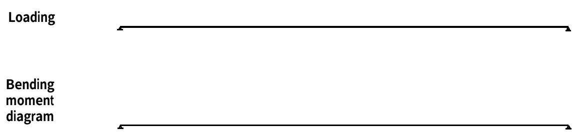
5.4. Design of Main Girder

5.4.3. Calculation of Sectional Forces

(2) Sectional Forces

1) Self Weight

★ Practice : Calculate sectional forces (bending moment, shear) and support reaction due to Self-weight.



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5. Basis of Design of Prestressed Concrete Bridges

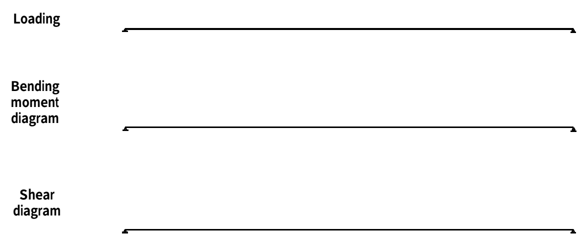
5.4. Design of Main Girder

5.4.3. Calculation of Sectional Forces

(2) Sectional Forces

2) Superimposed Dead Load

★ Practice : Calculate sectional forces (bending moment, shear) and support reaction due to Superimposed Dead Load.



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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.3. Calculation of Sectional Forces

(2) Sectional Forces

3) Live Load

★ Practice : Calculate sectional forces (bending moment, shear) and support reaction due to Live Load.

JICA Study Team 131

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.3. Calculation of Sectional Forces

(2) Sectional Forces

3) Live Load

★ Practice : Calculate sectional forces (bending moment, shear) and support reaction due to Live Load.

Loading

Shear diagram

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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.3. Calculation of Sectional Forces

(2) Sectional Forces

4) Summary of Sectional Forces due to Loads

★ Practice : Tabulate sectional forces due to loads.

	at Span center	at Support
	Bending moment	Shear
	[kNm]	[kN]
Self-weight		
Superimposed dead load		
Live load		
All dead loads		
Dead loads + live load		

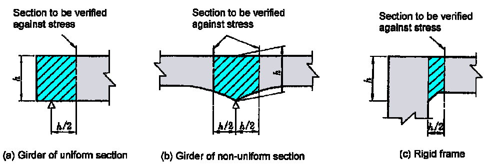

Figure 4.3.2 Section to be verified against shear force

(4), (5) Near a support of a girder and near a joint of a rigid frame, a compressive force due to support reaction acts on the web, so the tensile force acting on the diagonal tensile reinforcement is smaller than in the other portions. Therefore, the verification against shear force need not be performed in the area from the support to half the member height, and it is sufficient to place diagonal tensile reinforcement in the hatched area of Figure 4.3.2 in an such an amount that the member section satisfies the verification in Clauses (1) and (2) against the shear force at the distance of half the member height from the support.

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.3. Calculation of Sectional Forces

(2) Sectional Forces

★ Check of Sectional Forces

- **Adequacy of analysis can be roughly checked by simple methods. In the case of PC box girder bridges, for example,**
  - For self-weight, compare cross-sectional area at standard section with (total reaction due to self-weight) / (bridge length x unit weight (24.5 kN/m^3 for PC))
  - Live load is roughly 20% of total dead load (including superimposed dead load) for highway bridges.

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(1) Sectional Forces and Stresses due to Loads

- **Stress due to bending and axial force is obtained by the following equations.**

$$\sigma_{c'} = \frac{M}{Z_{c'}} + \frac{N}{A_c}$$ for top fiber of cross section

$$\sigma_c = \frac{M}{Z_c} + \frac{N}{A_c}$$ for bottom fiber of cross section

where
- M : Bending moment by loads
- N : Axial force by loads
- $\sigma_{c'}$ / σ_c : Stress due to bending moment and axial force by loads at top / bottom fiber of the section (positive when compressive, negative when tensile)
- $Z_{c'}$ / Z_c : Modulus of section at top / bottom fiber of the section (positive / negative for top / bottom fiber of the section)
- A_c : Cross-sectional area of the section

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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(1) Sectional Forces and Stresses due to Loads

★ Practice : Calculate bending stresses due to loads.

	Bending moment	Section modulus		Stress due to loads	
		at top	at bottom	at top	at bottom
	M_d [kNm]	Z_c' [mm^3]	Z_c' [mm^3]	σ_d' [N/mm^2]	σ_d [N/mm^2]
Self-weight					
Superimposed dead load					
Live load					
All dead loads					
Dead loads + live load					

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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

1) Calculation of Required Prestress

- **Required amount of prestress is calculated in order to adjust the stress due to loads to be within allowable tensile stress.**

$$\sigma = \left(\frac{N}{A} + \frac{M}{Z}\right) + P\left(\frac{1}{A} + \frac{e_p}{Z}\right)$$

where

σ	: Resultant stress
$\left(\frac{N}{A} + \frac{M}{Z}\right)$	: Stress due to loads (axial force + flexure)
$P\left(\frac{1}{A} + \frac{e_p}{Z}\right)$	: Stress due to prestressing (total prestress x (axial force + flexure))
A	: Cross-sectional area of the section
Z	: Section modulus
N, M	: Axial force and bending moment at the section
P	: Total prestressing force
e_p	: Eccentricity of tendons from centroid of the section

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

1) Calculation of Required Prestress (cont.)

- **For required prestress : P_e and allowable tensile stress of concrete : σ_{ca}',**

$$\Sigma\sigma_c + \frac{P_e}{A_c} + \frac{P_e \cdot e_p}{Z} \geqq \sigma_{ca}'$$

where $\Sigma\sigma_c$: Total stress due to loads at extreme tensile fiber
σ_{ca}' : Allowable tensile stress of concrete

- **The above expression is transformed to obtain P_e,**

$$\frac{P_e}{A_c}\left(1 + \frac{A_c \cdot e_p}{\frac{I_c}{y_c}}\right) \geqq -\Sigma\sigma_c + \sigma_{ca}' \quad \rightarrow \quad \frac{P_e}{A_c}\left(1 + \frac{y_c}{r_c^2} \cdot e_p\right) \geqq -\Sigma\sigma_c + \sigma_{ca}'$$

Hence, $P_e = \frac{(-\Sigma\sigma_c + \sigma_{ca}') \cdot A_c}{1 + \frac{y_c}{r_c^2} e_p}$

where e_p : Eccentricity of centroid of tendons from centroid of the section
I_c : Moment of inertia of the section
A_c : Cross-sectional area of the section
y_c' : Distance from centroid to extreme tensile fiber of the section
Z : Section modulus (= I/y_c)
r_c : Radius of gyration (= $\sqrt{I_c / A_c}$)

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

1) Calculation of Required Prestress (initial estimation)

- **Required number of tendons can be initially estimated assuming**

$\sigma_{pe} \fallingdotseq 0.5\,\sigma_{pu}$ (for tendons using strands)

where σ_{pe} : Assumed effective prestress
σ_{pu} : Tensile strength of prestressing steel

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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

2) Tendon Arrangement

- **Tendon arrangement is determined considering the followings as well as requirements on state of stress:**
  - Concrete cover of tendons
  - Minimum spacing between tendons (considering space for internal vibrator etc.)
  - Minimum radius of curvature
  - Spacing of anchor devices (depends on types and capacity)
  - Concrete edge distance of anchor devices (depends on types and capacity)
  - Detailed consideration (transverse tendons, reinforcement, bearings (anchor bolts), anchor bars, cut-outs for expansion joints ··· etc.)

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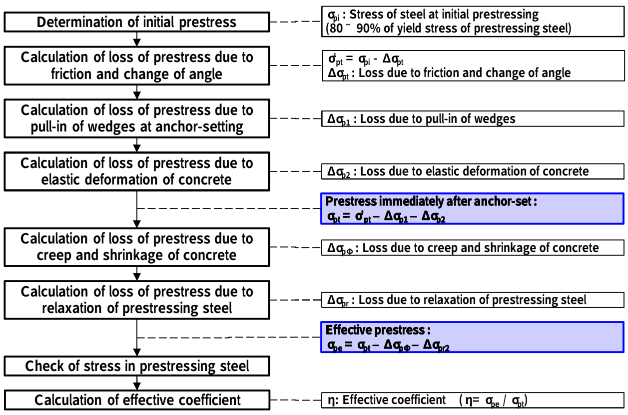
5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

3) Efective Prestress (Flow of calculation)



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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

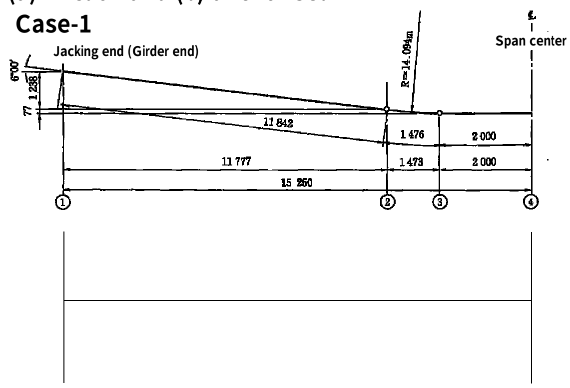
4) Loss of Prestress

★ Practice: Calculate initial prestress

(a) Friction and (b) anchor-set

Case-1

Pull-in : 8mm



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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

