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Prestressed Concrete Bridges in the Honshu-Shikoku Project

Ponts en béton précontraint pour le projet de liaison Honshu-Shikoku

Vorgespannte Betonbrücken im Honshu-Shikoku-Projekt

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SUMMARY

The Kojima-Sakaide route of the Honshu-Shikoku Bridge is a combined highway and railroad route that links Honshu to Shikoku. It is scheduled to be completed in the spring of 1988. This report describes the prestressed concrete bridges that are being constructed on this route.

RÉSUMÉ

La route Kojima-Sakaide de la liaison Honshu-Shikoku est une mixte (autoroute + voie ferrée) reliant Honshu à Shikoku. On prévoit que sa réalisation sera achevée au printemps 1988. Ce rapport décrit les ponts en béton précontraint qui sont en cours de construction sur cette axe.

ZUSAMMENFASSUNG

Die Kojima-Sakaide-Verbindung des Honshu-Shikoku-Projekts ist eine kombinierte Auto-Eisenbahnverbindung, die Honshu mit Shikoku verbindet. Die Fertigstellung ist für Frühjahr 1988 geplant. Dieser Bericht beschreibt die auf dieser Strecke errichteten Spannbetonbrücken.

1. INTRODUCTION

Kojima-Sakaide route of the Honshu-Shikoku Bridge is a combined highway and railroad route that links Honshu to Shikoku and is scheduled to be completed in the spring of 1988. This route, as shown in Fig. 1, consists of 37 km of highway section, 32 km of railroad section and 13 km of combined highway and railroad section on the strait, of which prestressed concrete bridge section accounts for 19% in the highway section and 20% in the railroad section as shown in Table 1.

In the construction of prestressed concrete bridges various construction methods are employed depending on the conditions of the sites as shown in Figs. 2∿5. This report mainly summarizes the outline of combined highway and railroad section with prestressed concrete bridge.

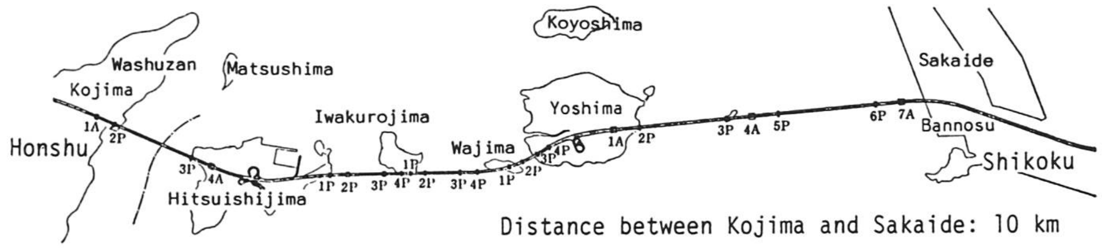

Fig. 1 Kojima-Sakaide Route in Honshu-Shikoku Bridge Projects

Table 1 Prestressed Concrete Bridges in Kojima-Sakaide Route

Section		Number of P.C. bridge	Length of P.C. bridge (m)	Type of construction (Number)				
				Staging	Cantilever erection	Movable staging	Precast	Incremental launching
Okayama side	Highway	22	4,350	2	1	1	19	0
	Railroad	20	900	4	1	0	14	2
Strait section	Highway	5	2,250	1	3	1	0	1
	Railroad	5	4,660	1	4	2	1	0
Shikoku side	Highway	6	520	0	1	0	5	0
	Railroad	2	930	2	1	0	0	1
Total	Highway	33	7,120	3	5	2	24	1
	Railroad	27	6,490	7	6	2	15	3

2. DESIGN CONDITION

The construction gauges for highway and railroad is shown in Fig. 6. The standards on highway are type 1, class 2 with four lanes and width of 22.5 m. The railroad is class 1 with double tracks for ordinary trains, and double tracks for Shinkansen which will be constructed in the future.

The strait section of this route is a combined highway and railroad bridge and both plane and longitudinal alignments are the same for highway and railroad. The alignment is determined depending on navigational height, topography, position of substructures and railroad. The plane alignment consists of radius of curvature larger than 1,300 m and longitudinal grade of below 1.5%.

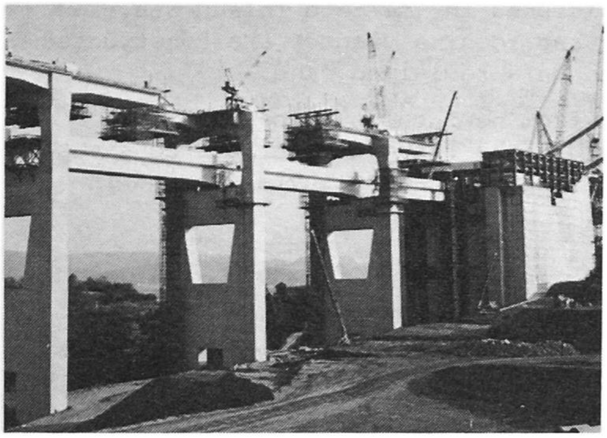

Fig. 2 Cantilever Erection (Yoshima Viaduct)

