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A Study on Rationalization of New Type of Shape of Steel Bridges

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Abstract

A new type shape-steel bridge is proposed, to rationalize fabrication and erection by integrating main girders and composite slabs with steel panels, by elimination of slab-haunch and simplification of connection between slab and girder, by reducing transverse stiffening structures, and by changing simple girder into continuous girder on site. This paper describes the validity of developed design methods through analytical and experimental studies. It is expected that this study contributes to expand the application of steel bridges.

1. Introduction

In recent years, concrete bridges such as pre-tension PC bridges account for most of small size bridges having a span length of about 30 m or less. This indicates that the economical competitiveness of steel bridge structures so far proposed for the size range is poor. Another reason may be that, whereas the forming work of a PC bridge up to the deck panel work covers all the super-structural work except for the deck pavement work, the girder and deck structures of a steel bridge are diversified and separate from each other, and various combinations of these structures are possible, and as a result, rationalization for saving construction costs has been insufficient.

In view of the above, the authors studied measures to drastically decrease the number of structural members to reduce fabrication costs, to simplify the site work to shorten the construction period to an extent that cannot be achieved by concrete bridges. As a result, the authors developed a new type of shape-steel bridge structure wherein composite deck slabs and shape-steel girder structures are integrated (see **Fig. 1**).

The new type shape-steel bridge consists of three kinds of main components: a steel cross beam installed on an intermediate support pier; a prefabricated girder panel integrating two main girders of rolled H-shape steel and a steel panel for a composite deck slab composed of I-beams and a bottom plate; and a connection panel installed at the construction site between two girder panels. While the joints between the intermediate cross beam and the upper flanges of the girder panels and the longitudinal joints between the girder panels and the connection panel are HTB joints, the stress transfer of all the other joints is to be established by concrete casting. As a result of the above combination of main components, the composite deck slab structure is simplified by elimination of slab haunch and studs, and

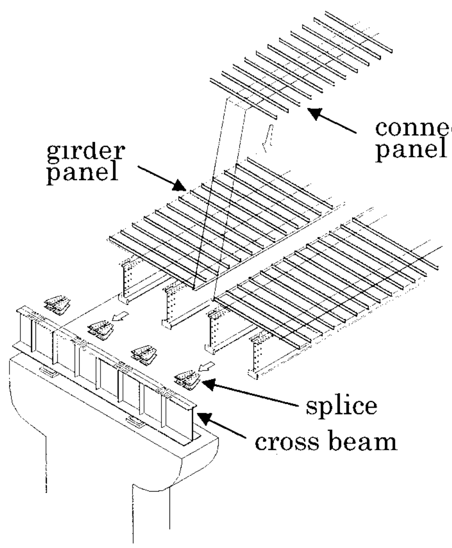

Fig. 1 Concept of new type shape-steel bridge

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the girder structure by elimination of lateral bracings and adoption of a site connection method. Because of the rationalization and simplification, the fabrication and site construction work are also simplified. The authors verified the adequacy of the method of stress transfer adopted for the bridge and that of the entire structure; the results are explained hereafter in detail.

2. Rationalization of Deck Slab Structure

Composite deck slabs are widely used recently because of their long durability and short construction period. Since the main members of a conventional composite slab are arranged evenly in the sectional direction of a bridge, the negative bending moment on the deck slab imposed just above a main girder is handled by forming a haunch to increase slab thickness. In addition, for integrating a deck slab and main girders at the construction site, it is necessary to arrange a great number of studs on the upper faces of the main girders (see **Fig. 2**).

In order to eliminate the haunch and the studs in the new type shape-steel bridge, the main girders of rolled H-shape steel and the steel deck plate are integrated in a fabrication plant by continuous fillet welding; here the I-beams serve also as substitutes for the studs. When the connection panel is set between two girder panels, the I-beams of the connection panel overlap with those of the girder panels in the portions along the main girders duplicating the arrangement density to withstand the negative bending moment on the deck slab (see **Fig. 3**).

The new type shape-steel bridge included technical issues such as the following. The bottom plates are not continuous in the bridge width direction; the density of the main-member I-beams change in the width direction and the joints in the width direction are formed by the overlapping of the I-beams and concrete; and the I-beams are welded to the bottom plate by intermittent fillet welding. To solve such issues, and to establish design procedures, the authors carried out static loading and wheel trucking tests as described below using part models.