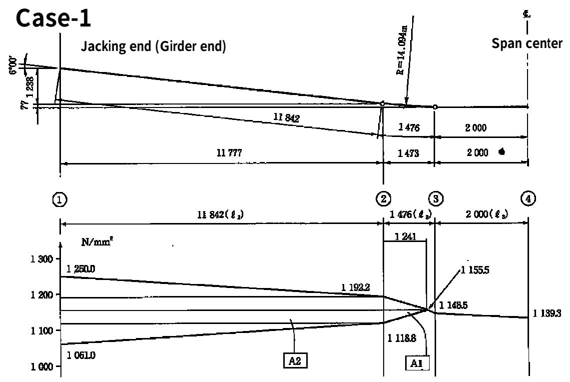
4) Loss of Prestress

★ Practice: Calculate initial prestress

(a) Friction and (b) anchor-set

Case-1

Pull-in : 8mm



5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

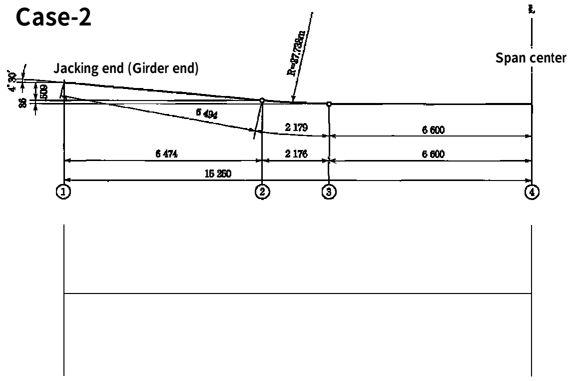
4) Loss of Prestress

★ Practice: Calculate initial prestress

(a) Friction and (b) anchor-set

Case-2

Pull-in : 8mm



5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

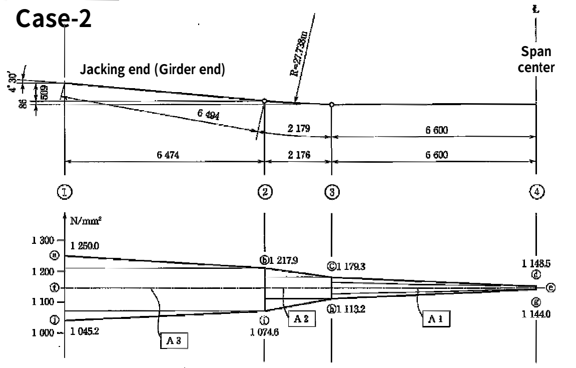
4) Loss of Prestress

★ Practice: Calculate initial prestress

(a) Friction and (b) anchor-set

Case-2

Pull-in : 8mm



5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

4) Loss of Prestress

★ Practice: Calculate initial prestress

(c) Loss of prestress due to elastic shortening

$$\Delta\sigma_p = \frac{1}{2} \cdot n \cdot \sigma_{cpg} \frac{N-1}{N}$$

Modulus ratio (assumed): $N = E_p/E_c = 2.0\text{x}10^5/2.92\text{x}10^4$ = 6.85

Average tendon stress : σ_{pt}' = 1142.2 N/mm²

Number of tendons : N = 4 tendons

Area of tendons : A_p = 1184.52 mm²/tendon

Total prestressing force : $P_t' = N \text{ x } \sigma_{pt}' \text{ x } A_p$ = = ________ kN

Concrete stress due to prestressing at the centroid of tendons :

$$\sigma_{ctg} = \frac{P_t'}{A} + \frac{P_t' \cdot e_p}{Z_e}$$ = ________ N/mm

Concrete stress due to self-weight at the centroid of tendons : σ_{dog} = -9.107 N/mm²
(Assumed)

Total concrete stress at the centroid of tendons : $\sigma_{cpg} = \sigma_{ctg} + \sigma_{dog}$ = ________ N/mm²

Hence, $\Delta\sigma_p = \frac{1}{2} \cdot n \cdot \sigma_{cpg} \frac{N-1}{N}$ = = ________ N/mm²

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

4) Loss of Prestress

★ Practice: Calculate initial prestress

(d) Prestress in steel immediately after anchor-set

$\sigma_{pt} = \sigma_{pt}' - \Delta\sigma_p$ = = ________ N/mm²

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

4) Loss of Prestress

★ Practice: Calculate initial prestress

(e) Concrete stress due to prestressing immediately after anchor-set

$\Delta\sigma_p = \frac{1}{2} \cdot n \cdot \sigma_{cpg} \frac{N-1}{N}$

Initial prestress (Total prestressing force immediately after anchor set) :

$P_t = N \times \sigma_{pt}' \times A_p =$ = ________ kN

Eccentricity of tendons (assumed) : e_p = -999 mm

Cross-sectional area of concrete : A = 0.855 m²

Section modulus at top : Z_c' = 0.4047 m³

at bottom : Z_c = –0.2293 m³

at centroid of tendons : Z_e = –0.2637 m³

Concrete stress due to prestressing

at top : $\sigma_{ct}' = \frac{P_t}{A} + \frac{P_t \cdot e_p}{Z_c'}$ = ________ N/mm²

at bottom : $\sigma_{ct} = \frac{P_t}{A} + \frac{P_t \cdot e_p}{Z_c}$ = ________ N/mm²

at centroid of tendon : $\sigma_{ce} = \frac{P_t}{A} + \frac{P_t \cdot e_p}{Z_e}$ = ________ N/mm²

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

4) Loss of Prestress

★ Practice: Calculate initial prestress

(f) Resultant stress immediately after anchor-set

Concrete stress due to load at top : σ_{d0}' = ________ N/mm²

at bottom : σ_{d0} = ________ N/mm²

Concrete stress due to prestress immediately after anchor set

at top : σ_{ct}' = ________ N/mm²

at bottom : σ_{ct} = ________ N/mm²

Resultant stress at top : $\sigma_c' = \sigma_{d0}' + \sigma_{ct}'$ = ________ N/mm²

at bottom : $\sigma_c = \sigma_{d0} + \sigma_{ct}$ = ________ N/mm²

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

4) Loss of Prestress

★ Practice: Calculate effective prestress

(a) Loss of prestress due to creep and shrinkage of concrete

$$\Delta\sigma_{p\varphi} = \frac{n \cdot \varphi \cdot (\sigma_{cpt} + \Sigma\sigma_{dog}) + E_p \cdot \varepsilon_s}{1 + n \cdot \frac{\sigma_{cpt}}{\sigma_{pt}}(1 + \frac{\varphi}{2})}$$

where σ_{cpt} : Concrete stress due to prestress at the height of tendon considered
σ_{cpt} = ________ N/mm²

$\Sigma\sigma_{dog}$: Concrete stress due to loads at the height of tendon considered assumed as $\Sigma\sigma_{dog}$ = -15.225 N/mm²

E_p : Modulus of elasticity of prestressing steel = 2.0 x 10^5 N/mm²

E_c : Modulus of elasticity of concrete at 28 days = 3.1 x 10^4 N/mm²

A : Cross-sectional area of the section

n : Modular ratio = E_p/E_c = 6.45

σ_{pt} : Stress in prestressing steel immediately after anchor-set
σ_{pt} = ________ N/mm²

Hence, $\Delta\sigma_{p\varphi}$ = = ________ N/mm²

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

4) Loss of Prestress

★ Practice: Calculate effective prestress

(b) Loss of prestress due to relaxation of prestressing steel

$\Delta\sigma_{pr}$ = 0.015 σ_{pt} = = ________ N/mm²

(relaxation coefficient of prestressing steel is assumed as 1.5%)

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(2) Calculation of Prestress

4) Loss of Prestress

★ Practice: Calculate effective prestress

(c) Effective prestress in prestressing steel

$\sigma_{pe} = \sigma_{pt} - \Delta\sigma_{p\phi} - \Delta\sigma_{pr}$ = = ________ N/mm²

Check $\sigma_{pe} < \sigma_{pa}$ = 1110.0 N/mm²

Effective coefficient : $\eta = \sigma_{pe} / \sigma_{pt}$ = = ________

(d) Concrete stress due to effective prestress

at top : $\sigma_{ce}' = \eta \times \sigma_{ct}'$ = = ________ N/mm²

at bottom : $\sigma_{ce} = \eta \times \sigma_{ct}$ = = ________ N/mm²

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(3) Resultant Stress

★ Practice: Calculate resultant stress

- At span center

		Immediately after anchor set		At service load state	
		at top	at bottom	at top	at bottom
		σ_u [N/mm²]	σ_l [N/mm²]	σ_u [N/mm²]	σ_l [N/mm²]
Internal prestress	immediately after anchor-set	-1.70	11.24		
	Effective prestress			-1.52	10.07
External prestress	immediately after anchor-set	-1.15	12.72		
	Effective prestress			-1.05	11.62
Total prestress	immediately after anchor-set				
	Effective prestress				
Self-weight					
Superimposed dead load					
Live load					
Immediately after anchor set					
All dead loads					
Dead loads + Live load					
Allowable stress σ_a [N/mm²]	compression	20.00	20.00	16.00	16.00
	tension	0.00	0.00	0.00	0.00

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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.4. Calculation of Bending Stress