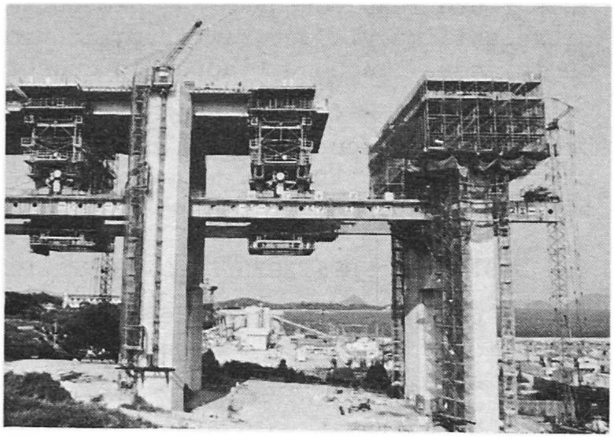

Fig. 3 Erection by Movable Staging (Hitsuishijima Viaduct)

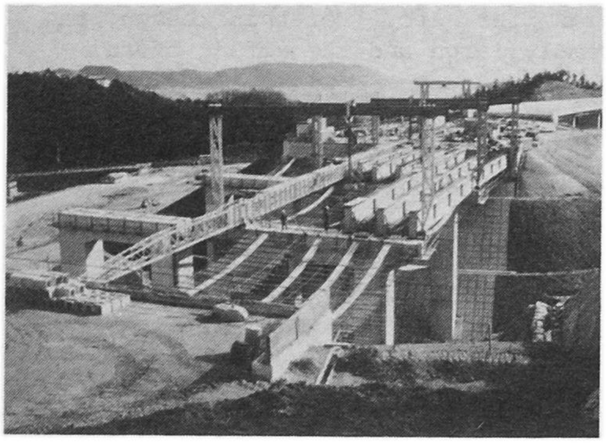

Fig. 4 Erection by Precast Girder

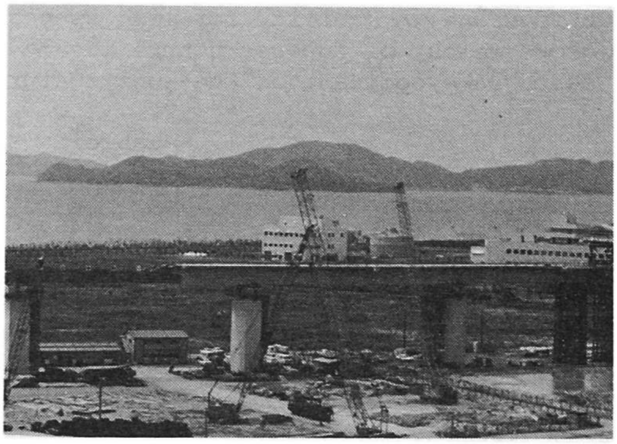

Fig. 5 Erection of Incremental Launching

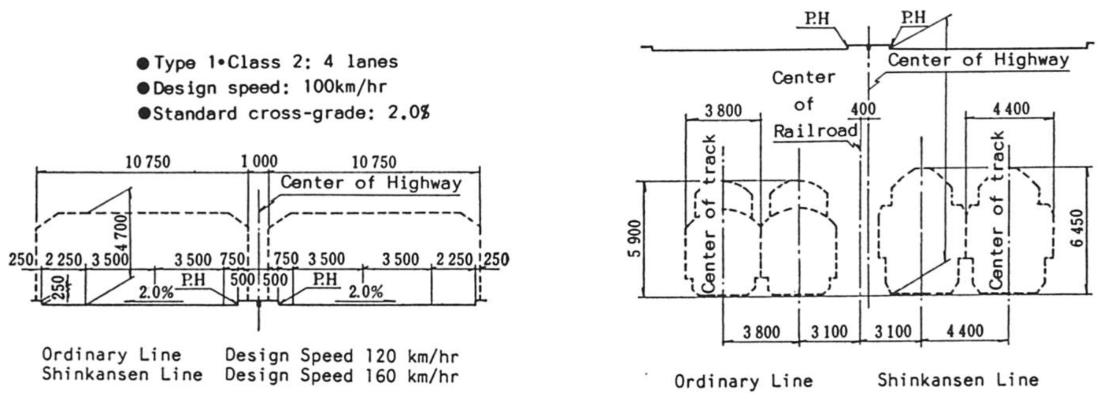

Fig. 6 Highway Standard, Railroad Standard, Etc.

This route runs south-north through small islands in the Seto Inland Sea. Hitsuishijima Viaduct, Iwakurojima Viaduct and Yoshima Viaduct are constructed on islands. Bannosu Viaduct is constructed on a reclaimed land.

