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Design of Togawa Bridge

Étude du pont de Togawa

Entwurf der Togawa-Brücke

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SUMMARY

Togawa Bridge is a three-span, continuous, partially prestressed, concrete through-girder bridge with an open floor for railways. This bridge is located in an area of much snowfall, so an open floor type with a mounted track is adopted for the first time in Japan for prestressed concrete girders. This paper reports on the outline of the design of this bridge.

RÉSUMÉ

Le pont de Togawa est un pont ferroviaire à plancher ouvert, formé de 3 travées continues et dont les poutres sont en béton partiellement précontraint. Il fallut, pour que le pont puisse être utilisé dans une zone fortement enneigée, adopter pour la première fois au Japon sur ce genre d'ouvrage, la technique de plancher ouvert. L'article présente le projet du pont.

ZUSAMMENFASSUNG

Die Togawa-Brücke ist eine teilweise vorgespannte Eisenbahn-Trogbrücke, die drei Felder durchläuft. Wegen dem vielen Schnee ist der Tafelträger teilweise geöffnet und die Schiene wird direkt mit den Tafelträger verbunden. Es ist das erste Mal in Japan, dass dieser Typ von Schienenverbindungen einer teilweise vorgespannten Brücke aufgenommen wird. Im Bericht wird der Entwurf vorgestellt.

1. INTRODUCTION

Togawa Bridge is a three span continuous partially prestressed concrete through girder with an open floor for railways. The total length of this bridge is 114.8 meter, the main span is 40.0 meter, and the height of the main girder is 2.5 to 3.0 meter. This bridge is constructed at the area where is famous to have much snow in winter, so the open floor type with a mounted track (Fig.1) is adopted in order to reduce snow on the bridge without maintenance works. Construction of this bridge is a part of river improvement works of the Togawa River. At first, the temporary track is executed adjacent to the present railway bridge, and next, the present bridge is withdrawn and the new bridge is constructed. The superstructures are executed on site by a staging with bent and girder during drought period.

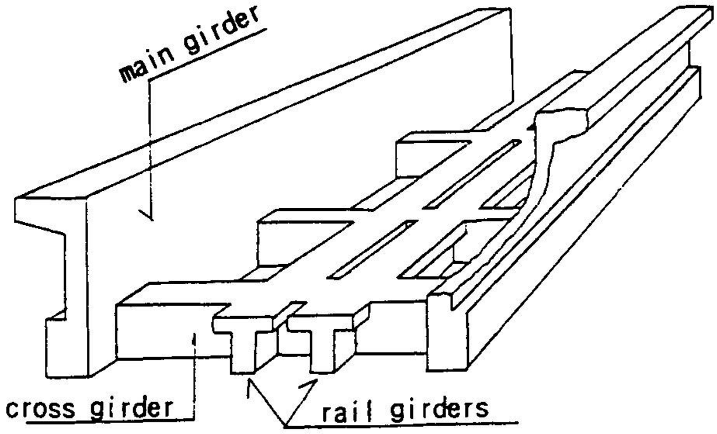

Fig. 1 Image of This Girder

Then, rubber bearings and damper stoppers are adopted for bearings. This combination is generally for railway concrete girders in Japan. Damper stoppers are not resistant against slowly horizontal movements by variations of temperature, creep, drying shrinkage and so on,and are resistant by viscosity of oils in dampers against abruptly horizontal movements by earthquakes.

2. PROCEDURES OF CONSTRUCTION OF SUPERSTRUCTURES

Table 1 shows the proceduresof construction of the superstructures of this bridge. For this structural type like this brige, more larger prestressing stresses are necessary for girders which support tracks directly (we call this girders rail girders in this report) than for main girders. So, if prestressing forces are introduced after completion of all members, too much prestressing strands are necessary to give enough prestressing stresses to rail girders.

Therefore, prestressing strands arranged in rail girders are planned to be tensioned before main girders are casted. Then, after completion of all members, because the concrete stress level are rather different in rail girders and main girders during permanent loads,large statically interminate forces occur by the influence of creep. Therefore, to make creep deformations as small as possible, prestressing strands arranged in rail are also planned to be tensioned just before the completion of connected parts with main girders and cross beams are executed.