(4) Increase of Stress in Tendons

- When loads are acting after all prestress losses (creep, shrinkage, relaxation), tensile stress are increased due to the loads.
- The stress of tendons is proportional to the distance from centroid of the section to each tendon, and the stress of tendons at the most outer layer are largest, which is thus shall be checked for increased value.
- Maximum tensile stress of tendon $\Delta\sigma_{pmax}$ is

$$\Delta\sigma_{pmax} = n\,(\Sigma\sigma_{dg} + \sigma_{lg}) + \sigma_{pe} < \sigma_{pa}$$

where
- n : modular ratio (E_p/E_c)
- σ_{pe} : Effective prestress of tendon
- $\Sigma\sigma_{dg}$: Concrete stress at the centroid of the tendon due to dead loads except self-weight
- σ_{lg} : Concrete stress at the centroid of the tendon due to live load

JICA Study Team 154

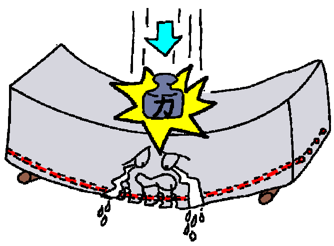
5. Basis of Design of Prestressed Concrete Bridges

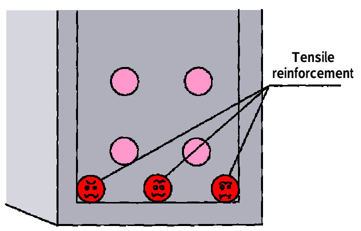
5.4. Design of Main Girder

5.4.5. Calculation of Tensile Reinforcement

(1) General

- Under service load state, tensile stress below allowable value might occur in the concrete of the cross section.
- Tensile reinforcement is provided in the region in which the above tensile stress occurs, aimed to maintain possible cracks within small range, and to improve ductility of the member.





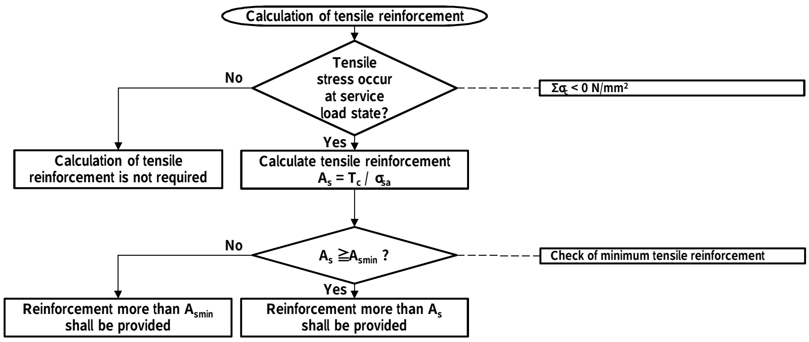
JICA Study Team 155

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.5. Calculation of Tensile Reinforcement

(2) Flow of Calculation



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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.5. Calculation of Tensile Reinforcement

(2) Flow of calculation (cont.)

- **There are 2 cases regarding tensile stress in concrete cross section.**
  1. **Tensile stress is induced in the section**
  2. **Tensile stress is not induced in the section**
- **In the case-1, tensile reinforcement needs to be calculated, and the larger of required tensile reinforcement or minimum tensile reinforcement shall be provided in the tensile region of the section.**
- **In the case-2, tensile reinforcement are not calculated.**

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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.5. Calculation of Tensile Reinforcement

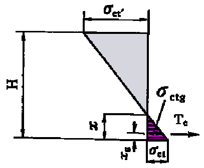
(2) Flow of Calculation

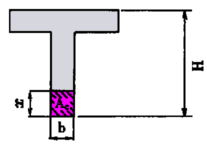
1) Required Tensile Reinforcement

- **Amount of required tensile reinforcement is calculated from the total tensile force of tensile region in the concrete cross section.**

$A_{sreq} = \frac{T_c}{\sigma_{sa}}$ ($A_{sreq} = \frac{b \cdot x \cdot \sigma_{ct}}{2\sigma_{sa}}$ for rectangular tensile region)

where
A_{sreq} : Required tensile reinforcement
T_c : Total tensile force in the concrete cross section
σ_{sa} : Allowable tensile stress of reinforcing steel (σ_{sa} = 180 N/mm^2)
b : width of tensile region element(s)
x : height of tensile region element(s)
= distance from extreme tensile fiber to neutral axis of the section





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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.5. Calculation of Tensile Reinforcement

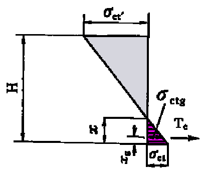
(2) Flow of Calculation

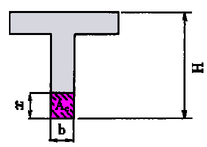
2) Minimum Tensile Reinforcement

- **Amount of minimum tensile reinforcement is calculated from the area of tensile region in the concrete cross section.**

$A_{smin} = 0.005\Sigma(b \cdot x)$

where
A_{smin} : minimum tensile reinforcement
b : width of tensile region element(s)
x : height of tensile region element(s)





5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.5. Calculation of Tensile Reinforcement

(2) Flow of Calculation

3) Arrangement of Tensile Reinforcement

- Spacing of rebars normally applied are ctc150mm (ctc 300mm) or ctc125mm (ctc 250mm) (ctc = center to center)
- "Smaller diameter with smaller spacing" is better than "larger diameter with larger spacing" in order to distribute stresses and cracks evenly and to avoid stress concentration.

5. Basis of Design of Prestressed Concrete Bridges
5.4. Design of Main Girder
5.4.5. Calculation of Tensile Reinforcement
(2) Flow of Calculation

3) Arrangement of Tensile Reinforcement (cont.)

- Size of deformed reinforcing steel bars typically used in Japan (Specified in JIS: Japan Industrial Standards)

Table C. 3.1.5 Unit mass and standard dimensions of deformed steel bars

Designation	Unit mass (kg/m)	Nominal diameter (d) (mm)	Nominal cross-sectional area (S) (mm^2)	Peripheral length (l) (mm)
D 6	0.249	6.35	31.67	20
D 10	0.560	9.53	71.33	30
D 13	0.995	12.7	126.7	40
D 16	1.56	15.9	198.6	50
D 19	2.25	19.1	286.5	60
D 22	3.04	22.2	387.1	70
D 25	3.98	25.4	506.7	80
D 29	5.04	28.6	642.4	90
D 32	6.23	31.8	794.2	100
D 35	7.51	34.9	956.6	110
D 38	8.95	38.1	1140	120
D 41	10.5	41.3	1340	130
D 51	15.9	50.8	2027	160

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.5. Calculation of Tensile Reinforcement

(2) Flow of Calculation

3) Arrangement of Tensile Reinforcement (cont.)

- **Mechanical properties of reinforcing steel bars typical in Japan (Specified in JIS: Japan Industrial Standards)**

Table C. 3.1.4 Mechanical properties of reinforced concrete steel bars

Symbol	Tensile test				Bendability	
	Yield point or 0.2% proof stress (N/mm^2)	Tensile strength (N/mm^2)	Tensile test piece	Elongation (%)	Bending angle	Inner diameter
SR235	235 or over	380 - 520	No. 2	20 or over	180°	1.5 times the nominal diameter
			No. 3	24 or over		
SD295A	295 or over	440 - 600	Those substantially equal to No. 2	16 or over	180°	D16 or less: 1.5 times the nominal diameter
			Those substantially equal to No. 3	18 or over		More than D16: Twice the nominal diameter
SD295B	295 - 390	440 or over	Those substantially equal to No. 2	16 or over	180°	D16 or less: 1.5 times the nominal diameter
			Those substantially equal to No. 3	18 or over		More than D16: Twice the nominal diameter
SD345	345 - 440	490 or over	Those substantially equal to No. 2	18 or over	180°	D16 or less: 1.5 times the nominal diameter
						More than D16 but D41 or less: Twice the nominal diameter
			Those substantially equal to No. 3	20 or over		D51: 2.5 times the nominal diameter

Note: For the deformed steel bars exceeding the designation D32 in dimensions, the elongation should be reduced 2% for each increment of 3 in designation. However, the reduction limit is 4%.

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

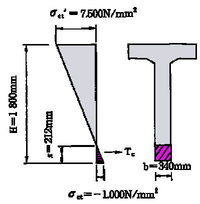
5.4.5. Calculation of Tensile Reinforcement

(3) Calculation

★ Practice: Determine tensile reinforcement to be provided.

