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**Autor:** Ohashi, Masamitsu / Narui, Shin / Fujii, Yuji

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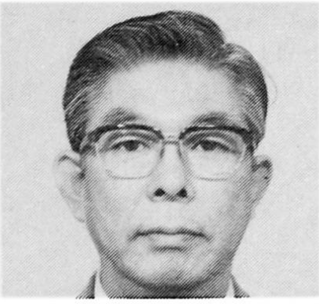
# Design of Long Span Suspension Bridges for Combined Highway and Railway

Conception d'un long pont suspendu mixte route et voie ferrée

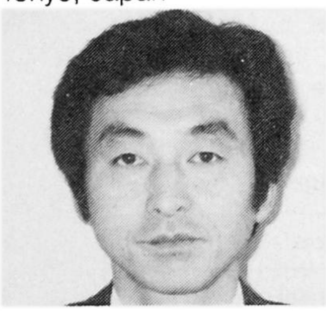
Entwurf von Hängebrücken als kombinierte Eisenbahn- und Autobahnbrücken

**Masamitsu OHASHI**
Dr.Eng.Dir.
Honshu-Shikoku Bridge Auth.
Tokyo, Japan



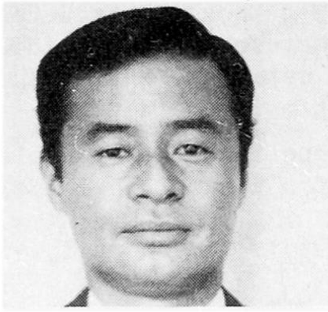
Born in 1928, obtained his Dr.Eng. degree in civil engineering at the Kyoto University, Japan. From 1969 to 1974, he worked for the construction of the Kanmon Bridge as a manager. Now, he is an executive director for the Honshu-Shikoku Bridge Authority.

**Yuji FUJII**
Civil Eng.
Planning Division, H.S.B.A.
Tokyo, Japan



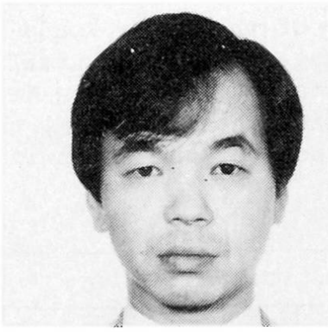
Born in 1949, received his masters degree in civil engineering at the Hokkaido University. He was engaged in the construction of the Shimotsui Seto Bridge.

**Shin NARUI**
Cief of Bridge Eng.
Naruto Maintenance Office,
Tokushima, Japan



Born in 1948, received his Dr.-Ing. degree in civil engineering at the Stuttgart University, West Germany, He was engaged in the construction of Minami and Kita Bisan Seto Bridges.

**Shigeru HIRANO**
Subchief
Second Constr. Bureau
Okayama, Japan



Born in 1953, received his masters degree in civil engineering at the Tokyo Metropolitan University. He was engaged in the construction of Minami and Kita Bisan Seto Bridges.

**SUMMARY**
This report introduces the design problems and solutions of the bridges for combined highway and high-speed railway, taking the case of the Minami Bisan-Seto Bridge, the longest suspension bridge on the Kojima-Sakaide Route of the Honshu-Shikoku Bridges.

**RÉSUMÉ**
Le rapport présente des problèmes et solutions dans la conception d'un pont mixte route et voie ferrée à grande vitesse: le Pont Minami Bisan-Seto qui est le plus long pont suspendu dans la section Kojima-Sakaide du projet de liaison Honshu-Shikoku par ponts.

**ZUSAMMENFASSUNG**
Diese Arbeit befaßt sich mit der Darstellung und Lösung von Entwurfsproblemen, die bei kombinierten Eisenbahn- und Autobahnbrücken auftreten und geht hauptsächlich anhand der Brücke Minamibisan-Seto als Beispiel vor, welches die längste Hängebrücke der Honshu-Shikoku-Verbindung auf der Strecke Kojima-Sakaide ist.

