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Stability of Prestressed Concrete Bridge with Corrugated Steel Web

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Summary

This Bridge (Ginzan-Miyuki Bridge) subjected in this study is a new type bridge of PC box girder bridge used corrugated steel girder at web and external cable, and has been constructed at 1996 as the largest bridge of this type in Japan. And this bridge is also constructed by incremental launching method. It is here investigated the Safety at construction stage by this construction method and the Serviceability for dynamic behavior and characteristics of this bridge based on the results of dynamic experiments.

1. Introduction

This Bridge is a mountain bridge built as part of road improvement works commonly known as Matsunoki Road that were carried out by Akita Prefecture (from 1974 to 1996). This is also a five span continuous girder bridge and bridge length is 210.0m. To satisfy construction conditions constrained by harsh topography and weather, the bridge was distinctively planned, designed and built. Namely, the bridge has a composite structure of PC and steel and was built by diagonally suspended, incremental launching erection method. Herein we will report on the main details of the bridge's design, construction and dynamic behavior and characteristics.

2. Determination of the Basic Type of Structure

A comparative study was conducted of structures and effective span apportionments predicated on harmony with the extremely rugged topography and limited alteration of the topography. As a result of the study, a continuous structure of few spans, which would lead to enlargement of the scale of the substructure, was deemed to be not advisable. Rather, it was concluded that a five span continuous girder structure with a maximum span length of 45.5 m would be optimal (Figure-1and Photos-1). Further, though restrictions on use of the space beneath the girder dictated that the basic erection method would be incremental launching method, it was considered most effective to reduce the main girder's weight to enable less labor-intensive construction. As a result of studying the potential alternatives, it was decided that the structure optimally suited to the conditions and the scale of the bridge in question was a PC box girder used corrugated steel web (Figure-2), a steel and PC composite structure lighter than a PC box girder and more economical than a steel girder.

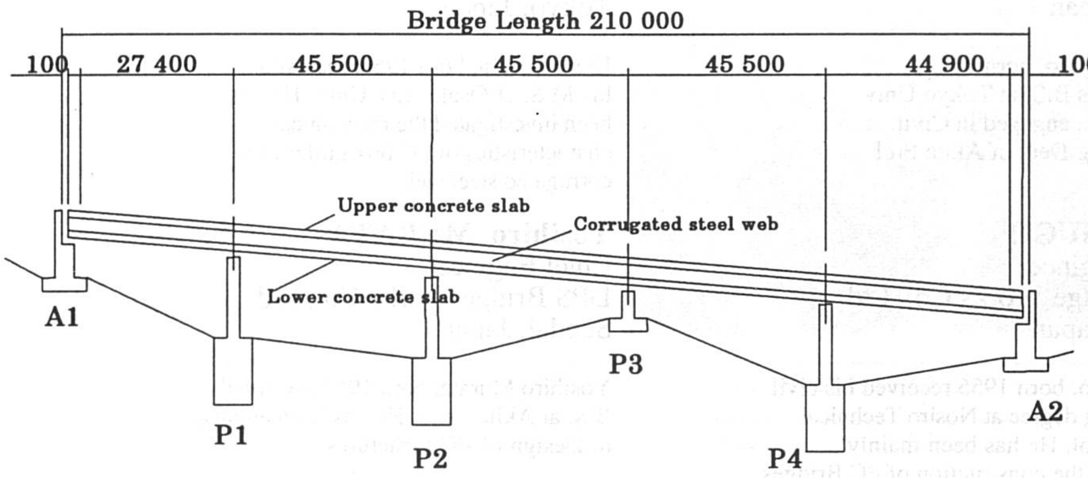
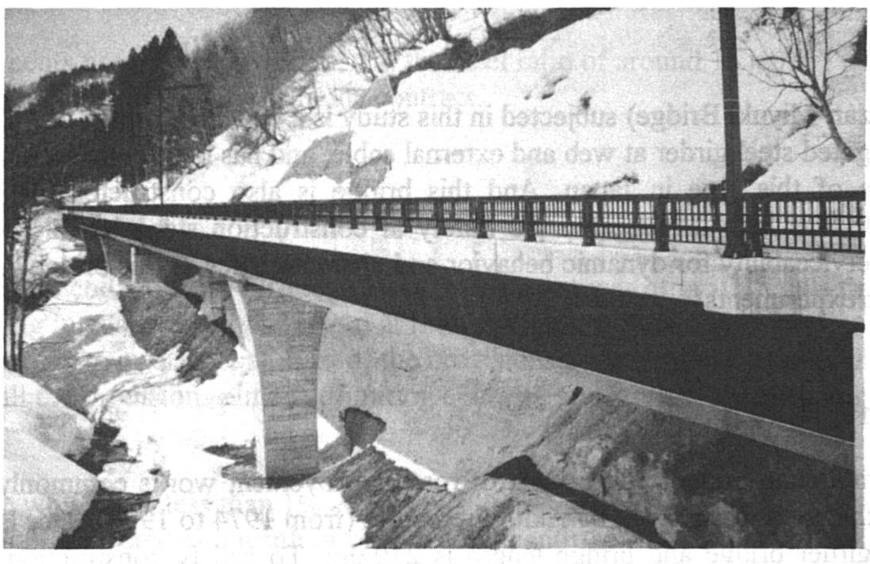