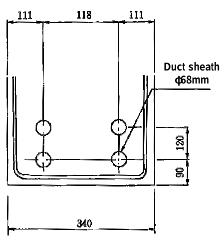
- **Calculate required tensile reinforcement A_{sreq}.**

$$A_{sreq} = \frac{T_c}{\sigma_{sa}}$$



- **Calculate minimum tensile reinforcement A_{smin}.**

$$A_{smin} = 0.005\Sigma(b \cdot x)$$



- **Determine tensile reinforcement to be provided.**
  - **Size**
  - **Number**

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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

(1) General

- **In JRA Specifications, prestressed concrete members shall be verified against both service load state and ultimate load state, in order to confirm their serviceability as well as their safety against failure. (Many of other international design specifications also have similar systems of state-based design such as "service limit state", "strength limit state", "extreme limit state", "fatigue limit state" etc.)**
- **At ultimate load state, the members are verified by confirming that ultimate moment due to ultimate loads (M) is within ultimate flexural resistance (M_u) of the section.**
- **Safety ratio against bending failure : $F = M_u/M > 1.0$**

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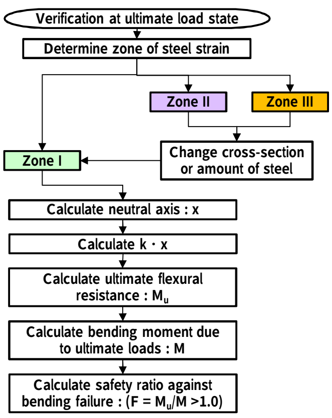
5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

(1) General

- **Flow of verification**



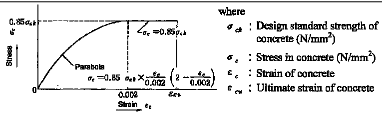
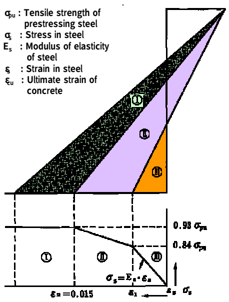


Figure 4.2.2 Stress-strain curve of concrete for calculation of resisting bending moment to failure

Table 4.2.2 Ultimate strain of concrete

Design standard strength of concrete σ_{ck} (N/mm²)	$\sigma_{ck} \leq 50$	$50 < \sigma_{ck} < 60$	$60 \leq \sigma_{ck}$
Ultimate strain ε_{cu}	0.0035	Linear interpolation between 0.0035 and 0.0025	0.0025



Strain zones of prestressing steel

Ultimate compressive strain of concrete is assumed as ε_u above.

[Strain zone I]
- Prestressing steel ε has reached its yield strain (1.5%).
- Concrete has not reached its ultimate strain ε_u.
- Yield of prestressing steel precedes.

[Strain zone II & III]
- Prestressing steel ε has not reached its yield strain (1.5%).
- Concrete has reached its ultimate strain ε_u.
- Crush of concrete precedes.

5. Basis of Design of Prestressed Concrete Bridges

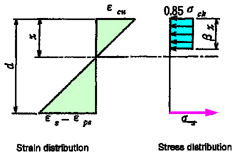
5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

(2) Calculation of Resistance Moment

1) Basic Conditions

- Fiber strain is proportional to the distance from neutral axis.
- Tensile strength of concrete is ignored.
- Distribution of compressive stress in concrete is as shown below:



$\beta = 0.8$ for $\sigma_{ck} \leqq 50$ N/mm^2

$\beta = 0.72$ for $\sigma_{ck} \geqq 60$ N/mm^2

Linear interpolation for $50 < \sigma_{ck} < 60$ N/mm^2

where
ε_{cu}: Ultimate strain of concrete
ε_s: Strain of steel
σ_{ck}: Design standard strength of concrete (N/mm^2)
ε_{pe}: Strain of PC tendon due to effective prestressing force
σ_s: Stress in steel (N/mm^2)
d: Effective height of member section (mm)
x: Distance from compression edge to neutral axis (mm)

Figure C. 4.2.3 Strain and stress distributions for calculating resisting bending moment to failure

5. Basis of Design of Prestressed Concrete Bridges

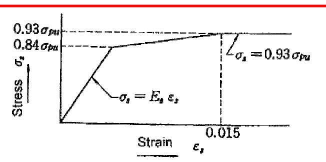
5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

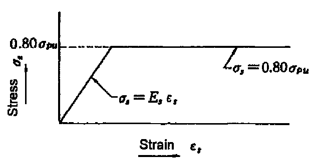
(2) Calculation of Resistance Moment

1) Basic Conditions (cont.)

- Stress-strain diagram for PC steel is as shown below.
- Only PC tendons are considered as tensile steel, and effective depth is taken as the distance from extreme compressive fiber to centroid of the tendons.
- Haunches on the top slab are omitted from compressive flange in the calculation.



(b) Prestressing wire, prestressing stranded wire and prestressing bar No. 1



(c) PC steel bar No. 2

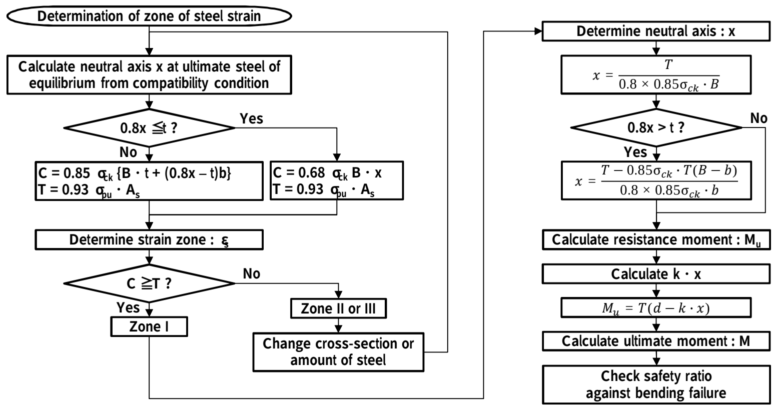
5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

(2) Calculation of Resistance Moment

2) Flow of Study



5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

(2) Calculation of Resistance Moment

3) Study on Safety against Bending Failure

(a) Determination of zone of steel strain

a) Assumption of neutral axis : x

- Assume that amount of tensile steel is same as ultimate steel of equilibrium.
- i.e. ultimate compressive stress of concrete (ε_u = 0.0035) and yield stress of tensile steel at its centroid (ε_s = ε_p = 0.015) occurs at the same time.

$$x = \frac{\varepsilon_{cu}}{\varepsilon_s - \varepsilon_{pe} + \varepsilon_{cu}}$$

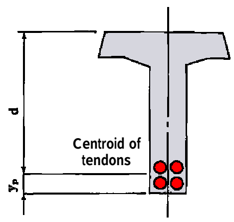
where x : Distance from extreme compression fiber to neutral axis [mm]

ε_u : Ultimate strain of concrete (0.0035)

ε_s : Yield strain of steel (0.015)

ε_{pe} : Strain of steel due to effective prestress $\varepsilon_{pe} = \sigma_{pe} / E_p$

d : Effective depth of the section



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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

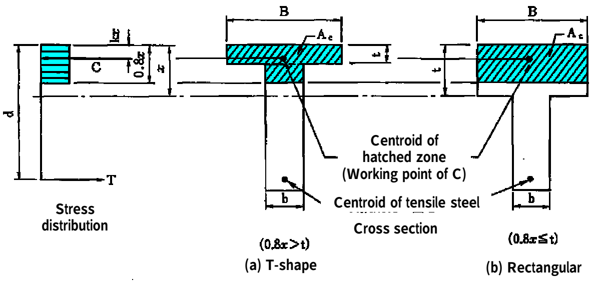
(2) Calculation of Resistance Moment

3) Study on Safety against Bending Failure

(a) Determination of zone of steel strain (cont.)

b) Determination of compressive zone

- **Calculation of resultant compressive forces differs depending on the shape of compressive zone (rectangular or T-shape).**



Point of Action of Resultant Force due to Compressive Stress

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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

(2) Calculation of Resistance Moment

3) Study on Safety against Bending Failure

(a) Determination of zone of steel strain (cont.)

c) Calculation of Compressive / Tensile Resultant Forces

- **Resultant tensile force of steel : T**

$T = 0.93\sigma_{pu} \cdot A_s$

where σ_{pu} : Tensile strength of prestressing steel [N/mm^2]
A_s : Total area of tendons [mm^2]

- **Resultant compressive force of concrete : C**

$C = 0.85\sigma_{ck}\{B \cdot t + (0.8x - t)b\}$ for T-shape compressive zone
$C = 0.85\sigma_{ck}B \cdot x$ for rectangular compressive zone

where σ_{ck} : Specified compressive strength of concrete [N/mm^2]
B : Width of top flange [mm]
x : Distance from extreme compressive fiber to neutral axis [mm]
t : Thickness of top flange [mm]
b : Width of web(s) of the girder [mm]

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

(2) Calculation of Resistance Moment

3) Study on Safety against Bending Failure

(a) Determination of zone of steel strain : ξ

a) When C ≧T

- **ξ is in zone I. Yield of tensile steel precedes crush of concrete.**

b) When C < T

- **ξ is in zone II or III, and change of cross section or amount of steel is required.**

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

(2) Calculation of Resistance Moment

3) Study on Safety against Bending Failure

(c) Determination of neutral axis : x

a) Neutral axis x is calculated assuming that the compressive zone is rectangular (within the thickness of top flange)

(when 0.8x ≦t)

$$x = \frac{T}{0.8 \times 0.85 \sigma_{ck} \cdot B}$$

where T : Resultant tensile force of tendon (0.93 σ_{pu} ・ A_s) [N]

σ_{ck} : Specified compressive strength of concrete [N/mm²]

B : Width of top flange of the girder [mm]

5. Basis of Design of Prestressed Concrete Bridges
5.4. Design of Main Girder

5.4.6. Safety against Bending Failure
(2) Calculation of Resistance Moment
3) Study on Safety against Bending Failure
(c) Determination of neutral axis : x
b) The shape of compressive zone is checked whether rectangular or not.
(If not, x is re-calculated)
(when 0.8x > t)

$$x = \frac{T - 0.85\sigma_{ck} \cdot t(B-b)}{0.8 \times 0.85\sigma_{ck} \cdot b}$$

where T : Resultant tensile force of tendons ($0.93\sigma_{pu} \cdot A_s$) [N]
σ_{ck} : Specified compressive strength of concrete [N/mm²]
t : Thickness of top flange [mm]
B : Width of top flange [mm]
b : Width of web(s) [mm]