## 1. INTRODUCTION

The construction of the Kojima-Sakaide Route, one of the three routes to link the Honshu (Mainland) and the Shikoku Island started in October 1978, and is scheduled to be opened to traffic in April 1988.
There are three long span suspension bridges on the route carrying both highway and railway; the Minami Bisan-Seto Bridge (center span: 1,100m), the Kita Bisan Seto Bridge (center span: 990m) and the Shimotsui-Seto Bridge (center span: 940m). (See Fig. 1)
At the very early stage of the project the Honshu-Shikoku Bridge Authority (to be called the Authority hereafter) faced many technical problems in design of the superstructures of the bridges such as the safety in the bullet train service, the establishment of the fatigue design criteria and the design against large deflection and forces.

This paper describes those problems we faced and the solutions we selected for the bridges for the combined use.

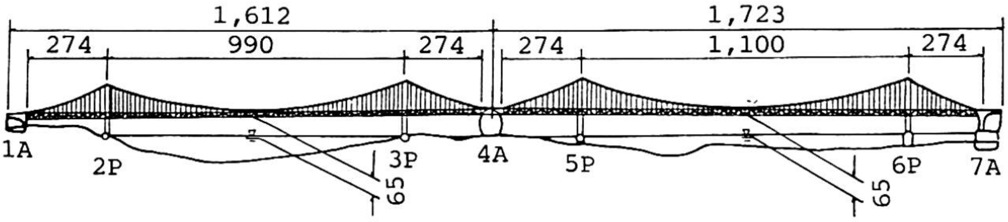



Fig. 1 General View of Kita and Minami Bisan-Seto Bridges (m)

## 2. DESIGN LOADS

We take the Minami Bisan-Seto Bridge as an example in this paper. We listed the designed loads for the bridge in Table-1. The significance in the design loading for the suspension bridge for such a combined use is considered to be live load, that is automobile traffic load and train load.
The intensity of the above loads was determined based on the actual surveyed data of highway and railway traffic. Although this suspension bridges are designed to carry four railway tracks, considering the actual service schedule and the traffic control system, the train load applied for the design purpose was of two tracks of the train instead of four.

Table-1 Design Loads (Minami Bisan-Seto Bridge)

| Classification | | | Design Load |
|---|---|---|---|
| Dead Load : D | | Uniform Load : $D_0$ | 434kN/m (Center span)<br>448 kN/m (Side span) |
| | | Ununiform Load : $D_1$ | Difference between actual dead load and $D_0$. |
| Live Load | Car load $L_H$ | Equivalent concentrated load : P | 1.05MN |
| | | Equivalent distributed load : p | 32.5kN/m |
| | Train load $L_R$ | Normally design | 2 lines of 37.2 kN/m |
| | | For fatigue stress<br>In times of an earthquake | 1 line of 26.5 kN/m |
| Impact : I | | Impact coefficient : i | i = 0.2 (Shinkansen)<br>i = 0.1 (Ordinary train) |
| Temperature Change:T | | | $\pm$30deg |
| Others | | Support displacement, Erection error, Wind, Earthquake | |

## 3. STRUCTURAL FEATURES

### 3.1 3-span-continuous suspension bridge

Carrying the railway tracks, the geometrical continuity is a very important factor for this bridge, where the angular bends at towers and girder ends shall be limited in order to assure the safety in railway service.
Therefore, 3-span-continuous girder was selected. We listed the angular bend and the expansion joint movement of 2-hinged suspension bridge and 3-spanned continuous suspension bridge for comparison purpose in Table-2.

Table-2 Comparison of suspension bridge types

| | Vertical angular Bend | Movement at Expansion Joints |
|---|---|---|
| 2-hinge suspension bridge | 3.1% at towers | ±108cm at towers |
| 3-span-continuous suspension bridge | 1.1% at ends | ±64cm at ends |

The major design solutions are as follows.

