UDC 624 . 2

Study on Connection of Crossbeams in Rationalized Plate-Girder Bridges

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Abstract

In Japan, many rationalized plate girders are constructed for the new Toumei/Meishin Expressway Project and for others. They reduce the number of main girders, using pre-stressed-concrete-slabs. The bending moment of the slabs, accordingly, is increased. Additionally, their reductions of diagonals and laterals cause stress concentration on the connection of cross-beams. Nippon Steel pursued analytic studies and experiments on real bridges, in several projects contracted with Japan Highway Public Corp et al.

1. Introduction

In rationalized plate-girder bridges (see **Fig. 1**), the span of floor slab support is made longer than conventional bridges (see **Fig. 2**) thanks to the application of pre-stressed concrete floor slabs and other technologies, which leads to a larger bending moment in the direction of the floor span. Further, since lateral and diagonal bracings are omitted, a floor slab works as a main load distribution member not only for normal traffic loads but also for lateral loads caused by winds and earthquakes.

For this reason, the joint of a girder with a floor slab is important; Japan Highway Public Corp., in its design guideline, instructs constructors to verify the tensile force on the joint in the design of shear-connectors, even in the case of a non-composite girder[1)]. However, although various study reports have been presented from various research/design institutes, no unified philosophy has been formed regarding the design of the joint yet.

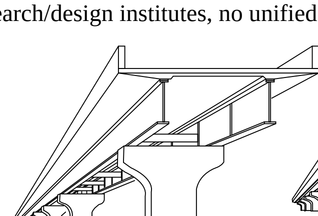

Fig. 1 Rationalized plate-girder bridge

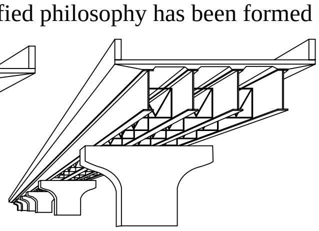

Fig. 2 Conventional bridge

Since 1999 Nippon Steel Corporation has been awarded construction orders of rationalized plate-girder bridges, from Takahari Viaduct of Higashi-Meihan Expressway to Sakae Viaduct, which is now in the fabrication stage. During the period, the company has focused attention on the issue of the joint design, and through analyses, measurements on real bridges and so forth, carried out a series of studies regarding the design of the connection of a crossbeam with a main girder in the rationalized plate-girder bridges. This paper reports the results of the studies.

2. Past Studies

Among various study reports, Ohgaki et al. presented a paper on analyses and tests[2,3)], paying attention to the studs and vertical stiffeners at the connection of the crossbeam, and there is a report of a loading test carried out on Hibakaridaira Bridge[4)]. The results of these reports are essentially as follows.

· When studs are arranged immediately above a vertical stiffener to which an intermediate crossbeam (a crossbeam between piers) is connected, a large axial force is imposed on the studs and stress concentration occurs at the upper end of the vertical stiffener, and as a result, fatigue problems may occur.
· When studs are not arranged immediately above such a vertical stiffener, the axial force on the studs is relaxed, but on the other hand, a large bending stress is imposed on the upper flange of the

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main girder and what is more, separation of the floor slab from the main girder or cracks between them may take place when the floor slab cannot follow deformation of the upper flange.

Observations obtained through other studies are basically the same, despite the fact that numerical data are different to some extent depending on conditions, such as the floor slab construction method (pre-cast or cast-in-place) and its structure (composite or non-composite).

3. Nippon Steel's Activities

In the above situation, Nippon Steel took measures and conducted analyses and loading tests on real bridges as described hereinafter.

3.1 Takabari viaduct

Takabari Viaduct is a continuous non-composite two plate-girder bridge having pre-cast PC floor slabs, located in an eastern suburb of Nagoya forming a part of Higashi-Meihan Expressway (between Osaka and Nagoya), and its order was placed by Higashi-Nagoya Construction Office of Japan Highway Public Corp. In this bridge, studs were arranged immediately above a vertical stiffener to which an intermediate crossbeam was connected and, in addition, for the purpose of relaxing the stress on the vertical stiffener, stiffening ribs called triangle ribs (see **Fig. 3**) were fitted to the upper flange and web of main girders. The design of the portion is explained below.