The geology consists of sound granite rock from near the surface stratum, becomes worse southward and, in particular, in the Bannosu districts consists of sand gravel stratum, mixed with clay, of diluvial and alluvial period in 50∿70 m depth.

3. DESIGN OF PRESTRESSED CONCRETE BRIDGE

In the design of the prestressed concrete bridges, the Specifications for Highway Bridges and Japan National Railway Design Standard for Structures were mainly applied.

The main materials used are shown in Table 2.

Prestressed concrete bridge has been adopted because of its advantageousness in maintenance, noise and vibration, in addition a multi-span continuous structure was employed as much as possible taking into account runnability of cars, reduction of expansion system that became a weak point from the viewpoint of structure, seismicity considering the prevention of falling of the bridge and workability for long span and high pier, etc. For this reason, the gross weight of superstructure became extremely large and the effect of an earthquake dominant on the substructure.

Table 2 Main Material

		Highway bridge	Railroad bridge
Concrete		σ_{CK} = 400 kg/cm² (Main girder) σ_{CK} = 240 kg/cm² (Handrail, Curb)	σ_{CK} = 400 kg/cm² (Main girder) σ_{CK} = 240 kg/cm² (Handrail, Curb)
Reinforcing bar		SD30	SD35
Prestressing steel	Main cable	Steel bar: SBPR 95/120 Steel strand: SWPR 7A	Steel bar: SBPR 95/120 Steel strand: SWPR 7A
	Horizontal cable of upper slab	Steel strand: SWPR1	Steel strand: SWPR 7A
	Vertical cable at web	Steel bar: SBPR 95/120	Steel bar: SBPR 95/110

Therefore, the conventional support system of concentrated one-point-fix and other ends movable would result in concentration of the inertia force of the superstructure in the direction of the bridge axis on one pier, thereby making it difficult to design and reduce cost. To avoid the disadvantages of such a concentrated fixed support system, the dispersion fixing system in which the force of inertia in the direction of bridge axis of the superstructure at the time of an earthquake is distributed to each bridge pier was applied, thereby improving cost performance and rationality and enhancing safety in case of an earthquake. There are three types of support systems: complete fixing, spring support, and damper support. In the construction of this viaduct, various types of support are employed in consideration of diverse conditions. At the pier which has to support two end supports of two continuous bridges, only one of them is fixed so as to avoid the insecure dispersion of reaction force.

In the railroad girder of the Yoshima Viaduct, the one point fixing system is employed because of the existence of massive abutments in front and rear and mitigating the horizontal force to the high pier.

Because the road surface and rail level have been kept constant in the suspension and cable stayed bridge, the adjacent prestressed concrete viaduct of large span (more than 40 m) is affected.

The highway girder is a solid rigid frame structure connected ridigly to the horizontal beam of each pier as shown in Figs. 2 and 3. As the highway girder axis line does not coincide with the pier post axial line because of restrictions imposed by construction limits of the railroad section below, combined flexure, shear and torsional stresses are applied by both dead load and seismic load (see Fig. 7). Thus, a prestressed concrete structure was adopted for the upper horizontal beam on the assumption that it will suppress the development of cracks under the design load conditions, including an earthquake.

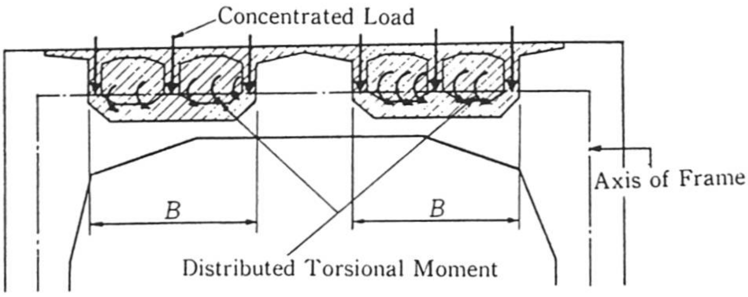

Fig. 7 Loading Condition at Pier

4. DESIGN AND CONSTRUCTION OF EACH BRIDGE

4.1 Hitsuishijima Viaduct

Fig. 8 shows the general view of Hitsuishijima Viaduct. The height of the pier of this viaduct is relatively lower as compared with other viaducts, i.e., 15∿58 m, supporting ground is sound and the design is based on the modified seismic coefficient method. The seismic coefficient used are k_{hm} = 0.19 for all but k_{hm} = 0.15 for 5P∿8P. Highway P.C. girder longer than the span of 40 m is connected rigidly with the horizontal beam of the bridge pier from the viewpoint of bearing interface (see Fig. 3). In this case, as the effect of expansion of the superstructure acts as a horizontal force on the substructures, the bridge length was made about 200 m and the number of continuous span used are three types, 3, 4 and 5 continuous span. In the part of the highway girder 1P∿9P, a complete fixing system is considered unfavorable because a large horizontal force acts on the substructure due to expansion of the superstructure, and dispersion of reaction is difficult due to difference in rigidity as the result of different pier height. Therefore, the rubber shoe was used in this section to disperse the reaction force.