1) Large bending moment at the intermediate support

The bending moment of the stiffening girder at the intermediate support is 1,450 MNm/Br., approximately four times as large as that at middle of the center span. The sectional dimension of the chord members at the intermediate support is 1,000mm wide x 1,200mm high with 75mm thick plates, while that of the typical section is 750mm x 750mm with 35mm thick plates.

2) Large reaction force at the intermediate support

As the reaction force at the intermediate support is as large as 34.3MN and the longitudinal movement is ±65cm, a solid-forged link structure was designed to link the tower and the stiffening girder with solid lubricant bushings in the contact surface to a sliding pin. Total weight of the link structure including the bushings is 637 kN.
Further, the tower link is connected to the lower chord member of the stiffening girder and is located between the lower and upper chords from an aesthetic point of view.

3) Negative reaction force (uplift) of the stiffening girder

As negative reaction forces due to live load would occur at the intermediate support and girder end, counterweights with concrete weighing 2,500 kN and 540 kN respectively, are placed in order to minimize the occurrence of the negative reaction forces.

4) Hanger bracket

In order to maintain the continuity of the stiffening girder through the two towers, the girder was designed with the hanger brackets where the hanger ropes are to be anchored (See Fig. 2).

### 3.2 Double deck structure

The stiffening girder has two layers of decks i.e. the lower deck for railway and the upper deck for highway (see Fig. 2).
Considering that the long-spanned girder is carrying both railway and highway, the dead load stress of the main cable comes up to 80% of its total stress.
As one of the approaches to reduce the above dead load, the upper deck for the highway is made up of the steel deck with 75mm thick asphalt pavement and the

lower deck for the railway is made up of tracks directly attached to the top flange of railway stringer with newly developed rail fasteners.

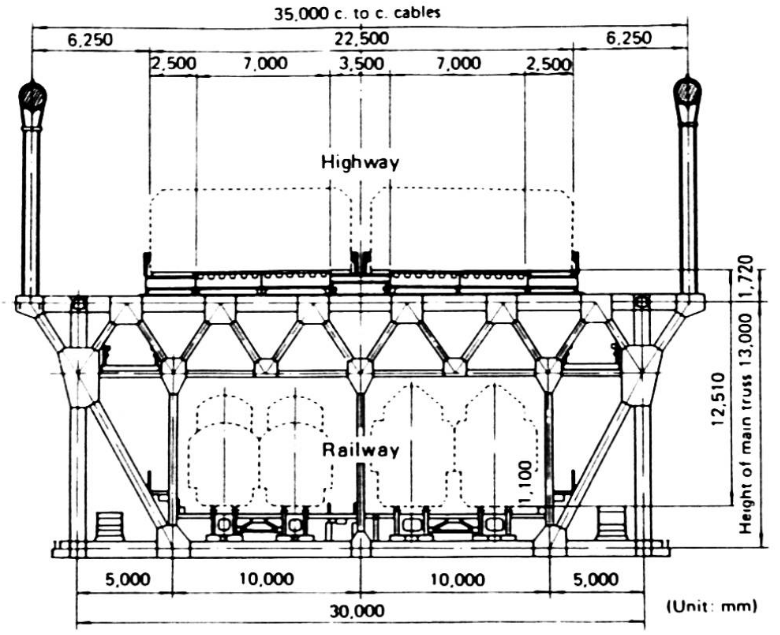



Fig. 2 Typical Cross Section of the Suspension Bridge

## 4. DYNAMICS OF TRAIN OPERATION

The runnability of trains was a major concern in this project. Our series of studies on this subject is summarized as follows.

### 4.1 Development of transit girder system

The problem of angular bend at the towers was solved by adoption of the 3-span-continuous bridge. The angular bend at the girder ends which is calculated to be 1.1% max. and the longitudinal movement at the points which is calculated to be ±64cm were, however still to be solved. The deflections at railway stringer and cross truss also lead to additional angular bend to that at girder ends. To solve this problem, the transit girder was developed. It has the capacity of the movement ±75cm and dispersing the amount of angular bend at the two points (see Fig. 3). Further, the performance of this assembly was confirmed through the field running tests with real vehicles.