- An analysis was made on a frame (rahmen) model consisting of main girders, a floor slab and crossbeams on two cases: Case-1 in which live loads were imposed on the extended portions of a floor slab and Case-2 in which live loads were imposed on the center of the floor slab support span (see **Fig. 4**).
- The arrangement and number of the studs were determined based on the stress resultant (M: bending moment, S: shearing force, N: axial force) at the upper end of the main girder web obtained from the above analysis. The bending and shearing composite stress on the studs was verified referring to the study of Hiraki et al.[5)]
- An X-shape section comprising a triangle rib, a main girder web and a vertical stiffener was examined as a member subjected to an axial force and a bending force. Also examined was the bearing stress of the floor slab to which the X-shape section was to be subjected.

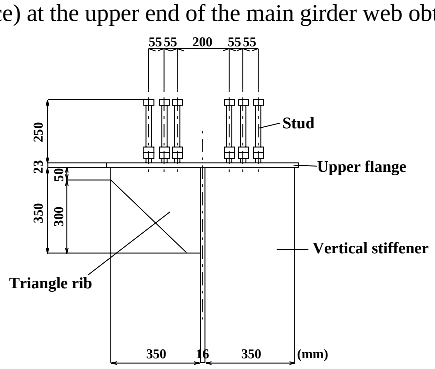

Fig. 3 Connection of intermediate crossbeam

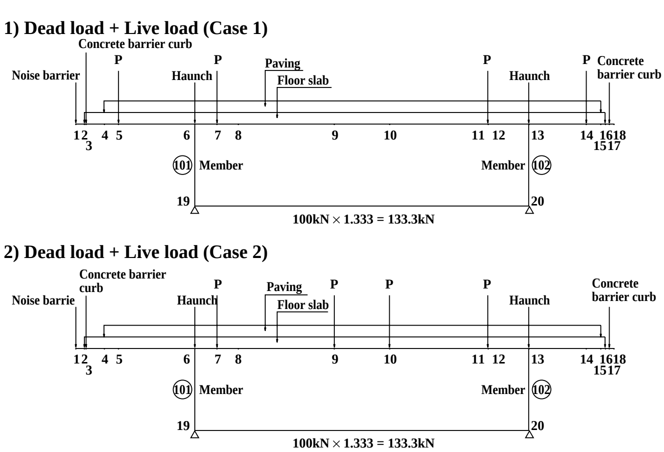

Fig. 4 Frame (rahmen) model

The construction work of the Viaduct was completed in June 2002. No cracks have been found near the upper end of the vertical stiffeners at the connections of crossbeams, and the structure is performing well.

3.2 Nobuno viaduct

Nobuno viaduct is a continuous non-composite two plate-girder bridge having cast-in-place PC floor slabs, located in the western part of Shimane Prefecture forming a part of Cross-Chugoku Expressway, and its order was placed by Matsue Construction Office of Japan Highway Public Corp. In this bridge, the triangle ribs introduced in Takahari Viaduct were arranged also on both the sides of the vertical stiffeners for the purpose of relaxing the bending stress on the main girder upper flange (see **Fig. 5**). Usefulness of these triangle ribs was confirmed through an analysis by the three-dimensional finite element method (FEM), and the result of the analysis was verified through measurements on the real bridge.

3.2.1 Analysis by three-dimensional FEM

The model for the three-dimensional FEM analysis was defined as shown in **Figs. 6 and 7** to cover the entire bridge. The floor slab, main girder webs, their flanges, crossbeam above a pier, vertical stiffeners and triangle ribs were regarded as shell elements in the model, and all the other members as beam elements. Two cases, with and without the triangle ribs, were analyzed so as to evaluate their effects, and these two cases were combined with a case with a dead load and another with a live load.