The prestressed concrete railroad girder also uses the damper type stopper in consideration of dispersion of reaction force as much as possible. Ratio of horizontal reaction force of this stopper was examined by dynamic analysis using direct response. In the section where the height of pier was even, one-point concentrated fixing or two-point dispersion were employed as the multiple point dispersion was inadequate considering the damping properties of the damper.

The highway girder in the rigid frame section is an integrated structure for in- and out-bound traffic and constitutes two box girders (one cell). And that in the rubber shoe section (1P∿9P) is a separate structure for in- and out-bound traffic and constitutes one box girder (one cell) for each one. There are sections where two cells box girder type was employed due to widening for a ramp. The railroad girder consists of three one cell box girder and was planned such that in the first phase one box girder (one cell) for double track was to be installed in the center and in the second phase two one cell box girders were to be constructed on outside (Refer to Fig. 9).

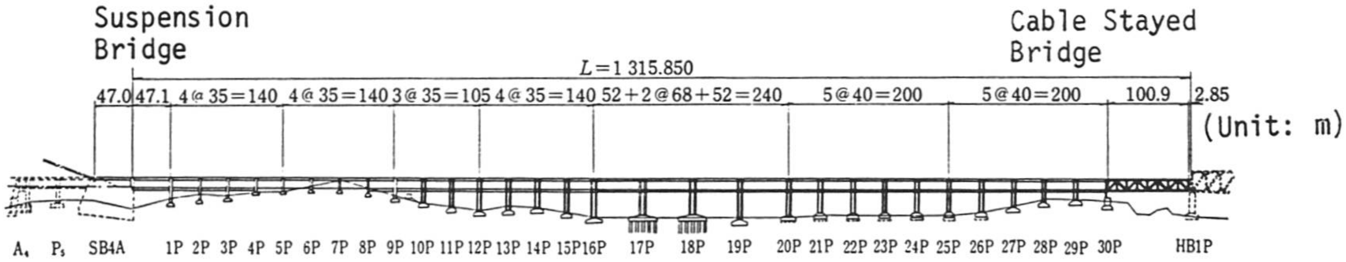

Fig. 8 General View of Hitsuishijima Viaduct

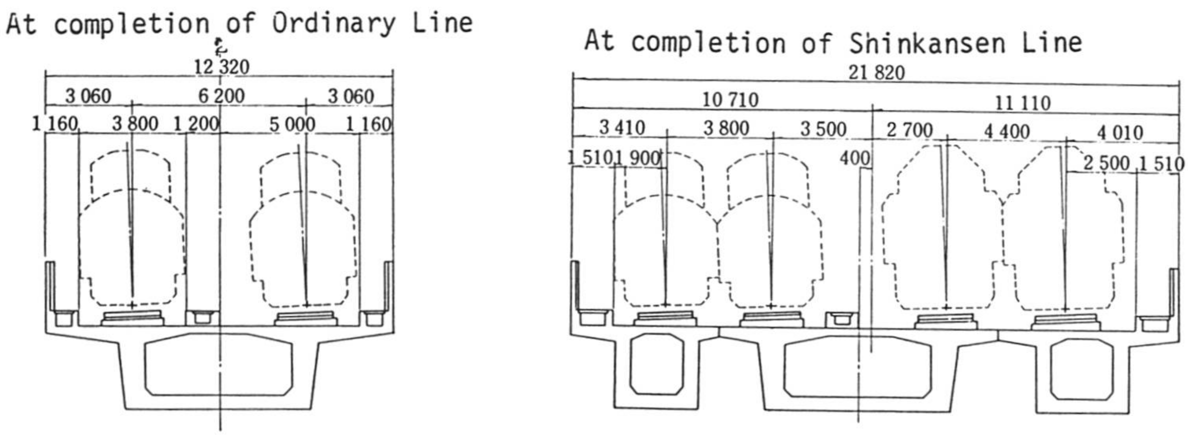

Fig. 9 Prestressed Concrete Railroad Girder

The type of floor slab used was prestressed concrete slab for highway girder and for double track railroad girder, and reinforced concrete slab for single track railway girder.

The slab of highway girder around the horizontal beam of pier was reinforced by reinforcing bars as it was assumed by FEM analysis that prestress could not be introduced too well on the floor slab due to the rigidity of horizontal beam.

As the bridge is of double deck structure for highway and railroad, the bridge pier was made gate-shaped rigid frame type of two layers. The pier is reinforced concrete structure mainly using D51, but horizontal beam in highway section uses three types of structure, i.e. R.C., P.R.C. and P.C. Reinforced concrete structure was used at the joint of superstructures with small reaction, P.R.C. structure in the intermediate pier of 35 m span with relatively low height and P.C. structure for horizontal beam of pier of greater than 35 m span.