Table 1 Procedures of Construction

1	Setting a Staging
2	Executing Rail Girders and Cross Beams
3	Introducing Prestressing Forces in Rail Girders
4	Executing Main Girders
5	Introducing Prestressing Forces in Two Cables in Cross Beam
6	Introducing Prestressing Forces in Three Cables in Main Girder
7	Introducing Prestressing Forces in Rest Cables in Cross Beam
8	Introducing Prestressing Forces in Rest Cables in Main Girder
9	Withdrawing a Staging
10	Executing the Second Part of Rail Girders

Then, because a mounted track is adopted in this bridge, in consideration of executed errors,unexpexted elastic deformations and so on, 5 cm height-part of rail girders are not structural members not but adjusting parts to keep the rail level.

3. OUTLINE OF DESIGN OF THIS BRIDGE

Fig.2 shows a general view of this bridge, Table 2 shows general design conditions, and Table 3 shows the material strength. Rail girders and cross beams, to which train live load act directly and which have the necessity to convey these load to main girders surely, are designed as prestressed concrete members. And main girders are design as partially prestressed concrete members which have low concrete compressive stresses by prestressing forces and small creep deformations in consideration that a mounted track is adopted in this bridge. For prestressed concrete members, design verifications are carried out to the ultimate limit state and the serviceability limit state. And, for partially prestressed concrete members, verifications are carried out to the ultimate limit state, the ultimate limit state of fatigue, and the serviceability limit state. Representative combinations of loads to each limit state are indicated in Table 4. For partially prestressed concrete members, concrete tensile stresses are restricted within the design tensile strength during the permanent

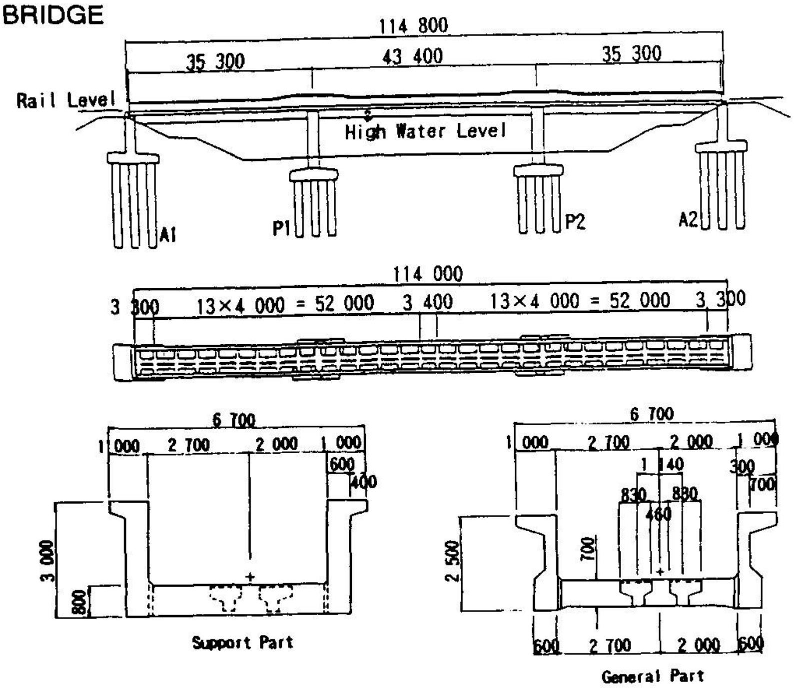

Fig.2 General View of This Bridge

Table 2 General Design Conditions

Length of Bridge (m)	114.8
Spans (m)	35.3+43.4+35.8
Alignment of Track	Straight
Track Type	Mounted Track
Design Horizontal Seismic Coefficient	Kh=0.2
Shoe Type	Rubber Shoe
Stopper Type	Damper Stopper

Table 3 Material Strength

Member	Design Compressive Strength of Concrete	Prestressing Strand Tensile Strength	Reinforcement Yield Strength
Main Girder	39.2 (MPa)	SWPR7B 12T12.7 1862 (MPa)	SD345 343 (MPa)
Cross Beam	44.1 (MPa)	SBPR 95/110 φ32 1078 (MPa)	SD345 343 (MPa)
Rail Girder	44.1 (MPa)	SWPR7B 12T12.7 1862 (MPa)	SD345 343 (MPa)

Table 4 Main Combinations of Loads (Load Factor)