5. Basis of Design of Prestressed Concrete Bridges
5.4. Design of Main Girder

5.4.6. Safety against Bending Failure
(2) Calculation of Resistance Moment
3) Study on Safety against Bending Failure
(d) Calculation of resistance moment
a) Calculation of k・x

- When compressive zone is rectangular,

$$k \cdot x = 0.4x$$

- When compressive zone is T-shape,

$$k \cdot x = \frac{B \cdot \frac{t^2}{2} + b \cdot (0.8x - t) \cdot (\frac{0.8x - t}{x} + t)}{B \cdot T + (0.8x - t) \cdot b}$$

where B : Width of top flange [mm]
t : Thickness of top flange [mm]
b : Width of web(s) [mm]
x : Distance from extreme compressive fiber to neutral axis [mm]

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

(2) Calculation of Resistance Moment

3) Study on Safety against Bending Failure

(d) Calculation of resistance moment

b) Calculation of resistance moment

$$M_u = T(d - k \cdot x)$$

where M_u : Resistance moment against failure (flexural resistance) [N・mm]
T : Resultant tensile force of tendons [N]
d : Effective depth of the girder [mm]

Load combinations at ultimate load state are:

a. 1.3 x (Permanent Load) + 2.5 x (Live Load + Impact)
b. 1.0 x (Permanent Load) + 2.5 x (Live Load + Impact)
c. 1.7 x (Permanent Load + Live Load + Impact)

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

(2) Calculation of Resistance Moment

3) Study on Safety against Bending Failure

(e) Verification of safety ratio against bending failure

$$F = \frac{M_u}{M} > 1.0$$

where F : Safety ratio against bending failure
M_u : Resistance moment [kN・m]
M : Bending moment at ultimate load state [kN・m]

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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.6. Safety against Bending Failure

(2) Calculation of Safety Ratio against Bending Failure

★ Practice : Calculate safety ratio against bending failure.

(a) Determine zone of steel strain ε_s.

(b) Determine neutral axis x.

(c) Calculate resistance moment/

(d) Calculate bending moment at ultimate load state/

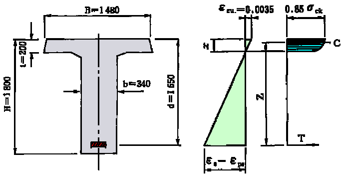
Permanent load : M_d = 4302.87 kN・m

Live load : M_ℓ = 1499.98 kN・m (w/ impact)

$M_1 = 1.3 \times M_d + 2.5 \times M_\ell$

$M_3 = 1.7 \times (M_d + M_\ell)$

(e) Calculate safety ratio against bending failure.



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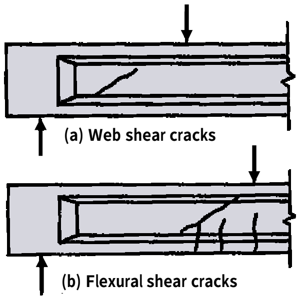
5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.7. Check for Shear

(1) General

- As failure due to shear normally shows brittle behavior, it is important to ensure shear failure not to precede flexural failure. It is thus required to provide sufficient shear reinforcement in the member.
- There are 2 types of shear cracks:
  - Web shear cracks : Diagonal cracks which occurs from center of webs in the region without flexural cracks. This type of cracks tends to occur when shear force is large while bending moment is small.
  - Bending shear cracks : Inclined cracks which is developed from flexural cracks and induced both by shear and bending. This type of cracks tends to occur in the region where both shear force and bending moment are large.



Type of cracks in PC members

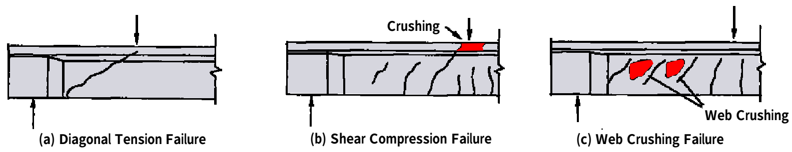
5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.7. Check for Shear

(1) General (cont.)

- There are 3 types of shear failure:
  - Diagonal Tension Failure: This type of failure is cause due to inadequate shear reinforcement. The diagonal shear crack forms in the member at 45 deg. and propagates rapidly causing failure.
  - Shear Compression Failure: This is crushing of concrete near the tip of the inclined crack in compression zone. This is caused by inadequate concrete strength in combination with effect of bending.
  - Web Crushing Failure: This happens when concrete crushes in a members with thin webs e.g. T-Beam. This is due to inadequate thickness of web.



Type of Shear Failure in PC Beams

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.7. Check for Shear

(1) General (cont.)

- Near the supports, verification for shear shall be carried out at the section h/2 away from bearings line or from the surface of column for rigid frames. Verification in the zone within h/2 (the hatched zone) is not required.

(4), (5) Near a support of a girder and near a joint of a rigid frame, a compressive force due to support reaction acts on the web, so the tensile force acting on the diagonal tensile reinforcement is smaller than in the other portions. Therefore, the verification against shear force need not be performed in the area from the support to half the member height, and it is sufficient to place diagonal tensile reinforcement in the hatched area of Figure 4.3.2 in an such an amount that the member section satisfies the verification in Clauses (1) and (2) against the shear force at the distance of half the member height from the support.

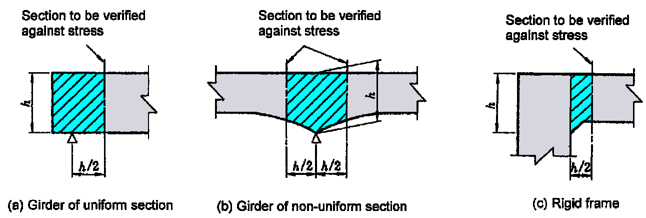


Figure 4.3.2 Section to be verified against shear force

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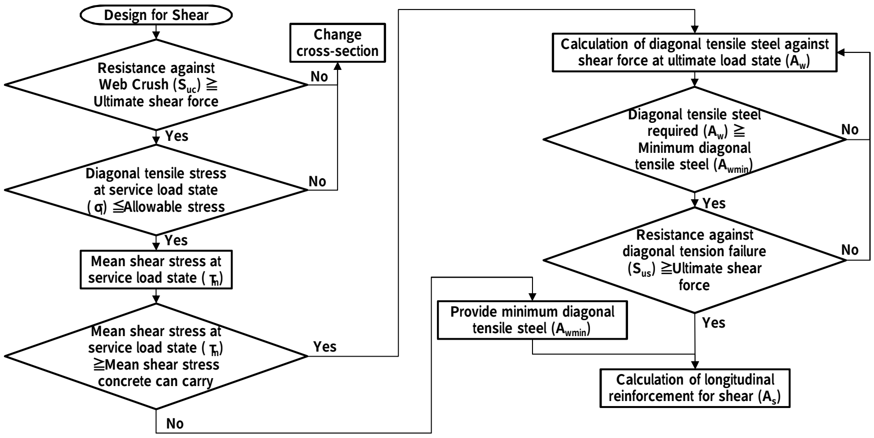
5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.7. Check for Shear

(2) Procedure of Check for Shear

1) Flow of Check for Shear



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5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.7. Check for Shear

(2) Procedure of Check for Shear

2) Verification of Stress against Crushing of Web Concrete at Ultimate Load State

- **In JRA Specifications, shear force at ultimate load state shall be smaller than resistance against crushing of web concrete.**

$$S_{uc} = \tau_{max} \cdot b_w \cdot d + S_p$$

where
- S_{uc} : Resistance against crushing of web concrete [N]
- τ_{max} : Maximum mean shear stress in concrete [N/mm²]
- b_w : Thickness of web(s) of the member [mm]
- d : Effective depth of the section [mm]
- S_p : Vertical component of tensile force in prestressing tendons [N]
  $S_p = A_p \cdot \sigma_{pe} \cdot \sin\alpha$
- A_p : Area of prestressing tendons in the section [mm²]
- σ_{pe} : Effective tensile stress of tendons in the section [N/mm²]
- α : Angle between member axis and prestressing tendons

5. Basis of Design of Prestressed Concrete Bridges

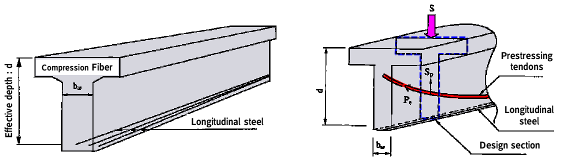
5.4. Design of Main Girder

5.4.7. Check for Shear

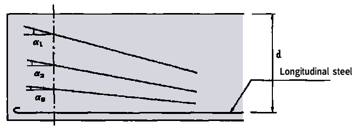
(2) Procedure of Check for Shear

2) Verification of Stress against Crushing of Web Concrete at Ultimate Load State (cont.)