Type of foundation employed was spread foundation as the bedrock generally is near the ground surface as mentioned previously. For 17P and 18P, pile foundation was employed as the bearing ground level became deeper.

Prestressed concrete girders were constructed using five methods as shown in Table 3 in consideration of various conditions.

As the variation of the width of P.C. girder became complex near the entrance to ramp, the highway girder was erected by cantilever erection method (one block: 6.25 m) while coping with the variation using large-sized movable staging as shown in Fig. 3. Railroad girder was also erected by cantilever election method using movable form that was installed on that staging. (see Fig. 10).

One cycle for that system is 1 erection of highway girder on one side, 2 erection of railroad girder and 3 erection of highway girder on the other side, and took approximately 30 days.

The length of each block is 6.25 m at cantilever erection. Fig. 11 shows the different types of movable stagings used for railroad girder between 20P and 30P. In this case, each span is constructed one at a time.

Table 3 Construction Method of Hitsuishijima Viaduct

	1P∿9P	9P∿16P	16P∿20P	20P∿30P
Highway	Staging	Large-scaled movable staging	Cantilever erection	Cantilever erection
Railroad	Staging	Large-scaled movable staging	Cantilever erection	Movable staging

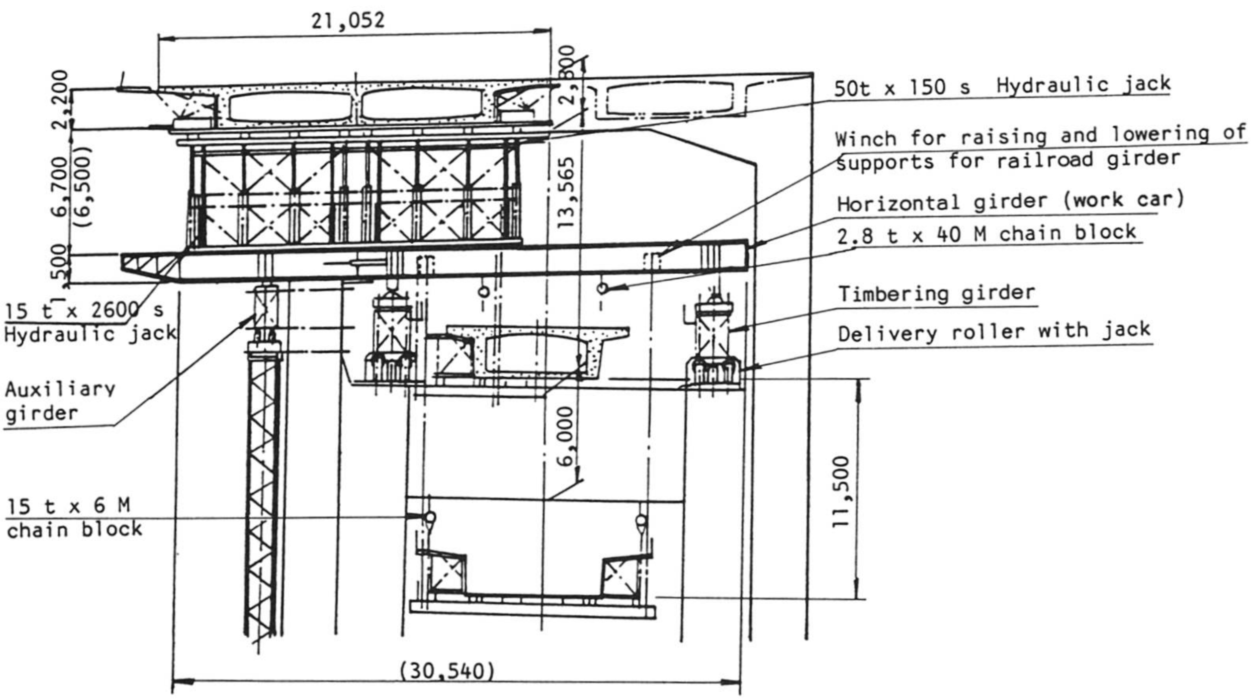

Fig. 10 Erection by Movable Staging (Cross Section)