Figure-1 Side elevation of bridge



Photos-1 Side view of bridge

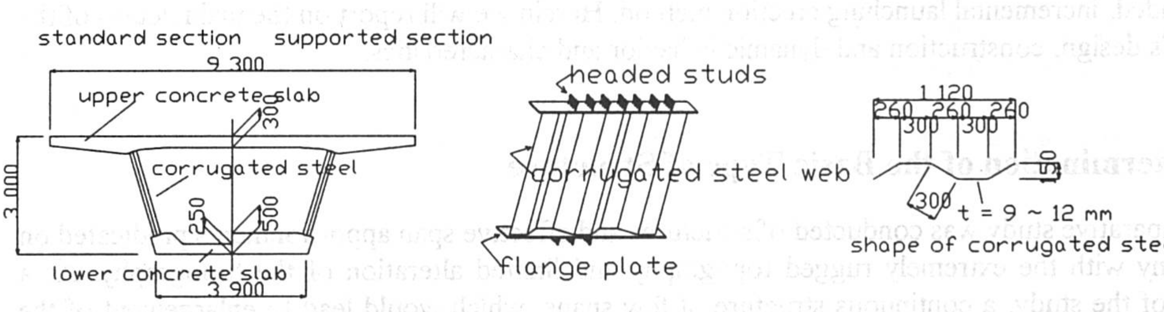


Figure-2 Cross section of box girder and shape of corrugated steel web

3. Construction of the Superstructure

3.1 Casting of the Main Girder

The main girder is composed of a total of 19 blocks whose standard length is 11.0 m. The main girder casting yard occupied about the rear 60 m of the A2 abutment, on the rear 30 m of which all weather sheds were set up. In terms of the formwork facilities for casting the main girder blocks, the lower concrete slab formwork facilities, where the corrugated steel web was assembled, and the upper concrete slab formwork facilities were arranged consecutively for the sake of convenience. In laying out the facilities, care was also taken so that concrete could be casted simultaneously so as to not disrupt the block casting cycle.
The corrugated steel web was fabricated by welding flange plates to the top and bottom of steel plate that had been pressed into a prescribed corrugated shape at the factory, and then welding stud dowels to the flange plates. It took two of these steel panels (5.5 m + 5.5 m) to make up the standard block length of 11.0 m.

3.2 Incremental Launching Erection

With conventional incremental launching construction method, an erection-use launching girder is attached to the end of the main girder and member force declines when the launching girder overhangs during erection stages. With the method employed in this case, however, as part of the approach of using the main girder section, the upper slab concrete was not poured for the three blocks on the forward end and a reinforced, lightweight structure of steel plate deck was used in place of the launching girder. Further, a hybrid of diagonally suspended and launching construction was used, whereby a pylon was erected on the fifth block's upper floor-slab and the forward-end protruding segment was reinforced with diagonal suspension cables (Figure-3 and Photos-2).