Verification		Dead Load	Train Load	Impact Load	*2
Ultimate Limit State		1.7	1.7	1.7	1.0
*1	Bending Tensile Stress of Concrete (PPC)	1.0	—	—	1.0
	Bending Tensile Stress of Concrete (PC)	1.0	1.0	1.0	1.0
	Bending Compressive Stress of Concrete	1.0	—	—	1.0
	Diagonal Tensile Stress of Concrete	1.0	1.0	1.0	1.0
	Bending Crack Width for Durability (PPC)	1.0	0.2	0.2	1.0
	Bending Crack Width for Appearance (PPC)	1.0	—	—	1.0
	Deformation	—	1.0	—	—
Ultimate Limit State of Fatigue		1.0	1.0	1.0	1.0

*1 : Serviceability Limit State
*2 : Statically Indeterminate Forces by Prestressing Forces, Creep and Shrinkage
PPC : Partially Prestressed Concrete Member
PC : Prestressed Concrete Member

loads in order that bending cracks do not occur until train live loads act. It is because the bending crack width becomes rather large by the influence of creep and local drying shrinkage, if cracks occur in younger concrete age. And then, also for partially prestressed concrete members, in the serviceability limit state, diagonal tensile stresses in concrete are restricted not to be occurred by shear cracks. This is because the design method to shear cracks can not be necessarily said to be cleared up.

Fig.3 shows the analysis model for completion. In the design works of concrete through girders, plane grid frame analysis is usually adopted, but in this design, grade grid frame analysis is adopted. The reason is that the axial forces in rail girders occurred by the bending deformations of main girders are not able to be estimated by plane analysis. Then, section forces are calculated by grade model in which centroids of main girders and rail girders are connected by virtual members. Infinite stiffnesses are given to these virtual members.

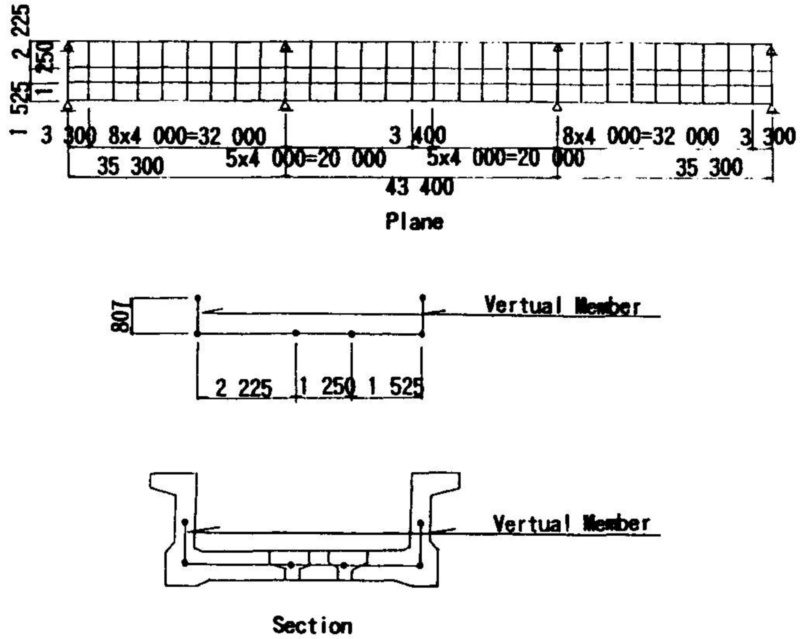

Fig.3 Analysis Model

4. DESIGN OF MEMBERS

4. 1 MAIN GIRDERS

In this bridge, rail girders are arranged eccentric in the cross direction, so section forces are different between the right and the left main girder. Design verifications are carried out only the larger section forces in the two main girders. As for prestressing cable system, Freyssinet 12T12.7 is adopted, and as for axial reinforcements to control bending cracks, deform 19 and 22 are arranged. Fig.4 shows the cable and axial rein-