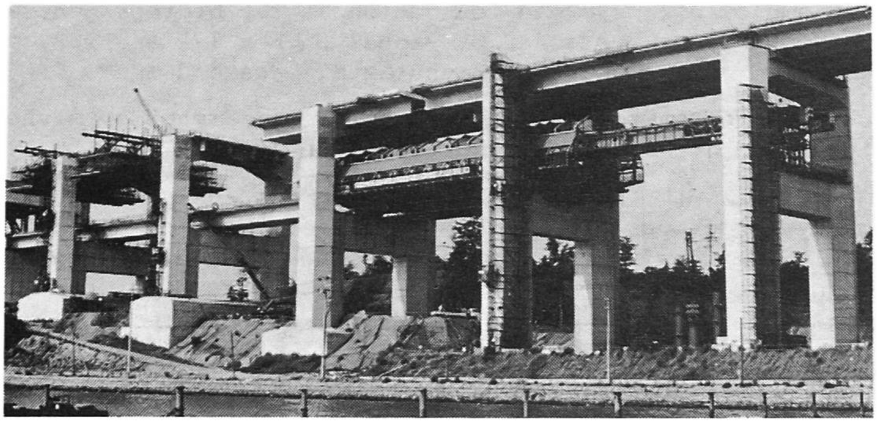

Fig. 11 Erection by Movable Staging for Lower Girder

4.2 Yoshima Viaduct

Yoshima Viaduct is 717 m long prestressed concrete bridge with high piers (max. height: 79 m), adjacent to a suspension bridge to be built over the international navigation as shown in Figs. 2 and 12. These high piers form extremely slender shape (width in the direction of bridge axis is 4 m). Therefore, aseismic design of the Viaduct was made by dynamic analysis (spectrum response analysis) in addition to the corrected seismic coefficient method to verify stability. The seismic coefficient became k_{hm} = 0.21 in the direction at right angle to the bridge axis and k_{hm} = 0.08 between 5P∿10P (period T ≒ 2.6). For the fixed support piers for railroad, k_{hm} = 0.19 for 4P and k_{hm} = 0.19 for BB1A.

All highway girders were rigidly connected with horizontal beam of intermediate piers, and four span continuous between YB4P∿4P and seven span continuous between 4P∿BB1A.

As the pier is extremely high and rigidity of substructure is small between 4P∿BB1A, seven span continuous girder, which has smaller effect on sectional force of substructure due to expansion of girder, was planned to improve runnability of vehicles and maintenance of expansion system. Ramp girder for highway separate at 1P and 7P and fixed pin shoes were used at the supports, in order to disperse reaction force as in the case of main traffic lane girder.

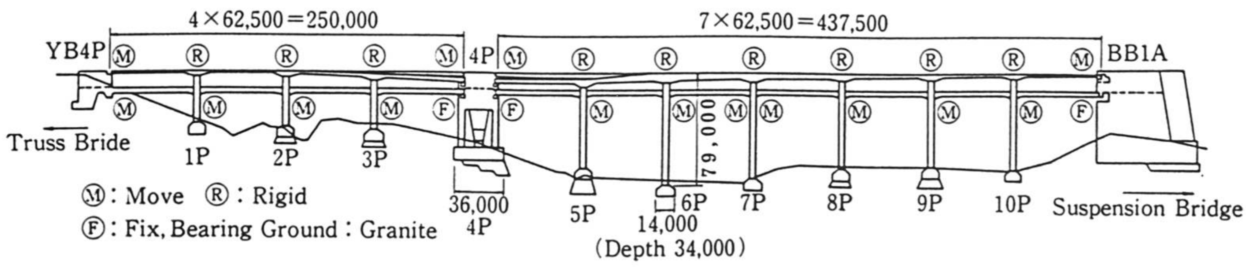

Fig. 12 General View of Yoshima Viaduct

The displacement in the direction of bridge axis at the time of an earthquake of rigid frame bridge in highway section of seven span continuous girder becomes about 15 cm, while that of railway girder is smaller, i.e., 1∿2 cm, as it is fixed to the large abutment. Therefore, the friction of movable shoe of railroad girder between 5P∿10P constitutes damping effect against seven span continuous rigid frame girder and conversely increases in horizontal reaction force against the concentrated fixed shoe of railroad girder. Therefore, to be on the safe side, the friction force of movable shoe of railroad girder against seven span continuous rigid frame girder was neglected and it was decided to consider the total friction force against concentrated fixed shoe of railroad girder.

The type of highway girder is an integrated structure for in- and out-bound traffic of two cell two box girder type for the standard width section and varied to 2∿5 cell type for wider section (see Fig. 13). The railroad girder is the same type as in the case of Hitsuishijima Viaduct.

For the floor slab highway girder, reinforced concrete structure is adopted because the width and slab span vary considerably. In the railroad girder, prestressed concrete structure for double track and reinforced concrete structure for single track are used.

The type of pier is long period structure with thin thickness (4 m) in the direction of bridge axis and rigid frame of two and three layers in the direction at right angle to the bridge axis as a high rigidity structure was required from the viewpoint of runnability of trains at the time of an earthquake and also from viewpoint of aesthetics. Sectional configuration of pier is a mixed structure in which a steel frame is encased in reinforced concrete (see Fig. 14), in consideration of ductility at time of an earthquake.