- **When the ultimate shear force is greater than the resistance against crushing of web concrete, cross-section needs to be changed.**



How to obtain S_p



$S_p = P_e \cdot \sin\alpha_1 + P_e \cdot \sin\alpha_2 + P_e \cdot \sin\alpha_3$

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

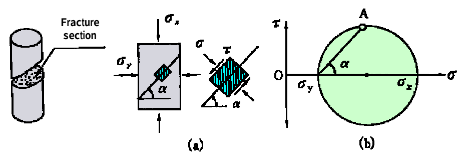
5.4.7. Check for Shear

(2) Procedure of Check for Shear

3) Calculation of Diagonal Tensile Stress at Service Load State (σ_I)

$$\tau = \frac{(S-S_p)\cdot Q}{b_w \cdot I}, \qquad \sigma_I = \frac{1}{2}\left(\sigma_c - \sqrt{\sigma_c^2 + 4\tau^2}\right)$$

where
- τ : Shear stress at service load state [N/mm²]
- S : Shear force at the section [N]
- S_p : Vertical component of tensile force in prestressing tendons [N]
- Q : Geometrical moment of area [mm²]
- τ_{max} : Maximum mean shear stress in concrete [N/mm²]
- b_w : Thickness of web(s) of the member [mm]
- I : Moment of inertia about the centroid of the section [mm⁴]
- σ_I : Diagonal tensile stress at service load state [N/mm²]
- σ_c : Compressive stress in concrete of the section [N/mm²]



Mohr's Stress Circle

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5. Basis of Design of Prestressed Concrete Bridges
5.4. Design of Main Girder

5.4.7. Check for Shear

(2) Procedure of Check for Shear

4) Mean Shear Stress at Service Load State (τ_m)

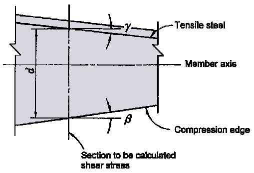
$$\tau_m = \frac{S - S_p}{b_w \cdot d}$$

where
- τ_m : Mean shear stress at service load state [N/mm²]
- S_h : Shear force considering the effect of variation of effective depth of the girder [N]
- S : Shear force at the section [N]
- S_p : Vertical component of tensile force in prestressing tendons [N]
- b_w : Thickness of web(s) of the member [mm]
- d : Effective depth of the section [mm]
- τ : Mean shear stress which concrete can carry [N/mm²]

- When $\tau_m > \tau$ →5)
- When $\tau_m \leqq \tau$ →6)

$$S_h = S - \frac{M}{d}(\tan\beta + \tan\gamma) \quad \text{(4.3.1)}$$

where
- S_h: Design shear force considering effects of changes in effective height of member (N)
- S: Shear force acting on member section (N)
- M: Bending moment acting on member section (N·mm)
- d : Effective height of member section (mm) (see Figure 4.3.1.)
- β : Angle formed by member's compression edge with member axis (see Figure 4.3.1.)
- γ : Angle formed by tensile steel with member axis (see Figure 4.3.1.)



(Note) Take β and γ as positive if the effective height increases with the absolute value of bending moment, and take them as negative if it decreases.

Figure 4.3.1 How to take β, γ and d

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5. Basis of Design of Prestressed Concrete Bridges
5.4. Design of Main Girder

5.4.7. Check for Shear

(2) Procedure of Check for Shear

5) Check of Resistance against Diagonal Tensile Failure at Ultimate Load State

- **In JRA Specifications, shear force at ultimate load state shall be smaller than resistance against diagonal tensile failure.**

$$S_{us} = S_c + S_s + S_p$$

where
- S_{us} : Resistance against diagonal tensile failure [N]
- S_c : Shear force which concrete can carry [N]
- S_s : Shear force which diagonal tension steel can carry [N]
- S_p : Vertical component of tensile force in prestressing tendons [N]

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.7. Check for Shear

(2) Procedure of Check for Shear

5) Check of Resistance against Diagonal Tensile Failure at Ultimate Load State (cont.)

(a) Shear force carried by concrete

$$S_c = k \cdot \tau_c \cdot b_w \cdot d$$

but,

$$k = 1 + \frac{M_0}{M_d} \leqq 2.0$$

where
- k : Coefficient for shear force which concrete can carry
- S_c : Shear force which concrete can carry [N]
- M_d : Bending moment at ultimate load state [N・mm]
- M_0 : Decompression moment (which compensate the stress due to prestress and axial force at the extreme tensile fiber to be zero) [N・mm]
- τ_c : Mean shear stress which concrete can carry [N/mm²]
- b_w : Thickness of web(s) of the member [mm]
- d : Effective depth of the section [mm]

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.7. Check for Shear

(2) Procedure of Check for Shear

5) Check of Resistance against Diagonal Tensile Failure at Ultimate Load State (cont.)

(b) Shear force carried by diagonal tension steel

$$S_s = \Sigma \frac{A_w \cdot \sigma_{sy} \cdot d(\sin\theta + \cos\theta)}{1.15a}$$

where
- S_s : Shear force which diagonal tension steel can carry [N]
- A_w : Area of diagonal tension steel arranged with a spacing "a" and an angle "θ" [mm²]
- σ_{sy} : Yield stress of diagonal tension steel [N/mm²]
- a : Spacing of diagonal tension steels in the longitudinal direction of the member [mm]
- θ : Angle between diagonal tension steel and the axis of the member

5. Basis of Design of Prestressed Concrete Bridges
5.4. Design of Main Girder

5.4.7. Check for Shear

(2) Procedure of Check for Shear

5) Check of Resistance against Diagonal Tensile Failure at Ultimate Load State (cont.)

(c) Vertical component of tensile force by prestressing tendons

$$S_p = A_p \cdot \sigma_{pe} \cdot \sin\alpha$$

where S_p : Vertical component of tensile force by prestressing tendons [N]
A_p : Area of prestressing tendons at the section [mm²]
σ_{pe} : Effective prestress of the tendons [N/mm²]
α : Angle between prestressing tendon and the axis of the member

5. Basis of Design of Prestressed Concrete Bridges
5.4. Design of Main Girder

5.4.7. Check for Shear

(2) Procedure of Check for Shear

6) Minimum Diagonal Tension Reinforcement (A_{wmin})

$$A_{wmin} = 0.002 b_w \cdot a$$

where A_{wmin} : Minimum diagonal tension reinforcement [mm²]
b_w : Width of web(s) [mm]
a : Spacing of diagonal tension reinforcement in the longitudinal direction of the member [mm]

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.7. Check for Shear

(2) Procedure of Check for Shear

7) Longitudinal Reinforcement for Shear (A_s)

$$A_s = \frac{S_{si}}{2\sigma_{sy}}$$

where
- A_s : Longitudinal reinforcement for shear [mm^2]
- S_{si} : Shear force carried by diagonal tension steel (= S_s) [mm^2]
- σ_{sy} : Yield strength of longitudinal reinforcement [N/mm^2]
  - σ_{sy} = 345.0 N/mm^2 for SD345

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.8. Calculation of Deflection

(1) General

- Deformations of member is categorized in
  - longitudinal extension / shortening, and
  - vertical deflection.
- These deformations are induced by prestress, self-weight, creep and shrinkage of concrete etc.
- In prestressed concrete members, cambers for these deformations shall be taken into account, as these deformations affect bridge alignment etc.
- Deflections calculated by engineers in design stage are for reference. Actual camber value to be applied shall be calculated by contractors at the construction stage upon their construction condition, construction schedule, materials etc. in order to obtain targeted alignment / profile of the structure.
- Deflections due to live load shall be checked to satisfy allowable value.

JICA Study Team 193

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.8. Calculation of Deflection

(1) General (cont.)

- **Typical deformations of PC girder (in case of CIP)**
  - **In the calculation of deflection, modulus of elasticity of concrete varies according to its strength (concrete age).**

(4) Young's modulus of concrete shall be as follows:

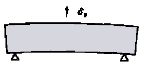
1) Young's modulus used in calculating the statically indeterminate forces or elastic deformation of a reinforced concrete structure and in the design calculation of prestressed concrete members shall take the values given in Table 3.3.3.

2) Young's modulus ratio, *n*, used in calculating the stresses in reinforced concrete members shall take a value of 15.

Table 3.3.3 Young's modulus of concrete (N/mm^2)

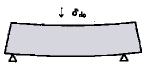
Specified compressive strength	21	24	27	30	40	50	60
Young's modulus	2.35×10^4	2.5×10^4	2.65×10^4	2.8×10^4	3.1×10^4	3.3×10^4	3.5×10^4

① Prestressing Force



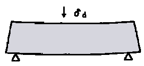
Concrete age : 4 days
Concrete strength :
σ_c = 34 N/mm²

② Self-Weight



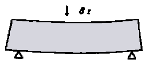
Concrete age : 4 days
Concrete strength :
σ_c = 34 N/mm²

③ Superimposed Dead Load



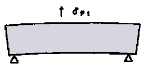
Concrete age : ≧28 days
Concrete strength :
σ_c = 40 N/mm²

④ Live Load



Concrete age : ≧28 days
Concrete strength :
σ_c = 40 N/mm²

⑤ Creep



Concrete age : 4~∞days
Concrete strength :
σ_c = 40 N/mm²

JICA Study Team 194

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.8. Calculation of Deflection

(2) Deflection (In the case of CIP simple girder)

- **Deflection for CIP simple girders can be approximated by the following formulas. (+ (positive) when downward, – (negative) when upward)**

1) Deflection due to Prestress

For uniform cross-section with varying M_p :
(Tendons are curved up from span center toward support)

$$\delta_p \fallingdotseq \frac{-M_p \cdot \ell^2}{9E_c \cdot I_{c0}} = -\frac{P_t \cdot e_{cop} \cdot \ell^2}{9E_c \cdot I_{c0}}$$

where
- M_p : Bending moment due to total prestress immediately after anchor-set [N · mm]
- P_t : Total prestress immediately after anchor-set [N]
- ℓ : Span length [mm]
- e_{pc0} : Eccentricity of tendons [mm]
- E_c : Modulus of elasticity of concrete immediately after anchor-set [N/mm²]
- I_{c0} : Moment of inertia of the girder (net concrete section) [mm⁴]