In the static loading tests, the stress conditions and loading capacities at various portions under the design loads (the bending moment of a composite deck slab specified in the Guidelines for Performance-Based Design of Steel-Concrete Hybrid Structure) were confirmed using part models for positive and negative bending (see **Figs. 4** and **5**). The outlines of the results are as follows:

- **Figs. 6** and **7** show the load-deflection curves obtained through the positive and negative bending tests, respectively. The static loading capacity of the new type bridge proved to be high enough: 10.6

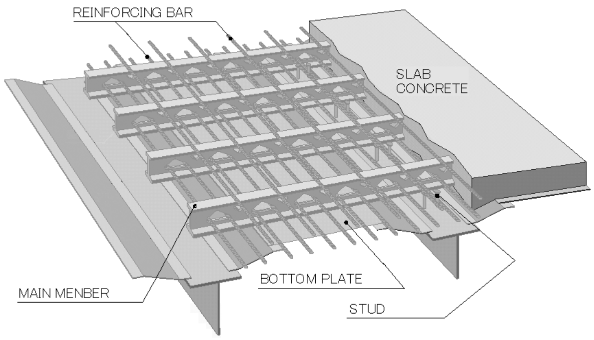

Fig. 2 Conventional composite slab

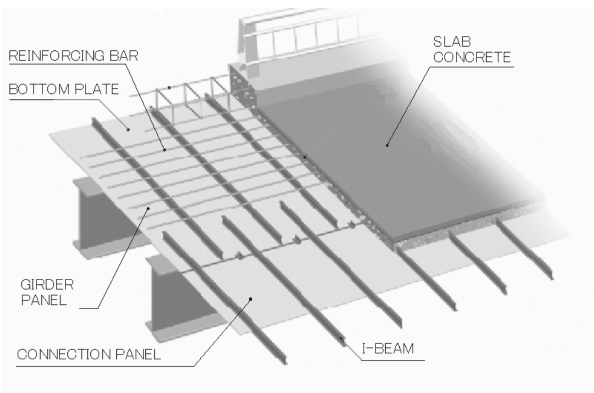

Fig. 3 New type composite slab

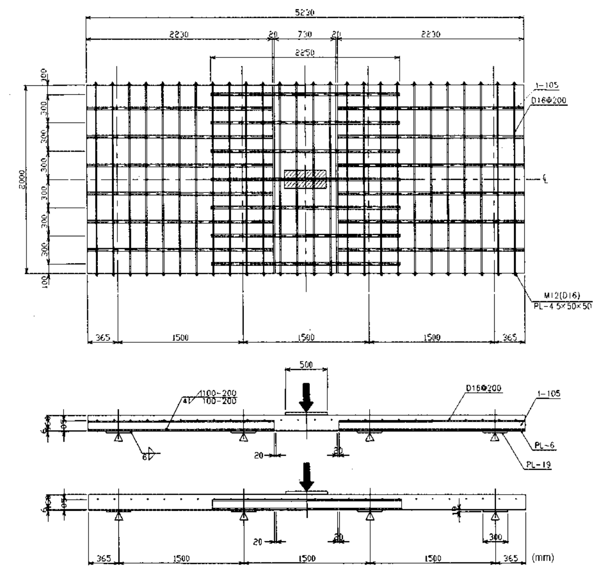

Fig. 4 Specimen of positive bending test

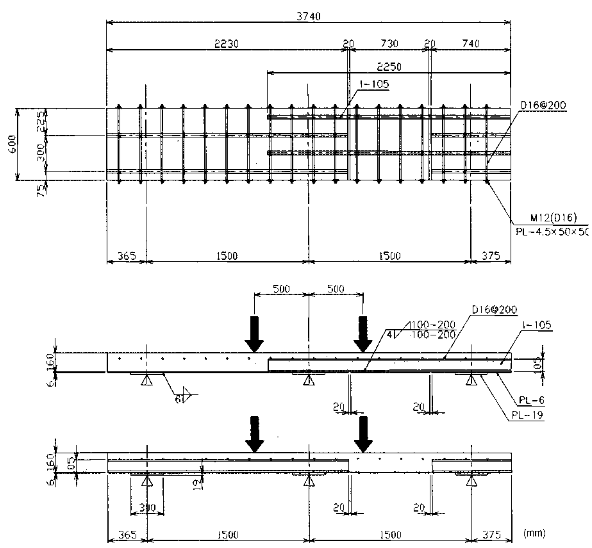

Fig. 5 Specimen of negative bending test

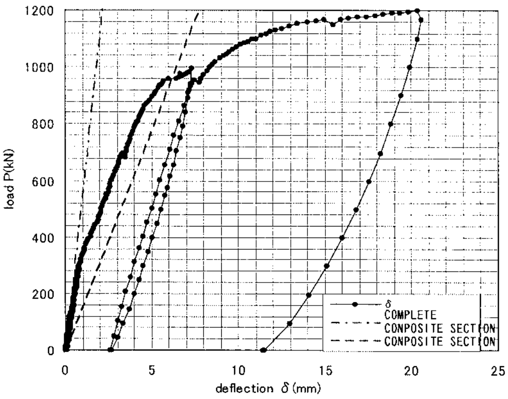

Fig. 6   Load-deflection curve of positive bending test

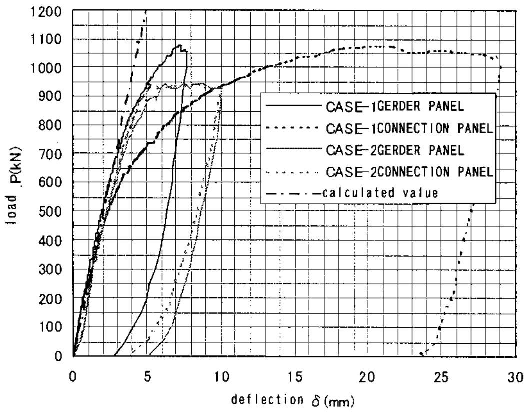

Fig. 7   Load-deflection curve of negative bending test

times the design load at the positive bending test, and 8.8 times at the negative bending test.

- The sectional rigidity at the positive bending test fell between the value of a total effective sectional area and that of a composite section (neglecting the tensile strength of concrete) up to about 8 times the design load.
- The negative bending tests were carried out on two specimens: one in which the overlapping width of the I-beams was 1/2 of the width between deck supports (Case 1), and the other in which the same was 1/4 of the width (Case 2). The loading capacity proved to be sufficiently high in either of the cases; the strain distribution within the section was sufficiently lower than the value estimated by design calculation.
- The bottom plates of the specimens were partially discontinuous, but no adverse effects such as a decrease in the rigidity of the whole structure or local stress concentration were observed.

In addition to the above, the fatigue resistance of the intermittent fillet welding of the I-beams and the joints of the deck slabs was confirmed using the wheel trucking tester of the Public Works Research Institute. **Fig. 8** shows the specimen used for the test. The specimen withstood 520,000 cycles of repetitive loading that was increased stepwise up to 392 kN as specified in the Specifications for Road Bridges, without being brought to an ultimate state.

3. Rationalization of Girder Structure

The new type shape-steel bridge lacks intermediate lateral bracings and employs a site girder connection method as measures to rationalize the girder structure.

First, in relation to the elimination of intermediate lateral bracings: Specifications for Highway Bridges was revised in 2002, newly incorporating performance codes. As a result, it became acceptable for a deck slab to have functions to distribute traffic loads and bear the