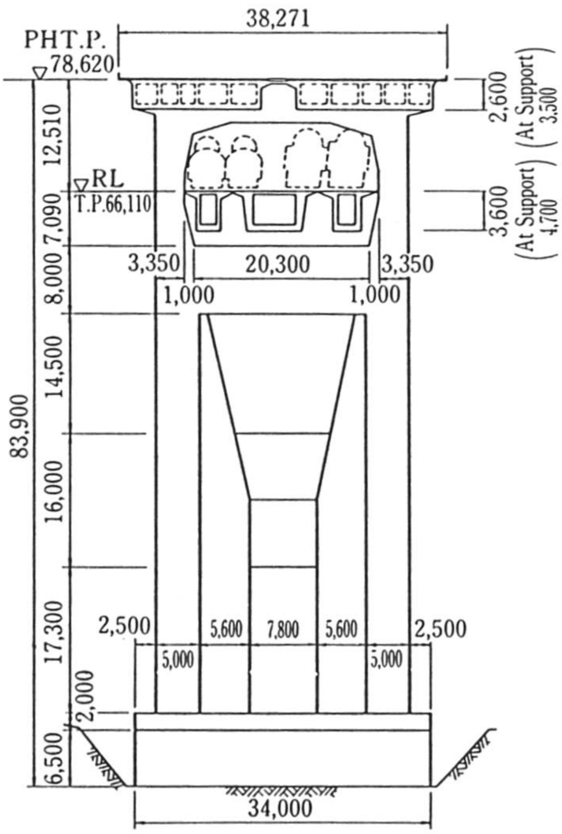

Fig. 13 General View of Pier (7P)

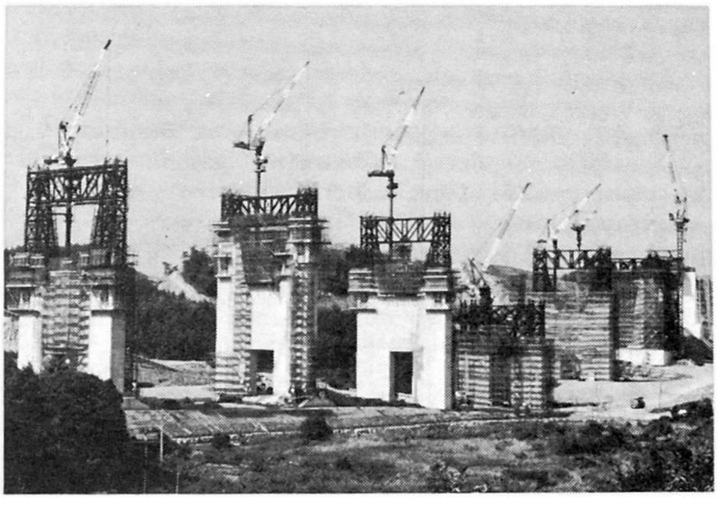

Fig. 14 Construction of Pier

The type of foundation is spread foundation as the good quality granite was either exposed or distributed below the thin overburden. Prestressed concrete box girders have been constructed by cantilever erection method as shown in Fig. 2. In the construction, the lower deck railroad girder was started first, followed by the upper deck highway girder. Upon completion of railroad girder, it was temporarily fixed at each support and utilized for construction of highway girder.

4.3 Iwakurojima Viaduct

Iwakurojima Viaduct is 92.6 m long double decked prestressed concrete bridge (2 continuous span) between cable stayed bridges. Type of girders are similar to Hitsuishijima Viaduct. But the width of highway girder is very wide (30.5∿38.5 m) because of bus stop facilities on the viaduct, thus seven cell box girder was adopted as shown in Fig. 15.

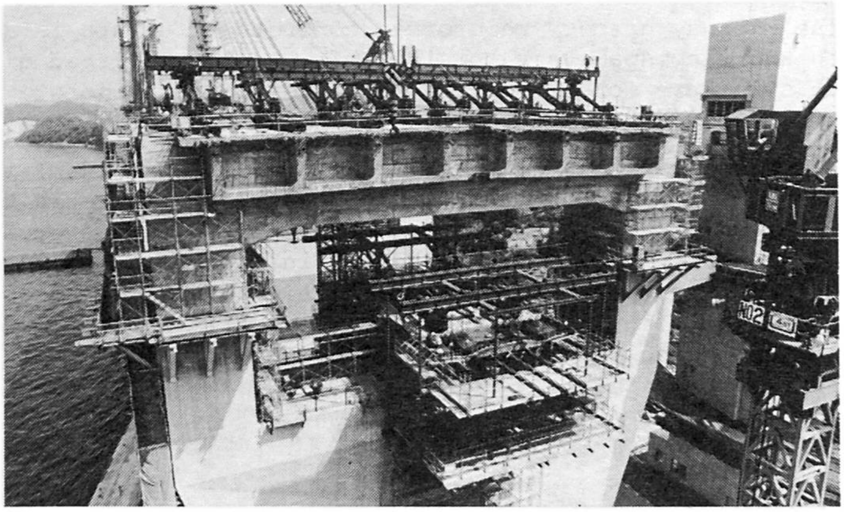

Fig. 15 Construction of Iwakurojima Viaduct

4.4 Bannosu Viaduct

Fig. 16 shows the general view of Bannosu Viaduct. It has a very high bridge pier (50∿75m) and the bearing ground is very deep (40∿60m). Therefore, its seismic coefficient is the largest among this route, i.e., corrected seismic coefficient k_{hm} = 0.25. The aseismic design of this bridge included dynamic analysis (spectrum response analysis, dynamic analysis in consideration of elastic-plastic history of R.C. member) taking into account the fact that pier is tall and burried very deeply into the bearing ground in addition to the corrected seismic coefficient method.