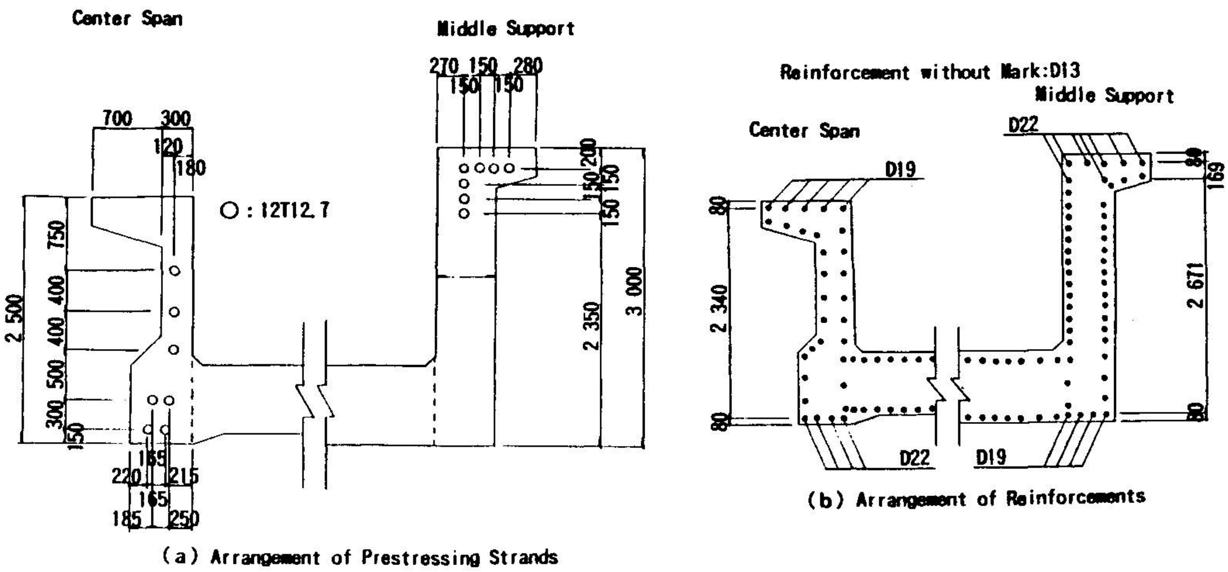

Fig.4 Arrangements of Prestressing Strands and Reinforcements

forcement arrangements at the center span section and the middle support section. As mentioned before, main girders are designed as partially prestressed concrete members, so axial reinforcements are much arranged than prestressed concrete members as usual. By this reasons, resistant forces in reinforcements are rather larger against deformations in the axial direction by prestressing forces, creep, drying shrinkage and so on. So, this influence are considered in this design. Table 5 shows design results of concrete stresses during permanent loads, the ultimate limit state, and the ultimate limit state of fatigue in main sections. Further, the verifications of the maximum bending crack width in the serviceavility limit state are carried out under the load conditions shown in Table 4, so, this time,agaist these loads' combinations, bending cracks do not occur. Next, the arrangements of stirrups are mensioned. In this bridge, diagonal tensile stresses inconcrete is restricted within the design tensile strength in the serviceability limit state not to be ocurred by shear cracks. Then, stirrups are arranged against the ultimate limit state. Generally, stirrups in the main girders are both as hanging reinforcements for lower slabs. In this bridge, assumed the punching shear failure surface in Fig.5, in these section, stirrups are calculated both as stirrups for shear forces and the punching forces by cross beams in the ultimate limit state.

Table 5 Design Results of Main Girders

			Center of Side Span	Middle Support	Center of Main Span
Number of Prestressing Cables			7	7	7
Number of Reinforcements		Upper Verge	D 1 9 × 5	D 2 2 × 7	D 1 9 × 5
		Upper Verge	D 2 2 × 4	D 1 9 × 4	D 2 2 × 4
Ultimate Limit State	Safety Ratio (Bending)		1.63	1.46	1.88
* 1	Concrete Stress at Parmanent Load (MPa)	Upper Verge	5.81	1.84	3.90
		Lower Verge	3.64	4.30	2.74
		Limit Value	−1.86~15.68		
	Bending Crack Width (mm)	Calculated Value	———	———	———
		Limit Value	0.004 c (c : covering)		
	Diagonal Tensile Stress of Concrete at Design Load (MPa)	Without Torsion	−0.10	−1.72	−0.02
		With Torsion	−0.10	−1.76	−0.02
		Limit Value	−2.06		
* 2	Prestressing Strand (MPa)	Stress Variation	37.85	43.82	40.73
		Strength of Fatigue	256.85	294.75	341.78
	Reinforcement (MPa)	Stress Variation	42.48	49.99	45.55
		Strength of Fatigue	343.00	343.00	343.00