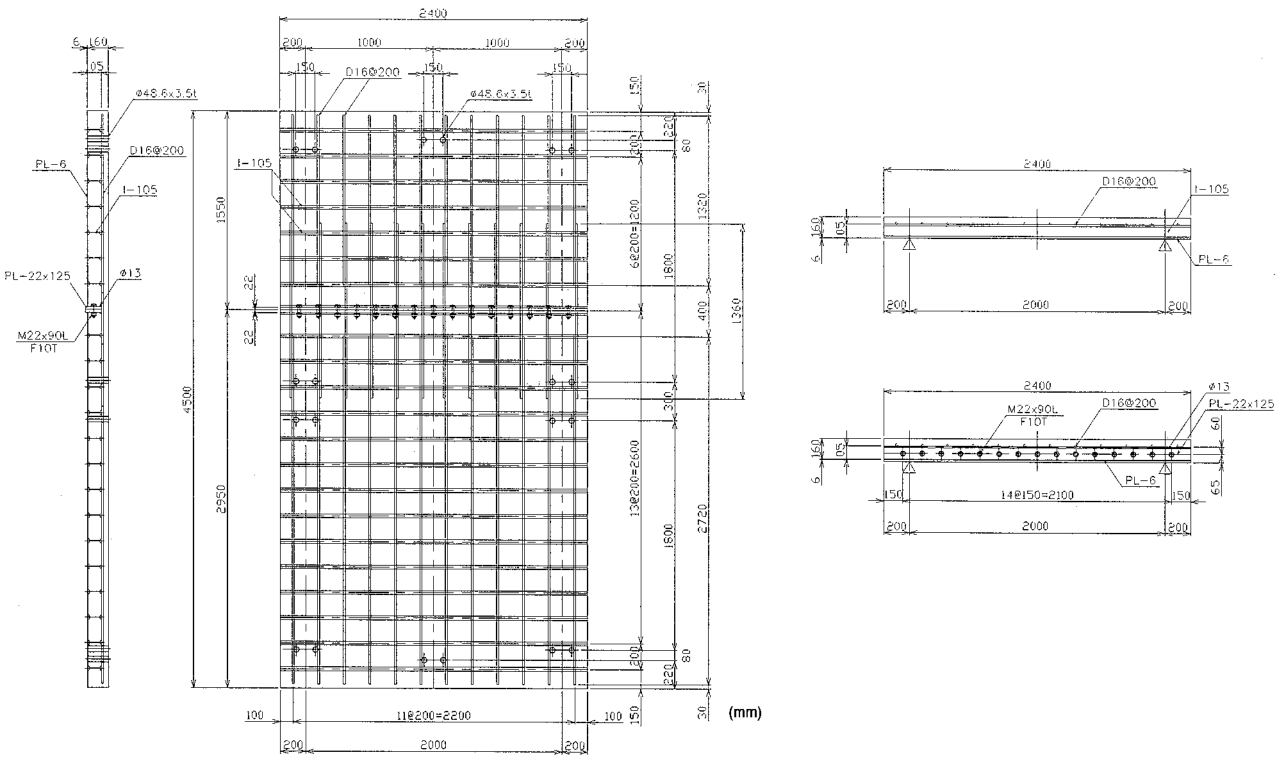

Fig. 8   Specimen of wheel trucking test

resistance to lateral loads on condition that evidence of three-dimensional FEM analysis or the like be provided. In consideration of the above, intermediate lateral members such as lateral beams and bracings are totally omitted in the new type shape-steel bridge to rationalize fabrication work (see **Fig. 9**).

Through three-dimensional FEM analysis, the authors confirmed the behavior of the members of the deck slab acting as lateral beams under live loads and based on the results, studied the method of combining the cross-sectional strength of a deck slab alone with that in consideration of the load distribution function of the deck slab. They also confirmed the behavior of the deck slab members under lateral loads of earthquake, wind, etc., to verify the safety of the structure (**Fig. 10**).

Next, with respect to the site girder connection method: In studying a continuous girder structure using H-section steels as main girders, if a bridge is designed as a fully continuous girder structure, the section at an intermediate support that is composed of distribution reinforcing bars and steel sections and has a low sectional rigidity is determined by the compression stress on the lower girder flanges under a negative bending moment, and as a result, the maximum length of a continuous girder of conventional H-sections is limited to 20 m or so.

In consideration of the above, the authors decided to adopt the site connection method, commonly practiced for concrete girders, to expand the span of the new type bridge. They worked out the intermediate support structure shown in **Fig. 11**. In this structure, the weight of a girder is borne at the time of its installation by the cross beam through the shear key plates provided on the upper flange of the main girder, and only the upper flange is connected to the cross beam by HTB joints. This composes a simple girder structure with respect to the dead weights of the girder and slab concrete before they are formed into a composite structure. Then, concrete is cast around the cross beam, and when it solidifies, compression force is transferred from the girder to the cross beam through the bearing plate provided at the end of the lower flange of the main girder. Thus a continuous girder is formed with respect to the dead weight of the composite structure (deck pavement work) and live loads.