Figs. 8 to 11 show the results of the analysis. The figures show the force in the axial direction of the studs, from the position of an intermediate crossbeam (shown as 0 m) to the center of the distance to an adjacent crossbeam. The analysis made it clear that the tri-

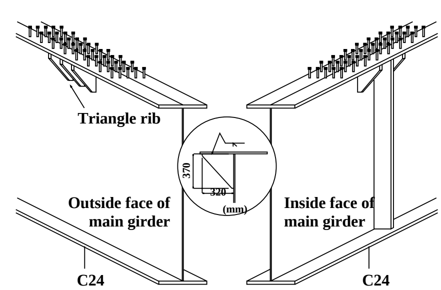

Fig. 5 Detail of upper end of vertical stiffener at crossbeam connection

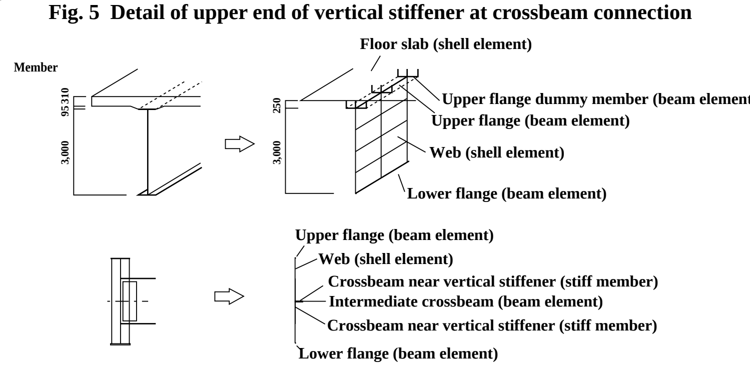

Fig. 6 Analysis model (1)

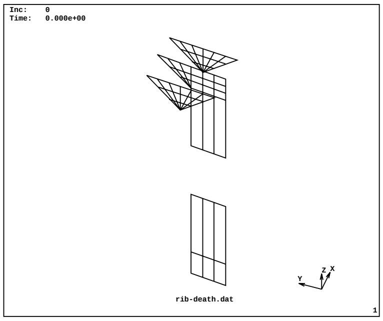

Fig. 7 Analysis model (2)

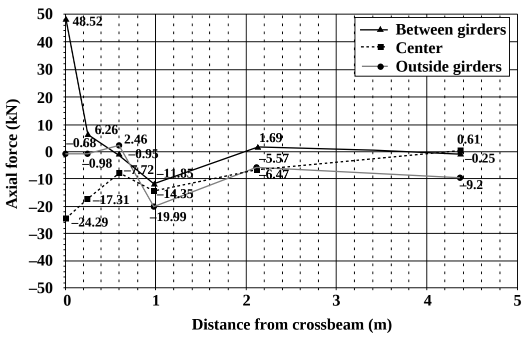

Fig. 8 Axial force on studs (without triangle ribs, under dead load)

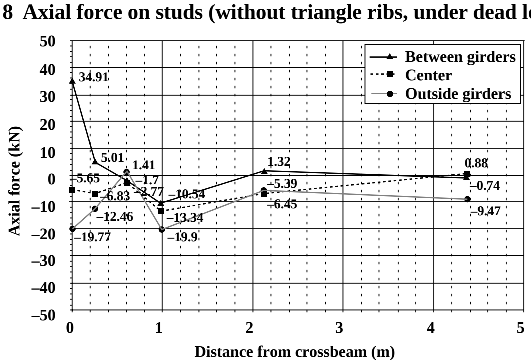

Fig. 9 Axial force on studs (with triangle ribs, under dead load)

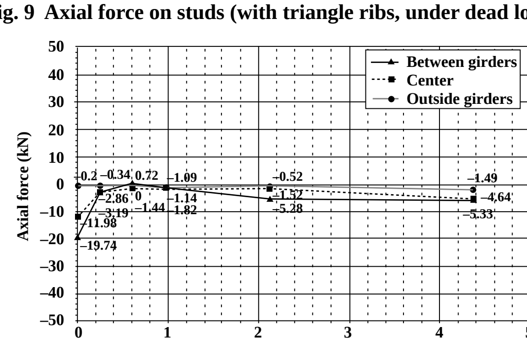

Fig. 10 Axial force on studs (without triangle ribs, under live load)