### 4.2 Restriction of stringer deflection

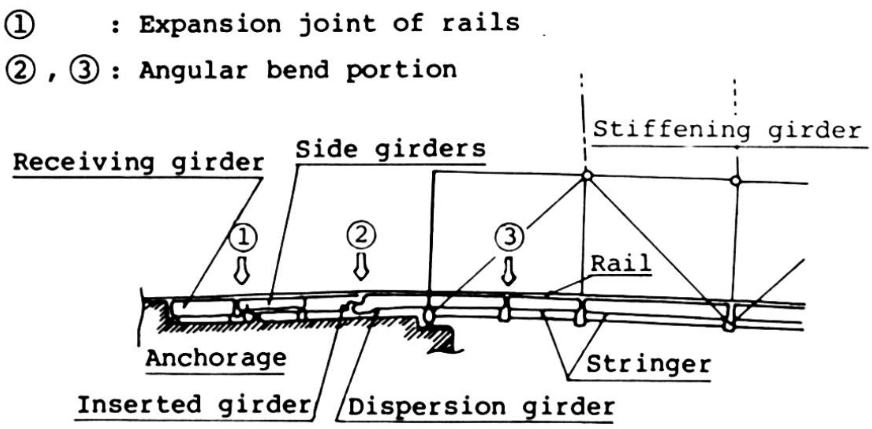



Fig. 3 Transit Girder System of Inserted Girder Type

With the trains running at high speed on the railway stringers as they have deflection due to the train load, the wheel load is reduced and consequently it would increase the risk of derailing. The vibration of the train will also reduces riding comfort.
After analyses and simulations, it was decided to solve this problem that the stringer deflection shall be restricted to be L/900 max. for the ordinary train, where L is length between two supports.

### 4.3 Runnability against earthquake

The lateral vibration due to earthquake would threaten the safe running of the trains on the stiffening girder. The series of model testings on the shaking table and computer simulations were carried out to evaluate the reactions

against earthquake.
Based on the above studies, the running safety limit curve was prepared (see Fig. 4) to evaluate the runnability in case of earthquake.

### 4.4 Runnability against wind

In order to evaluate the influence of the disturbed wind blowing (30m/sec.) through trussed stiffening girder members to runnability, the series of the wind tunnel tests were carried out. The safety of the running on the bridge was confirmed through these tests.

## 5. FATIGUE DESIGN

The bridges designed for the Kojima - Sakaide route are expected to carry more than 6 million passages of the trains during the bridge life i.e. 100 years. Furthermore, considerable amount of the quenched and tempered high strength steel (570 ~ 790 MPa) whose structural fatigue behaviour was not fully clarified is used for those bridges' primary members. Therefore fatigue problem was considered one of most important subjects for the project. We carried out number of full-scaled fatigue tests for the structural elements and researches from the view point of fracture mechanics.
Based on the result of the above efforts, the fatigue design criteria for the project was established.
In actual design of the structural members, each detail was carefully examined in order to assure sufficient fatigue life. Especially the design of hanger bracket(see Fig. 5), which has relatively complicated detail, was supported by FEM analysis and full scaled fatigue tests.
In order to maintain the fabrication workmanship required for the project, the additional requirements such as welding procedure tests with full size member, selection of welding materials, additional requirements for welder qualification and severer dimensional tolerances of welding defects were specified.
The automatic ultrasonic testing was carried out for the primary members' corner welding to assure the quality of the weldment satisfies the above mentioned fatigue requirements.