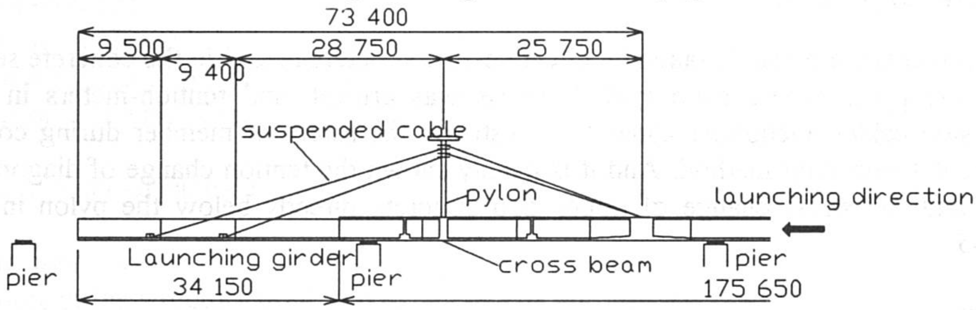
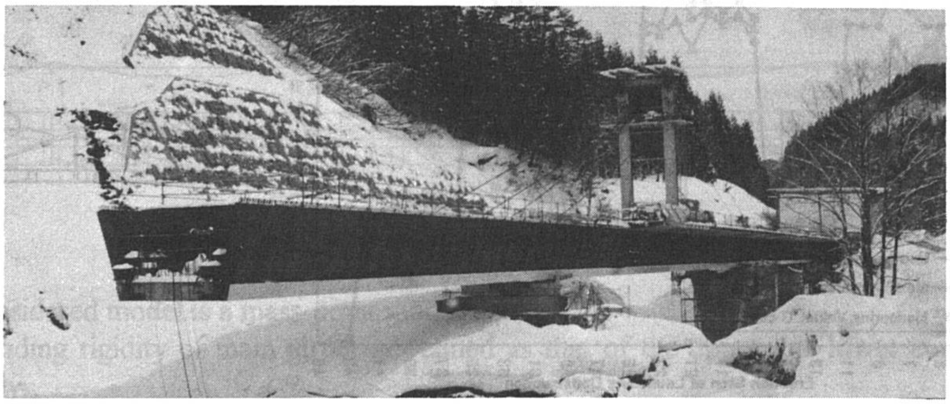


Figure-3 Set up of launching girder, Pylon and diagonally suspended cables



Photos-2 Incremental launching condition

The diagonal suspension cables were tensioned on the pylon side. Thereforer, the diagonal members' tension is propagated as axial tension from the pylon to the main girder and has a major effect on the stress of the main girder section directly below the pylon. Hence, it was adjusted the cables' tension in accordance with each step in the erection process. And it was used PC bars in the slabs of main girder as prestressing on incremental launching condition.

3.3 External cable

For the external cables arranged inside the box girder, two-span continuous cables were used in consideration of factors such as workability and prestressing-loss due to angular change. The external cables use the support cross-beams as their anchoring points and are laid out so they overlap with a different cable on every span . And for the cable's protective sheathing, high-density polyethylene tubing (PE tubing) was used.

4. Experiments of Actual Bridge

4.1 Objective of Experiments

Ginzan-Miyuki Bridge is the first PC bridge in Japan used as a full-scale roadway bridge that has a composite structure used corrugated steel web. External cables were also used progressively in its construction. Consequently, much about its behavior was uncertain. Hence, the experiments were conducted with the aim of ascertaining the bridge's behavior on the actual-bridge level and contributing to the future development of this type of PC bridges by demonstrating the dynamic reasonableness of its behavior.

4.2 Static Experiments

Measurements were mainly taken by effective-stress-meters placed in the concrete section directly below the pylon where main girder's stress was critical, and tention-meters in the diagonal suspension cables anchorage zones to investigate the safety of member during construction by incremental launching method. And it is mainly shown the tention change of diagonal suspension cables and the stress change of upper slab concrete directly below the pylon in figure-4 and figure-5.