* 1 : Serviceability Limit State
* 2 : Ulitimate Limit State of Fatigue

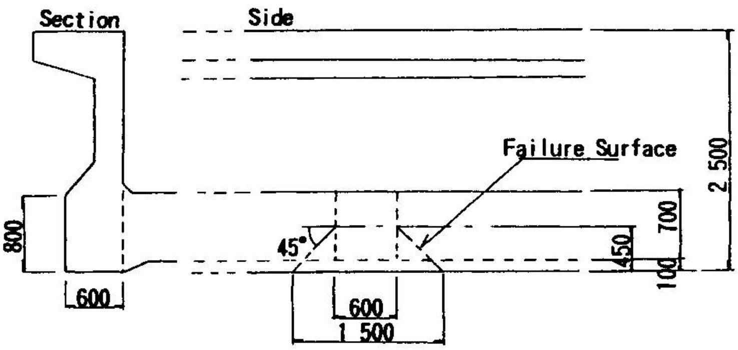

Fig.5 Assumption of Shear Failure Surface

4. 2 RAIL GIRDERS

This members are design as prestressed concrete members. In consideration of thes afety side, the bending moments are cal-culated by the 3 span continuous frame model assumed that connected parts with cross beams are hinge supports, and the design is carried out against this bending moments and other section forces by

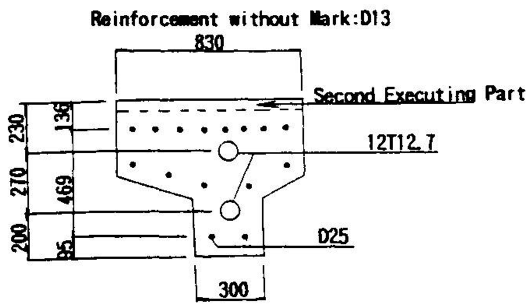

Fig.6 Arrangements of Prestressing Strands

grade grid frame analysis. Fig.6 shows the arrangements of prestressing cables.and axial reinforcements. Table 6 shows the design results of the ultimate limit state and the serviceability limit state.

Table 6 Design Results of Rail Girders

			Crossing Part with Cross Beam	Center between Cross Beams
Number of Prestressing Cables			2	2
Ultimate Limit State	Safety Ratio (Bending)		6.43	2.83
* 1	Concrete Stress at Parmanent Load (MPa)	Upper Verge	5.59	6.01
		Lower Verge	6.67	6.00
		Limit Value	0 ~17.64	
	Concrete Stress at Design Load (MPa)	Upper Verge	2.04	9.20
		Lower Verge	7.92	2.46
		Limit Value	−2.07	
	Diagonal Tensile Stress of Concrete at Design Load (MPa)	Without Torsion	−0.01	−0.04
		With Torsion	−0.11	−0.29
		Limit Value	−2.01	

* 1 : Serviceability Limit State

4. 3 CROSS BEAMS

Rather large out-of-plane forces by prestressing forces in main girders and the defference of axial deformations between main girders and rail gerders act to cross beams. So, verifications for safety are carried out to two directions. And, by grade grid frame analysis, minus bending forces scarecely occur at connected parts of cross beams and main girders mainly by vertical and torsional deformations in main girders. But, also in consideration of thesafety side, this parts are design minus moments equal to one-half of plus bending moments at the center span of cross beams by grade grid frame analysis. Then, cross beams have the same stiffness except ones on supports. Each cross beams has different section forces. But, this design, to make the design works simple, the design iscarried out reprezentative section forces.

5. CONSIDERATION FOR VERTICAL DEFORMATIONS

Because the mounted track type is adopted, it is very important to make vertical deformations by creep smaller for views of the maintenance works and the comfortness of train-running. So, special verifications are carried out for the vertical deformations in main girders which give much influences to deformations of the total structures. Then, concrete stresses at the upper verge and lower verge during permanent loads are design to be as ballanced as possible. By this considerations, vertical deformations by creep can be reduced, and if the errors of stifness and creep coefficient ocurr, these influence to rails can also be reduced.

6. CONCLUSION

This paper reports on the outline of the design of partially prestressed concrete through girder with open floors adopted first time in Japan. In areas where works of getting rid of snow are very hard in winter, this type seems to be much effective if only considerations for vertical deformations are taken adequately. We hope this report will of some use in the design of concrete bridges in which maintenance works are reduced.