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.8. Calculation of Deflection

(2) Deflection (In the case of CIP simple girder)

2) Deflection due to Dead Load

(a) Self-weight

$$\delta_{d0} \fallingdotseq \frac{M_{d0} \cdot \ell^2}{9.6 E_c \cdot I_{c0}}$$

where M_{d0} : Bending moment due to girder self-weight [N・mm]
E_c : Modulus of elasticity of concrete immediately after anchor-set [N/mm^2]
I_{c0} : Moment of inertia of the girder (net concrete section) [mm^4]

(b) Superimposed dead load

$$\delta_{d1} \fallingdotseq \frac{M_{d1} \cdot \ell^2}{9.6 E_{c1} \cdot I_{c1}}$$

where M_{d1} : Bending moment due to superimposed dead load [N・mm]
E_{c1} : Modulus of elasticity of concrete at service load state [N/mm^2]
I_{c1} : Moment of inertia of the girder (tendon-transformed section) [mm^4]

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.8. Calculation of Deflection

(2) Deflection (In the case of CIP simple girder)

3) Deflection due to Live Load

(c) Live load

$$\delta_{\ell} \fallingdotseq \frac{M_{\ell} \cdot \ell^2}{9.6 E_{c1} \cdot I_{c1}}$$

where M_{ℓ} : Bending moment due to live load (excluding impact) [N・mm]
E_{c1} : Modulus of elasticity of concrete at service load state [N/mm^2]
I_{c1} : Moment of inertia of the girder (tendon-transformed section) [mm^4]

5. Basis of Design of Prestressed Concrete Bridges

5.4. Design of Main Girder

5.4.8. Calculation of Deflection

(2) Deflection (In the case of CIP simple girder)

4) Deflection due to Creep

$$\delta_{\varphi t} \fallingdotseq \varphi_t \cdot (\frac{1+\eta}{2} \cdot \delta_p + \delta_d)$$

where
- φ_t : Creep coefficient
- η : Effective coefficient of prestress
- δ_p : Deflection due to prestress [mm]
- δ_d : Deflection due to dead loads (self-weight and superimposed dead load) [mm]

5. Basis of Design of Prestressed Concrete Bridges

5.5. Design of Joint between Segments

5.5.1. Design for Bending Moment

(1) General

- **As reinforcement are not continuous at joints between segments, tensile stress is not allowed under service load state.**
- **Even when live load or impact larger than assumed act on the deck slab, tensile stress at joints shall be limited to avoid cracks at joints.**

JICA Study Team 199

5. Basis of Design of Prestressed Concrete Bridges

5.5. Design of Joint between Segments

5.5.1. Design for Bending Moment

(2) Stress Check for Girder

- **For girder :** $\sigma_0 + 1.7\,\sigma_L < f_{bck}$
- **For deck slab :** $\sigma_0 + 1.7\,\sigma_{Ls} + 0.5\,\sigma_g < f_{bck}$

where
- σ_0 : Bending tensile stress in concrete due to primary loads other than live loads and impact [N/mm²]
- σ_L : Bending tensile stress in concrete due to live loads and impact [N/mm²]
- σ_{Ls} : Bending tensile stress in concrete as a deck slab due to live loads and impact [N/mm²]
- σ_g : Bending tensile stress in concrete as a girder due to live loads and impact [N/mm²]
- f_{bck} : Allowable bending tensile stress [N/mm²]
  $f_{bck} = 3.0$ N/mm² for $\sigma_{ck} = 50$ N/mm²

JICA Study Team 200

5. Basis of Design of Prestressed Concrete Bridges

5.5. Design of Joint between Segments

5.5.1. Design for Shear

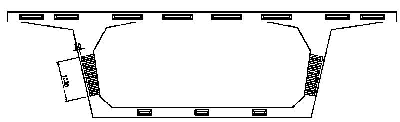
(1) Design of Web Shear Keys

(1) The verification of shear forces at joints of precast segmental bridges shall be performed for situations during erection and under ultimate load, and shear forces acting on each joint key shall be not greater than the shear force that the joint key can bear.

(2) The shear forces acting on joints between precast segments under ultimate load may be calculated considering the frictional resistance occurring at joints due to the prestressing force.

$$\left.\begin{aligned} S_{ku} &= S_u - S_{pf} \\ S_{pf} &= \mu\ P_e \cos\theta \end{aligned}\right\} \quad \text{(C. 17.3.4)}$$

where
- S_{ku}: Total of shear forces acting on all joint keys of joint under ultimate load (N)
- S_{pf}: Shear resistance force at joint due to friction of prestressing force (N)
- S_u: Shear force acting at joint under ultimate load (N)
- μ : Shear resistance factor due to friction of prestress. It may be taken at 0.3 in general.
- P_e: Effective prestressing force of all PC tendon placed in joint (N)
- θ : Angle formed by the direction of effective prestressing force at the joint with the joint surface



(2) The average shear stress at joint surface of multiple trapezoidal or undulated joint keys may be calculated by Equation C. 17.3.10.

$$\tau = \frac{S_{sl}}{bh} \quad \text{(C. 17.3.10)}$$

where
- τ : Average shear stress of joint key surface (N/mm²)
- S_{sl}: Shear force acting on one joint key (N)
  In the situation under ultimate load, the shear resistance force due to prestressing force may be taken into account.
- h : Effective height of joint key (mm)
- b : Width of joint key (mm)

Area of shear key : 1030 x (300-50) = 515 000 mm²
(Web thickness = 300mm)

Allowable shear stress : 2.00 N/mm² for $\sigma_{ck} = 50$ N/mm²

JICA Study Team 201

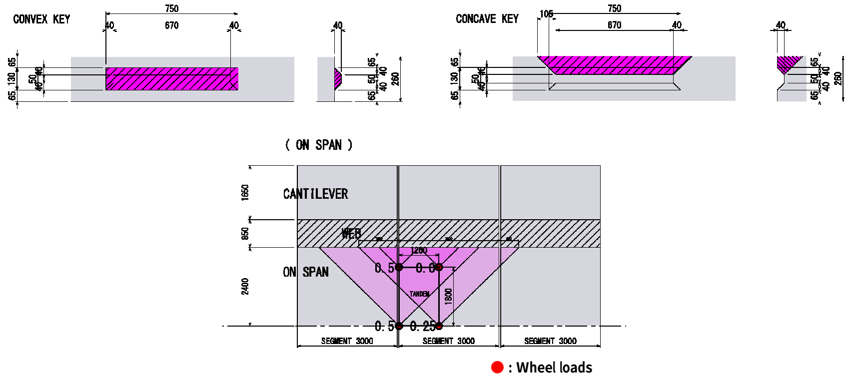
5. Basis of Design of Prestressed Concrete Bridges

5.5. Design of Joint between Segments

5.5.1. Design for Shear

(2) Design of Slab Shear Keys

- Slab shear keys shall be designed to adequately transfer forces due to wheel load(s) on deck slab to the webs.
- Example of slab shear key is shown below.



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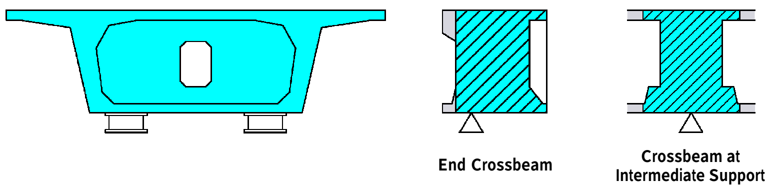
5. Basis of Design of Prestressed Concrete Bridges

5.6. Design of Crossbeam

5.6.1. General

(1) Structure of Crossbeam

- Crossbeams of PC box girders are provided in order to obtain transverse stiffness of the main girder (against torsional deformation or differential deflection etc.)
- The structure of crossbeams can be either reinforced or prestressed concrete.



Typical Shape of Crossbeam
for PC box girder

5. Basis of Design of Prestressed Concrete Bridges

5.6. Design of Crossbeam

5.6.1. General

(2) Arrangement of Crossbeam

- **Crossbeams of PC box girders are generally arranged at**
  - **End support**
  - **Intermediate support (at pier etc)**
  - **Span center (intermediate diaphragm, if necessary)**

5. Basis of Design of Prestressed Concrete Bridges

5.6. Design of Crossbeam

5.6.2. Shape and Properties of Cross Section

(1) Effective Flange Width

(3) Half effective width of a compressive flange under a bending moment shall be calculated by Equation 4.2.1.