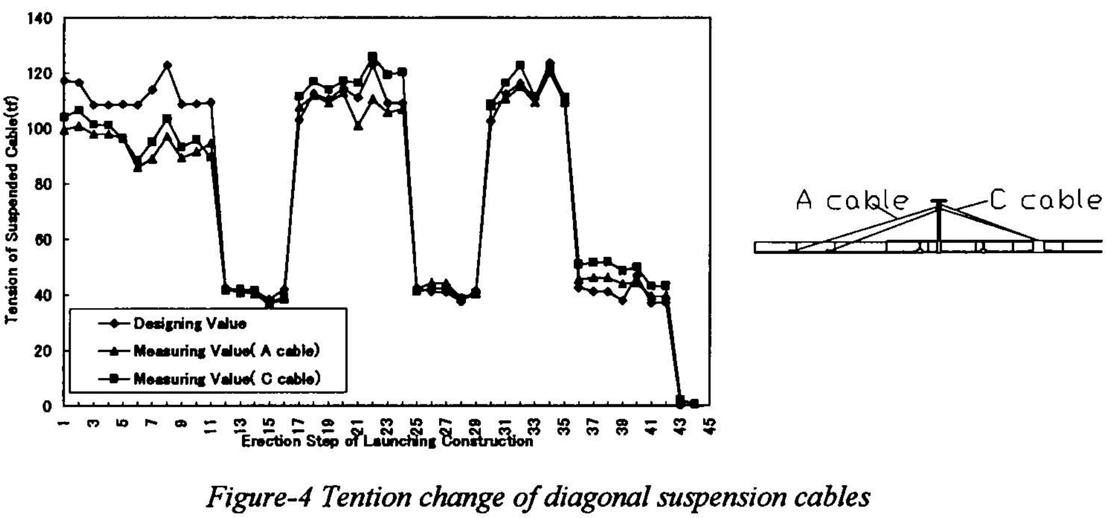


Figure-4 Tention change of diagonal suspension cables

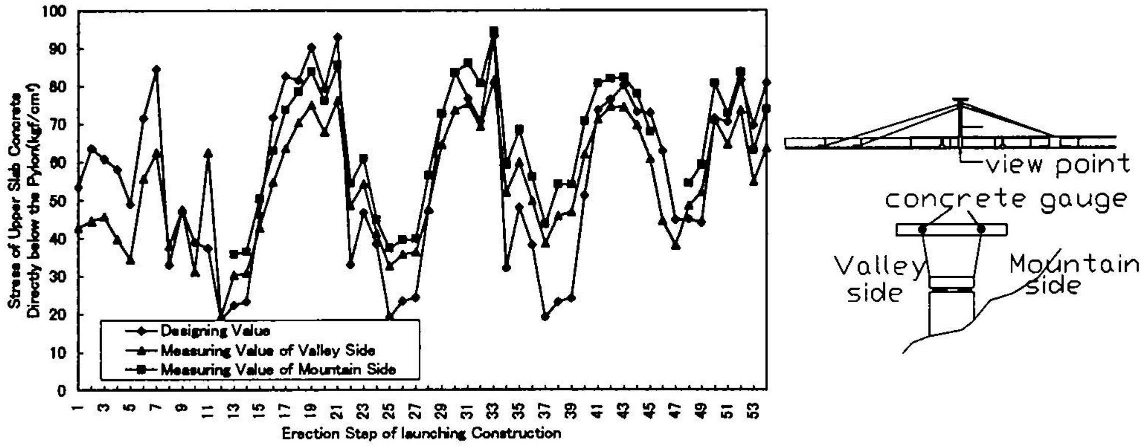


Figure-5 Stress change of upper slab concrete directly below the pylon

Though the values obtained through measurement exhibit a slight dispersion, overall they represent values close to the design values calculated by beam theory. The results in these figure indicates that the actual girder's behavior vis-a-vis diagonal suspended-member tension is consistent with design theory.

4.3 Dynamic experiments

4.3.1 Objective of dynamic experiments

The dynamic behavior of this type bridge has heretofore scarcely been studied. Therefore, we conducted mainly the experiments described below to investigate the subject bridge's dynamic behavior and characteristics.

(1) Investigation of the dynamic behavior and characteristics PC box girder used corrugated steel webs under moving vehicles(Table-1) on the bridge.

(2) Investigation of external cables' vibration characteristics with under moving vehicles on the bridge.

(3) Investigation of external cables' resonance with vehicles traveling on the bridge

4.3.2 Eigenvalue analysis

The dynamic model of the structure used to conduct eigenvalue analysis is a three-dimensional skeleton model that takes into consideration the main girder and external cables(Figure-6). The model is based on the following assumptions:

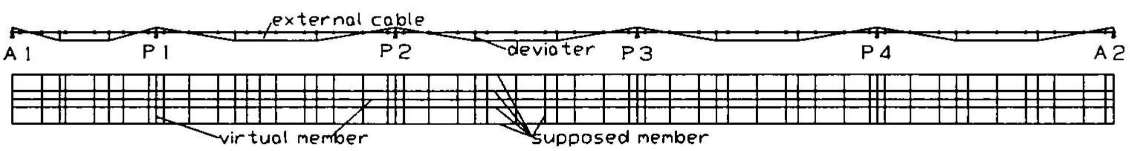


Figure-6 Three-dimensional skeleton model for analysis

(1) The considered model is a mass-point model.