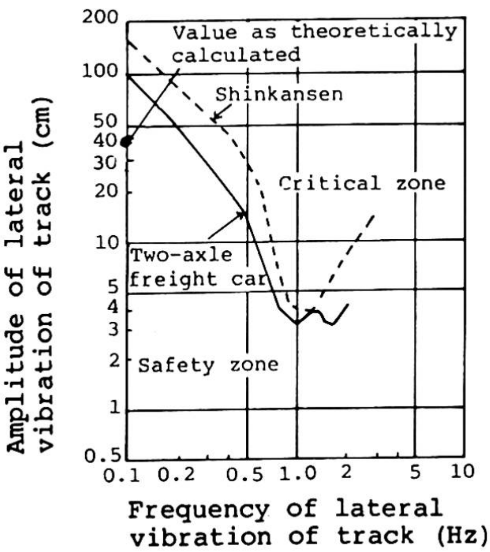



Fig. 4 Running Safty Limit Curve

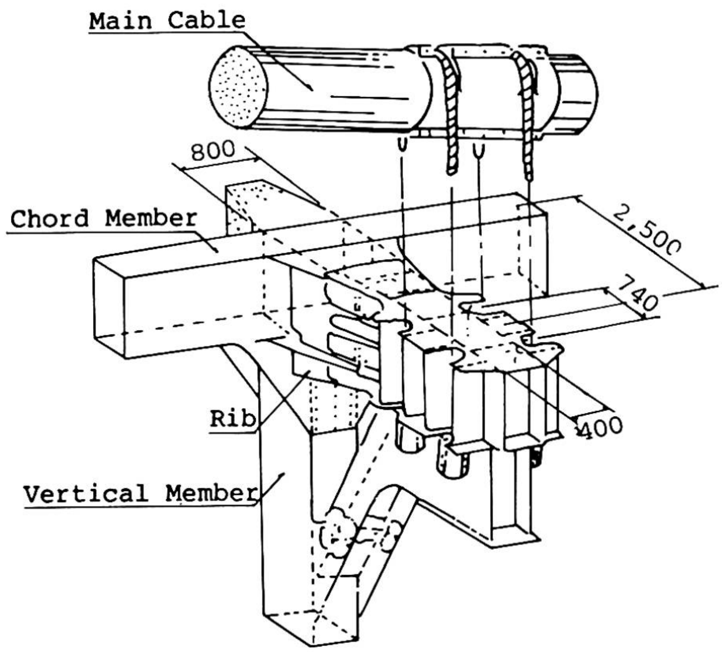



Fig. 5 Detail of Hanger Bracket

## 6. CONCLUSION

As stated in this paper, we have solved many problems we faced at the every early stage of the project through number of experiments, trial fabrications and so on clarifying the structural characters of long span suspension bridge for both highway and railway uses. In the following table (Table-3) we summarized dead load used for the bridges we designed and for other major bridges as a part of the results we gained through our efforts.
In comparing those listed in the table, it can be remarked that the intensity of train load is a significant factor to determine the dead load per unit bridge length.
After the completion of the bridges, deflection, stress and angular bend of stiffening girder etc. will be measured on the train running tests and the vibration tests of completed bridges to confirm the design concept we stated herein.
We sincerely hope that the results we gained through our projects can be any of assistance for those who share the field of suspension bridge for the combined use of highway and railway.

Table-3 Comparison of Dead Load

*: Lower deck added.

**: Shinkansen can be provided in future.

| Name of Bridge | | | Innoshima Bridge | Minami Bisan-Seto Bridge | George Washington Bridge | Golden Gate Bridge | Verrazano Narrows Bridge |
|---|---|---|---|---|---|---|---|
| Item | Year of completion | | 1983 | 1988 | 1931('60)* | 1937 | 1964 |
| Item | Span (m) | | 250+770+250 | 274+1,100+274 | 190+1,067+186 | 343+1,280+343 | 370+1,298+370 |
| Item | Number of Lanes | Highway | 4 | 4 | 14 | 6 | 12 |
| Item | Number of Lanes | Railway | - | 2(4)** | - | - | - |
| Item | Dead Load | Stiffening girder (kN/m) | 156 | 314 | 423 | 165 | 379 |
| Item | Dead Load | Cable (kN/m) | 46 | 121 | 160 | 146 | 155 |
| Item | Dead Load | Total (kN/m) | 202 | 435 | 583 | 311 | 534 |