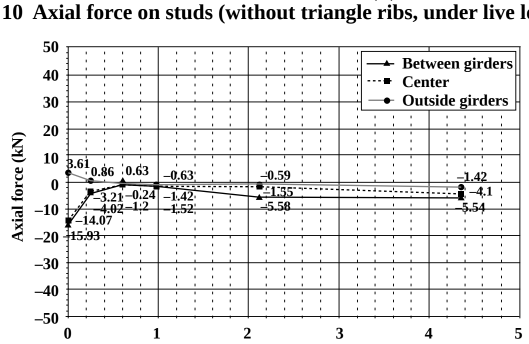

Fig. 11 Axial force on studs (with triangle ribs, under live load)

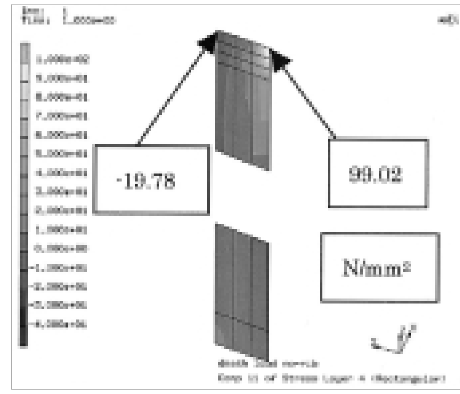

Fig. 12 Stress on vertical stiffener (without triangle ribs, under dead load)

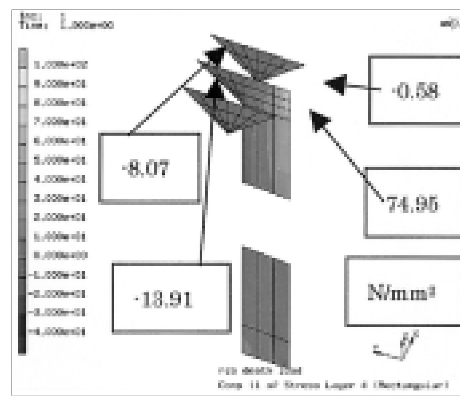

Fig. 13 Stress on vertical stiffener (with triangle ribs, under dead load)

angle ribs reduced the force in the axial direction of studs and the fluctuation of the axial force by 30% or so. **Figs. 12 and 13** show the stress condition at the upper end of a vertical stiffener under a dead load. It is clear in the figures that stress concentration was relaxed by about 20%.

3.2.2 Measurements on real bridge

For verifying the validity of the above analysis, measurements were carried out on Nobuno Viaduct using a roughter crane corresponding to the live load B specified in the roadway bridge specification. The measurements were done automatically in every 30 min. using a personal computer for a four-month period from before the concrete casting of the floor slabs to the casting of concrete barrier curbs and loading tests (from late June to early November), focusing on the axial force on the studs, the stress concentration at the upper end of vertical stiffeners, the bending stress on the upper flanges and so on.

As a typical example of the measurements, **Fig. 14** shows the axial force on the studs under a wheel load imposed from above a crossbeam connection. Compared with Fig. 11, which shows the analysis result under the same loading condition, the tensile axial force on the studs actually measured was about one half that of the analysis. This is presumably because, while the analysis assumed that studs alone were responsible for the load transmission from a floor slab, in the actual load transmission bearing stress, adhesion of concrete and other factors were involved. For the same reason, the measured stress at the upper end of a vertical stiffener was roughly 1/3 that of the analysis.