The highway girder, which is a steel box girder, is rigidly connected with the horizontal steel box beam. And horizontal beam is supported by BP fixed shoe of hinge type. As it is a complete fixing system, horizontal force acts upon the substructure against expansion of the main girder of highway due to high temperature. Therefore, 5, 4 and 3 span continuous girder sections were provided depending on the pier height (depending on the rigidity of sub-structure).

As a result the horizontal force will distribute uniformly over each pier at the time of an earthquake, because the height of bridge pier will become uniform.

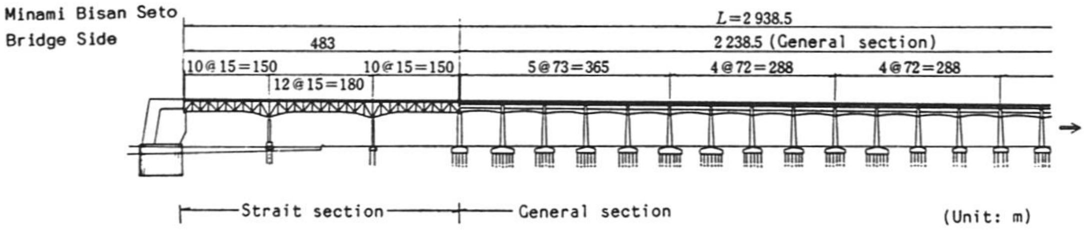

Fig. 16 General View of Bannosu Viaduct

The prestressed concrete railroad girder employs a damper type stopper, which helps to distribute the horizontal force uniformly over each bridge pier. In this bridge, as the horizontal force by means of the dynamic analysis proved to be extremely large, it was compared and examined and was decided to use the seismic coefficient of 0.7 for highway and 0.3 for railroad.

Also, various studies were implemented on the runnability of trains at the time of an earthquake and as a result, a short period system of bridge in Fig. 17 was employed. The studies on the runnability of trains mean the examination of possibility of derailment and overturning of trains because of vibration due to an earthquake in the direction at right angles to bridge axis, which is largely affected by displacement and period on the track surface. Therefore, running simulation of trains was made to check the safety by static examination, dynamic analysis by means of spectrum response and direct response analysis using direct input seismic wave. B.P. shoe was used by taking into account the variations in the direction of rotation of girder and expansion in the curved section, and the desirability of use of low shoe height in combination with the stopper.

Floor slab for railroad girder is constructed by prestressed concrete for double track girder and reinforced concrete for single track girder. The type of pier is I section configuration (aseismic wall: 2 m thick) with two upper columns that support highway girder.

The type of foundation was determined to be pile foundation. Cast in place reinforced concrete pile of ø3 m was used in consideration of effects of a group of piles and that of fluidization of ground. The spacing of piles was two times the pile diameter in order to minimize the footing size which makes it more economical for the whole structure.

Prestressed concrete of railroad girder was constructed by cantilever erection method as shown in Fig. 18.

5. CONCLUSION

Construction of prestressed concrete viaducts is almost completed as planned in the whole route. And pavement and railing work are underway to meet the opening of the bridge next spring (1988).

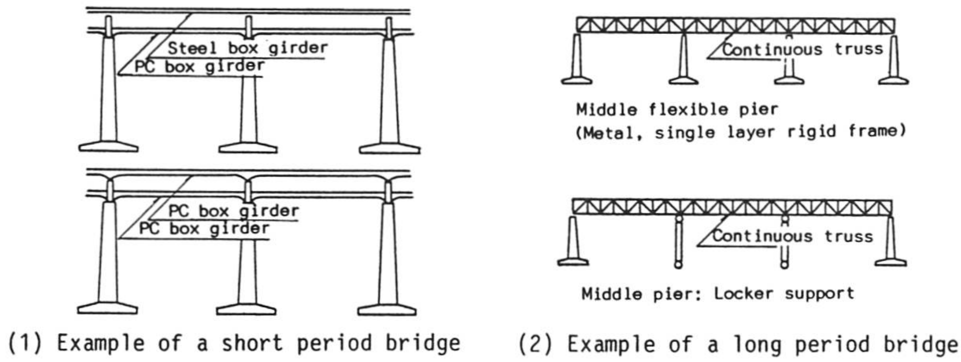

Fig. 17 Comparison of Bridge Pier for Bannosu Viaduct

Fig. 18 Construction of Bannosu Viaduct