1) Main girder and cross beam at a support (directly supported beam)

$$\lambda = \frac{l}{8} + b_s$$

for a continuous slab and simple slab: $\lambda \leqq l_b / 2$

for a cantilever slab: $\lambda \leqq l_c$

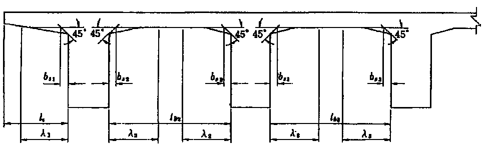
2) Intermediate cross beam (indirectly supported beam) .... (4.2.1)

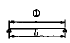
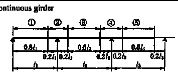
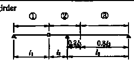
$$\lambda = \frac{n-1}{6}(l_b + b_w) + b_s$$

for a continuous slab and simple slab: $\lambda \leqq l_t / 2$

for a cantilever slab: $\lambda \leqq l_c$

where
- λ: Half of the effective width of compressive flange (mm)
- l: Span length for calculation of effective width (mm) (Value in Table 4.2.1)
- b_s: Effective width of haunch (mm)
- l_b: Clearance between main girders (mm)
- l_c: Length of overhanging of cantilever slab (mm)
- l_t: Clearance between cross beams (mm)
- n: Number of main girders
- b_w: Web thickness of main girder (mm)



Girder type	Segment	Span length (l) for calculation of effective width
Simple girder 	①	l_1
Continuous girder 	①	$0.8\ l_1$
	②	$0.2\ (l_1 + l_2)$
	③	$0.6\ l_2$
	④	$0.2\ (l_2 + l_3)$
	⑤	$0.6\ l_3$
Gerber girder 	①	l_1
	②	$2\ l_2$
	③	$0.8\ l_3$

JICA Study Team 205

5. Basis of Design of Prestressed Concrete Bridges

5.6. Design of Crossbeam

5.6.2. Shape and Properties of Cross Section

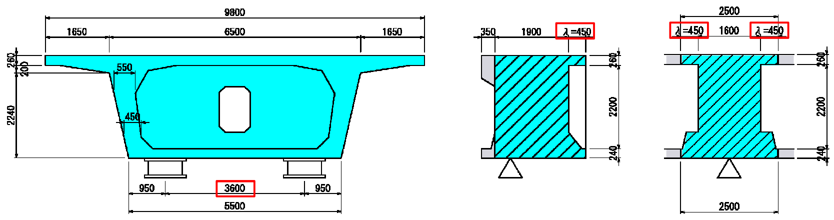
(1) Effective Flange Width

- **Effective width of compressive flange :**

$$\lambda = \frac{\ell}{8} + b_s \qquad \text{(for directly supported beams)}$$

where
- λ : Effective width of compressive flange (at one side)
- ℓ : Span length for calculation of effective width
- b_s : Allowable tensile stress of reinforcing steel (σsa = 345 N/mm²)

When ℓ = 3600 mm & b_s = 0 mm, λ= 450mm



End Crossbeam

Crossbeam at Intermediate Support

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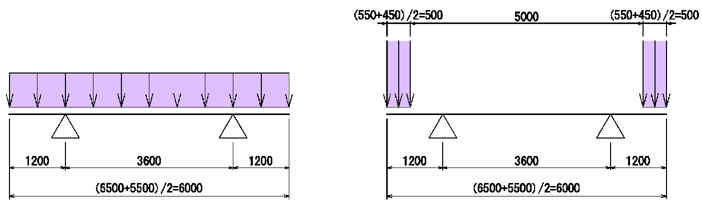
5. Basis of Design of Prestressed Concrete Bridges

5.6. Design of Crossbeam

5.6.3. Design Loads and Sectional Forces

(1) Design Loads

- **Design loads are separated into the following 2 types :**
  - Direct load on the crossbeam
    - Self-weight of crossbeam
    - Superimposed dead load, and live load placed directly on the crossbeam
  - Load from webs
    - Total dead load (The above direct load due to self-weight and superimposed dead load are deducted.)
    - Live load (The above direct load due to live load is deducted.)



(DIRECT LOAD ON THE CROSSBEAM) (LOAD FROM WEB)

5. Basis of Design of Prestressed Concrete Bridges

5.6. Design of Crossbeam

5.6.4. Design for Bending

Crossbeams are designed against bending for

- **Serviceability (Stresses under service load state)**
- **Safety (Safety against bending failure under ultimate load state)**

same as main girder.

5.6.5. Design for Shear

Crossbeams are designed against shear for

- **Serviceability (Stresses under service load state)**
- **Safety (Safety under ultimate load state)**

same as main girder.

5. Basis of Design of Prestressed Concrete Bridges

5.6. Design of Crossbeam

5.6.6. Design for External Tendon Anchorages

(1) General

- **As external tendons are anchored at end / intermediate crossbeams, crossbeams are designed against these anchorage forces as well.**

JICA Study Team 209

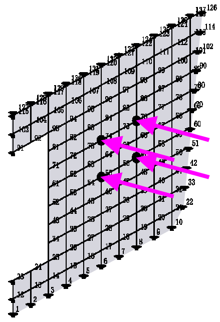
5. Basis of Design of Prestressed Concrete Bridges

5.6. Design of Crossbeam

5.6.6. Design for External Tendon Anchorages

(2) Load distribution

- ➢ **Load distribution of anchorage forces to webs (transverse direction) and vertical direction (top / bottom slabs) can be estimated by analysis such as plane grid models.**



Plane Grid Model
(at end crossbeam)

JICA Study Team 210

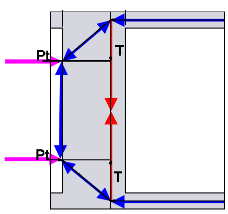
5. Basis of Design of Prestressed Concrete Bridges

5.6. Design of Crossbeam

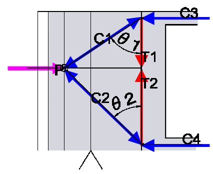
5.6.6. Design for External Tendon Anchorages

(3) Calculation of Reinforcement

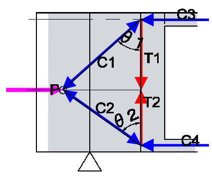
- ➢ **Based on the load distribution obtained from the plane grid analysis etc., transverse / vertical tensile force can be calculated using "strut & tie" models.**



Upper Cable



Lower Cable



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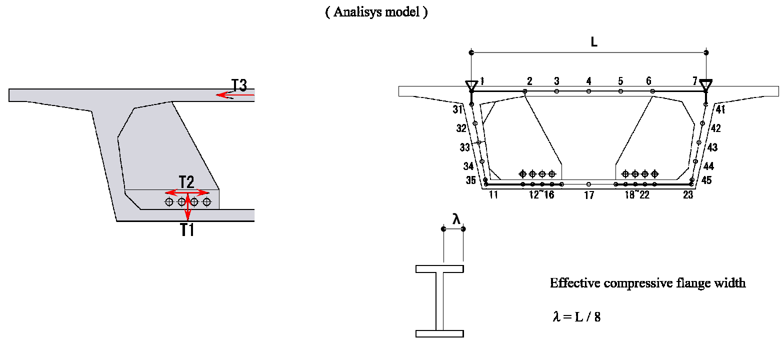
5. Basis of Design of Prestressed Concrete Bridges

5.7. Design of Deviators for External Tendons

5.7.1. General

- Deviators for external tendons are designed to transfer tendon deviation forces (vertical and transvers components) properly to the main girder.
- Reinforcement shall be arranged against vertical / horizontal tensile forces at deviation block, and tensile force at deck slab.



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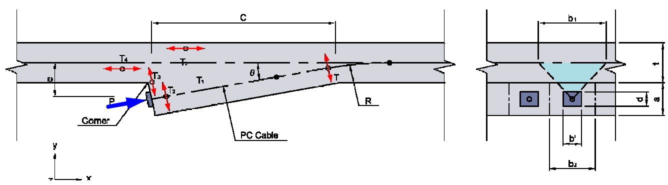
5. Basis of Design of Prestressed Concrete Bridges

5.8. Design of Anchorage Blisters for Internal Tendons

5.8.1. General

- Anchorage blisters for internal tendons shall be designed to resist local bursting force behind anchor plate and tendon radial force at curve.
- Slabs or webs adjacent to anchor device shall also be properly reinforced against local bending / stress concentration.
- Blisters shall be placed at the corner of slab and web, not in the middle of slabs.



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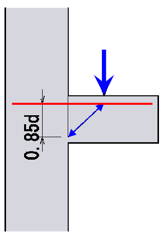
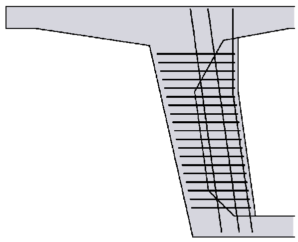
5. Basis of Design of Prestressed Concrete Bridges

5.9. Design of Web Ribs for Temporary Prestressing

5.9.1. General

- During assembling / adhesion work of segments in the span to be erected, the segments shall be temporarily prestressed to maintain uniform compressive stress (˜ 0.3 N/mm^2) at the joints between segments until the epoxy adhesive are sufficiently hardened. On this purpose, web ribs are provided at all segments in Bago river bridge (approach bridge).
- These web ribs shall be designed to resist the force due to temporary prestressing bars. The member is designed as a corbel.





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5. Basis of Design of Prestressed Concrete Bridges

5.10. Support Reaction

5.10.1 General

- In general, support reactions of bridges are calculated for bearings (including impact due to vehicles) and for substructures (excluding impact).

★ Check of Reaction

- Adequacy of analysis can be roughly checked by simple methods. In the case of PC box girder bridges, for example,
  - For self-weight, compare cross-sectional area at standard section with (total reaction due to self-weight) / (bridge length x unit weight (24.5 kN/m^3 for PC))
  - Live load is roughly 20% of total dead load (including superimposed dead load) for highway bridges.