(2) The bending rigidity of main girder is defined as that of the upper and lower concrete floor slabs only.

(3) The shear rigidity of main girder is taken into consideration with shearing deformation related the section area and virtual length of the corrugated steel web.

(4) The torsional rigidity of the main girder defined as that considered geometrical profile of the main box girder.
(5) The external cables are modeled and their tension taken into consideration.

4.3.3 Results of on the dynamic experiment

The vibrational characteristics of the subject bridge are compared with the results of the measurements and eigenvalue analysis in Table-2. The damping coefficient derived by measurement is 0.01-0.02. It is considered the damping coefficient of the subjected bridge (corrugated-steel web PC box bridges) will fall somewhere between the vibrational characteristics of steel bridges and prestressed concrete bridges.

Table-1 Overview of moving-vehicle experiments

	Vehicle weights (tf)	Number of Vehicles	Vehicle speeds (km/h)	Remarks
Case1	10	1	20	Vertical vibration
Case2	"	"	40	"
Case3	20	"	20	"
Case4	"	"	40	"
Case5	10	"	20	Torsional vibration
Case6	"	"	40	"
Case7	20	"	20	"
Case8	"	"	40	"

Table-2 Natural frequencies of the main girder

Type of Analysis	Type1	Type2	Type3
Shearing Deformation	considered	considered	not considered
Torsional Rigidity	oblaten of main gider considered	oblaten of main gider not considered	oblaten of main gider considered

	Natural Frequency(Hz)				Damping Coefficient
	Empirical Value(A)	Type1 (B)	Type2 (C)	Type3 (D)	
1st Vertical Mode	2.861	2.923	2.924	3.168	0.0215
2nd Vertical Mode	3.203	3.303	3.313	3.737	0.0240
3rd Vertical Mode	3.772	3.848	3.863	4.696	0.0146
1st Torsional Mode	5.750	5.925	5.698	5.922	——
2nd Torsional Mode	——	6.220	5.995	6.218	——
3rd Torsional Mode	——	6.706	6.496	6.704	——

As is clear from the comparison of natural frequencies shown in Table-2, for the vertical modes, the influence of shearing deformation is extremely large. As for the torsional modes, there was no significant difference between the torsional rigidity that takes into consideration the geometrical profile of the box and the torsional rigidity that does not. It can be recognized this result to be attributable to the fact that the profile of the subject bridge is not so flatness. The predominant frequency of the external cables exhibits values larger than those of the main girder. From this result, it confirmed the fact that the bridge and external cables do not resonate. The stress variation of the external cable will be not believed likely to result in a fatigue problem.

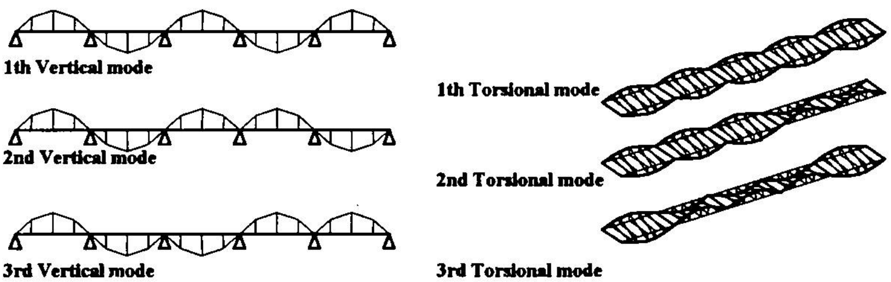


Figure-7 Diagrams of the natural vibration modes of the main girder

5. Conclusion

Through the construction method, the static and dynamic experiments summarized above, we verified that it is confirmed the safety of member during construction and it is possible to conduct eigenvalue analysis using methods for evaluating torsional and shear rigidity verified through static analysis.

In closing, we hope that this report will be useful in furthering the development of corrugated-steel web PC bridges.