As a result, it was confirmed that the measures taken in the design of Nobuno Viaduct were sufficient against tensile force caused

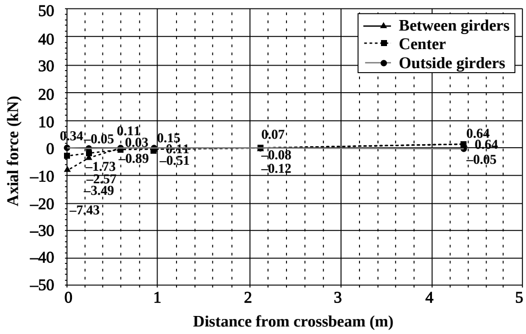

Fig. 14 Axial force on studs (actual measurement under live load)

by live loads. Watching the aging with the passage of time in the period of 2 months or so after the concrete casting of the floor slabs (see **Figs. 15 and 16**), however, it became clear that temperature changes caused an axial force and a bending force on the studs immediately above an intermediate crossbeam connection and they formed a tensile force amounting to an allowable stress, and that the stress amplitude was very large. Therefore, in view of a service life

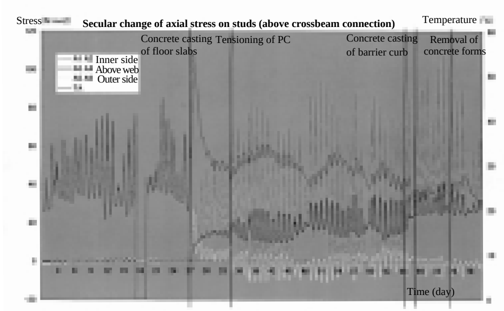

Fig. 15 Secular change of axial stress on studs (above crossbeam connection)

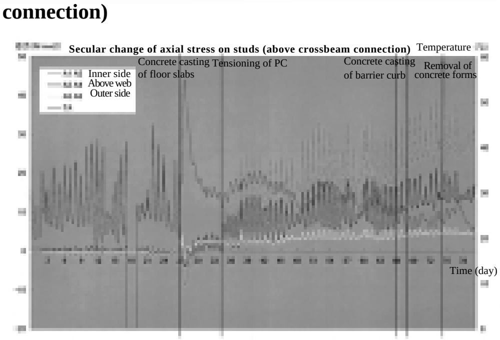

Fig. 16 Secular change of bending stress on studs (above crossbeam connection)

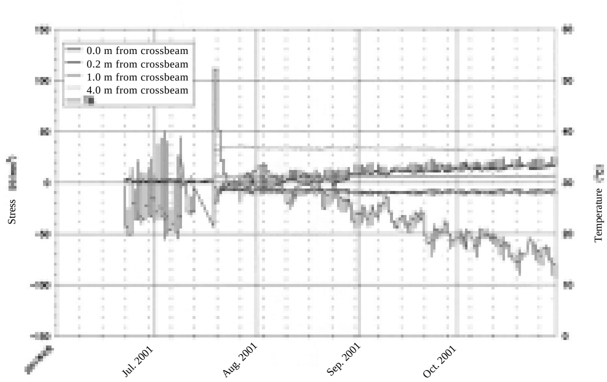

Fig. 17 Bending stress on flange

of 100 years, it is necessary to study the issue of the tensile stress on studs in consideration not only of live loads but also of temperature changes.

Fig. 17 shows the bending stress on the upper flange of a main girder. The measured stress in the portion around an intermediate crossbeam connection was roughly 10 N/mm^2 and the stress amplitude was also about 10 N/mm^2, showing that the measures taken in the design of the viaduct were sufficient. However, considering the fact that a bending stress of roughly 35 N/mm^2 occurred on a flange at the center between two crossbeams during the concrete casting of a floor slab, attention must be paid in the case that composite girders are used.

3.3 Matsudate viaduct

Matsudate Viaduct is a continuous non-composite two plate-girder bridge having pre-cast PC floor slabs, and its order was placed by Aomori Construction Office of the Ministry of Land, Infrastructure and Transport. There is a study report on the relationship between a vertical stiffener to which a crossbeam is connected and cracks of concrete at haunch portions of a rationalized plate-girder bridge having cast-in-place PC floor slabs[6]. The conclusion of the study is that, for suppressing the force to cause concrete cracking, it is desirable to increase the width of the vertical stiffeners to somewhere close to the flange width. In view of this, the authors carried out a study using the analysis by the two-dimensional FEM, for the purpose of confirming if the same thing occurred in the case of a precast floor slab having adjustment mortar and a different shape of the haunch and determining an optimum width of vertical stiffeners.