This structure reduces the negative bending moment on an intermediate support, and makes it possible to form a continuous girder about 30 m in length using commercial-size rolled H-sections. A static loading test of this intermediate support structure was carried out using a real-size specimen; **Figs. 12** and **13** show a photograph

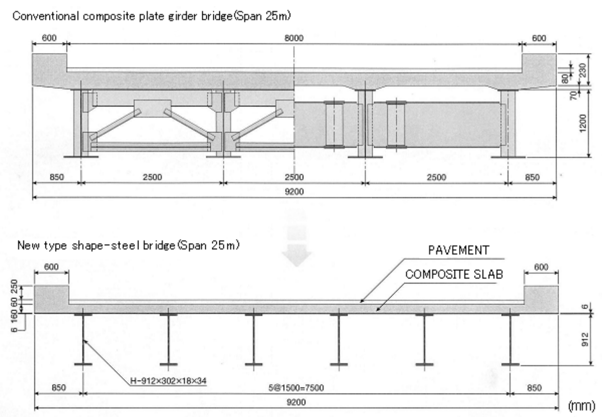

Fig. 9 Cross-section of conventional composite plate girder and new type shape-steel bridge

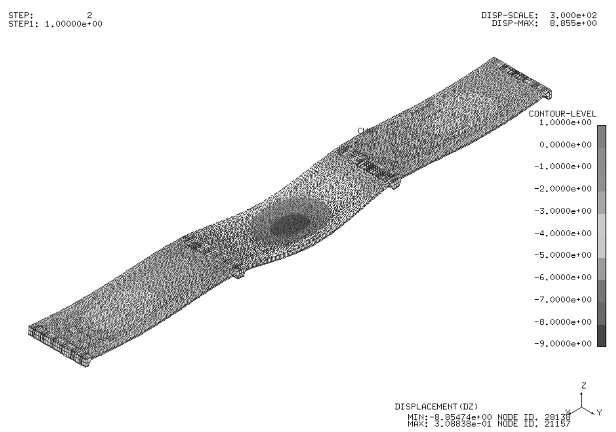

Fig. 10 3D FEM analysis result (deflection)

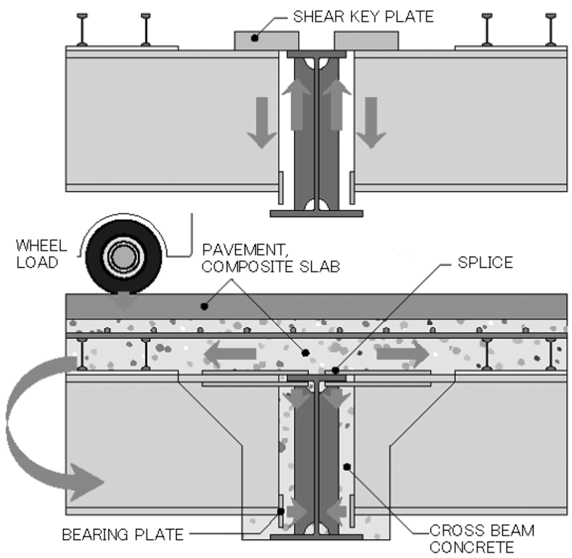

Fig. 11 Concept of intermediate support structure

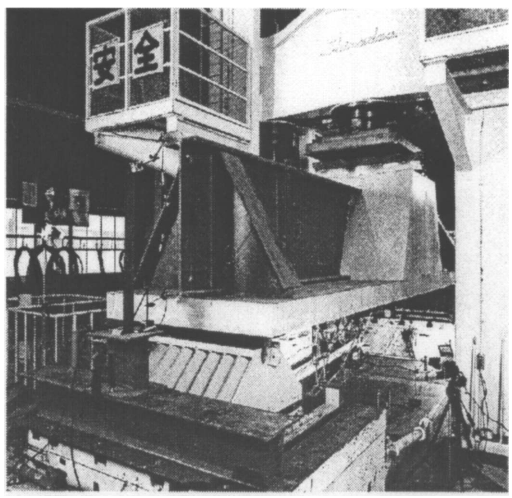

Fig. 12 Loading test of intermediate support structure

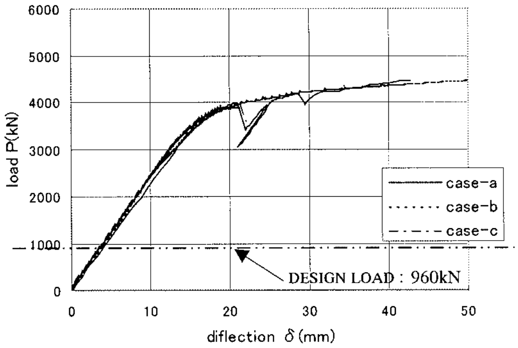

Fig. 13 Load-deflection curve of intermediate support sturucture

of the test and the test results, respectively. The test confirmed that the loading capacity of the specimen was 3.9 times the design load, and the stresses on the steel members and the concrete under the design load were sufficiently on the safety side of the design calculation.

The authors carried out detail three-dimensional FEM analysis, not described herein, to confirm that the test results were fully reproducible, then verified the effects of changes of various parameters such as the shape of the bearing plates through analyses, and incorporated the results into the bridge design.

4. Rationalization of Design, Fabrication and Installation

The structure described above makes it possible to rationalize the design, fabrication and site construction of the new type bridge.

In the design aspect, the number of the sizes of the H-section is limited to eight on an assumption of a bridge length of about 30 m or less, and the sizes of small components are thoroughly standardized. As a result, the costs and time of design calculations and drawing issuance are reduced to less than half those of conventional steel bridges of the same scale.

With respect to fabrication, the standardization of the components shortens material lead time to about 1/3 that of conventional steel bridges, and a decrease in the degree of processing of the components significantly reduces fabrication time. In addition, painting processes are simplified by the use of a thick layer of modified epoxy resin paint as the intermediate coating.

Fig. 14 compares the site installation work processes of the new type shape-steel bridge with those of a conventional steel-plate-girder bridge. The new type bridge involves less installation work steps, does not require the setting and dismantling work of hanging scaffolding and the forms for concrete casting for deck slabs, and as a result, the total site work time is markedly shortened.

Thanks to these rationalization measures, it is possible to construct a 3-span continuous girder bridge having a span of 25 m in a total period nearly 1/3 that of a conventional steel-plate-girder bridge, as seen in **Fig. 15**.

By the site connection method of the panels of the new type steel-shape bridge, when the concrete around an intermediate cross beam is cast at the same time or after the concrete of the girder panels on both sides, there will be no tensile stress on the concrete cast later, and therefore, no special attention is required for the quality control in the concrete casting work at the site (see **Fig. 16**).

Furthermore, because the new type bridge does not require any work beneath the girder panels for lateral bracings, the scaffolding

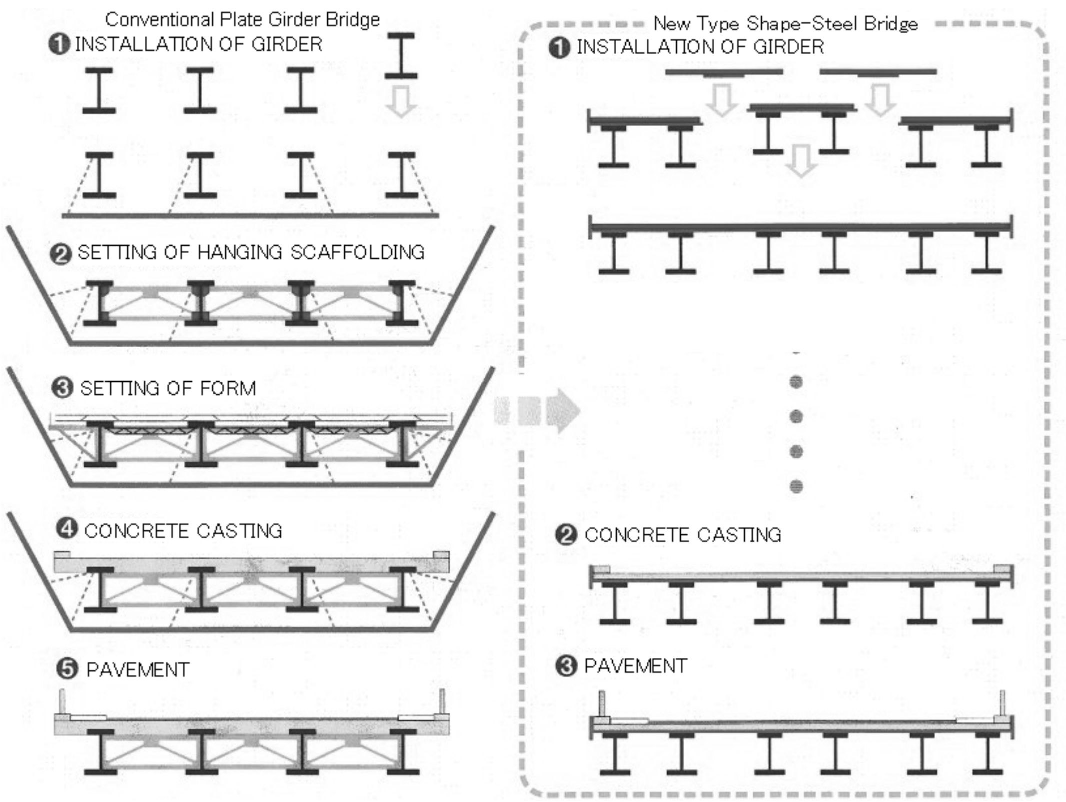

Fig. 14 Comparison of installation process

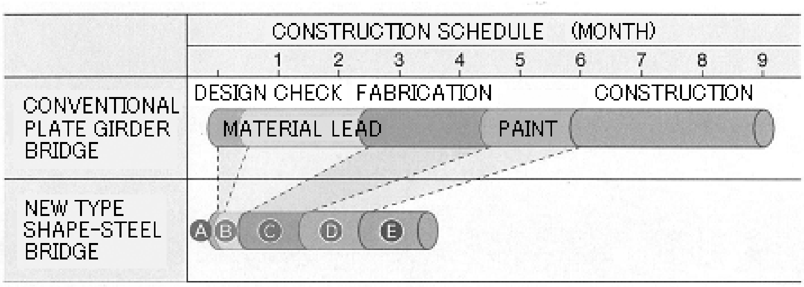

Fig. 15 Comparison of construction schedule

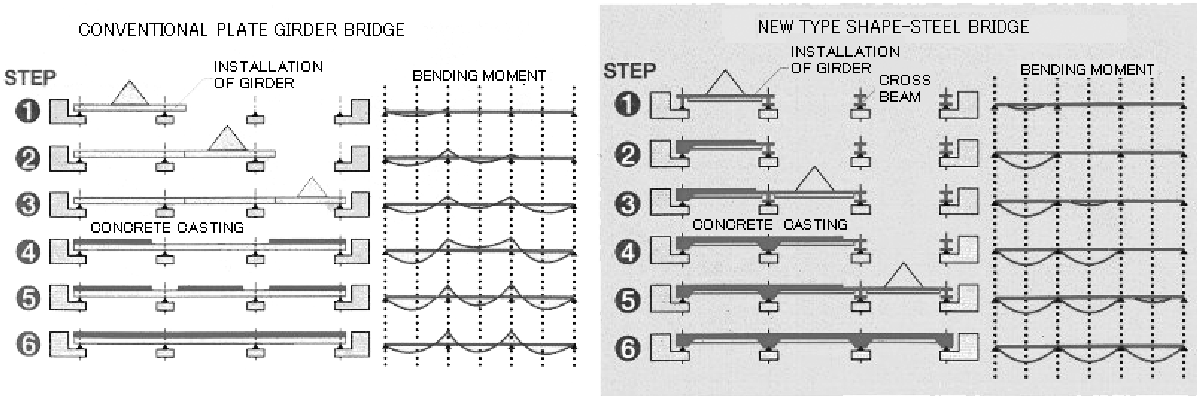

Fig. 16 Sequence of concrete depositing

and the forms, restrictions on traffic under the bridge, if any, can be minimized.

5. Closing

Technical questions related to the new type steel-shape bridge were examined through tests and analyses, and safety-side results were obtained regarding all the new design features. Cost estimation showed that the construction costs of the new type bridge would be equal to or lower than those of a pre-tension or post-tension PC bridge of the same size. For enhancing the market competitiveness of the new type bridge, the authors intend further to improve the bridge design so that it is applicable to a variety of conditions (slanted or curved bridges), standardize structural details and solve problems that may arise in site construction work.