The result of the analysis is as follows. **Fig. 18** shows the stress distribution when the width of vertical stiffeners is small and **Fig. 19** the same when the width is increased to the flange width. Whereas laminar tensile stress distribution is seen in the joint of the upper flange with the floor slab in Fig. 18, it is confirmed in Fig. 19 that the occurrence of the tensile stress can be suppressed. The tensile stress in the above is considered to cause the upper flange to separate from the adjustment mortar, leading to a problem of corrosion in a long

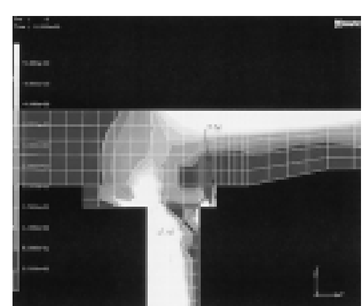
Fig. 18 Stress on vertical stiffener (narrow width)

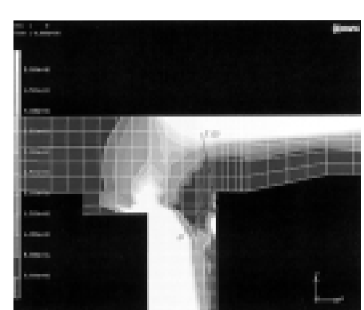
Fig. 19 Stress on vertical stiffener (increased width)

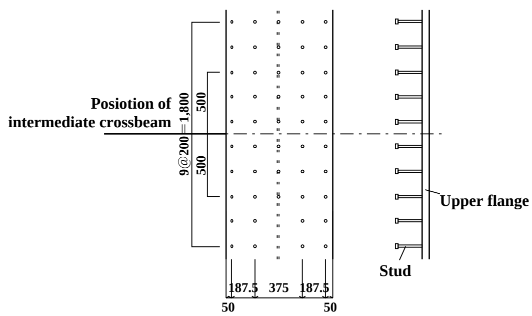

Fig. 20 Stud arrangement

term.

It was confirmed, based on the above, that for inhibiting the separation of the upper flange from the adjustment mortar, it was effective, in the case of pre-cast PC floor slabs, to increase the width of the vertical stiffeners at the crossbeam connections to somewhere near the width of the flange, although the cracking force was not as large as in the case of cast-in-place floor slabs.

3.4 Sakae viaduct

Sakae viaduct is a continuous two plate-girder bridge of integrated super- and sub-structures having cast-in-place PC floor slabs, forming a part of Outer Circular Expressway around Tokyo, and its order was placed by Saitama Construction Office of Japan Highway Public Corp. The design of the crossbeam connections of the viaduct, which is presently in the design stage, is explained hereafter as an example of the latest design trend of this kind of connections of a rationalized plate-girder bridge.

In view of past experiences and study results in other bridge projects, for reducing the axial force on the studs and preventing floor slabs from separating from the flanges, the following philosophy was adopted in the stud arrangement of the viaduct (see **Fig. 20**).

· No studs are arranged just above an intermediate crossbeam connection.
· The outermost row of studs is 50 mm from an edge of the flange, and the center row is as close to above the web as possible. The center row studs are arranged exactly above the web particularly in the range within 500 mm from a crossbeam connection[7].

In a design wherein studs are arranged not on the centerline of a vertical stiffener but on both the sides of it, local bending force is imposed on the flange owing to the restriction between the floor slab, studs and vertical stiffener. According to an analysis by FEM regarding another bridge project, under a certain loading condition, a stress amounting to roughly 410 N/mm^2 is formed in the area above a vertical stiffener. In Sakae Viaduct, however, no reinforcement is provided on the bases that an analysis by FEM tends to yield larger stress figures than is likely to actually occur, that non-composite girders are used in the viaduct, and that the design presupposes the most unfavorable situation little likely to actually take place in terms of loading conditions.

4. Conclusion

Analytical and experimental studies related to the design of crossbeam connections of several rationalized plate-girder bridges were outlined in this paper. At present, since the specification regarding the tensile fatigue endurance of studs is not clearly set forth, it is considered desirable that the studs be arranged avoiding the position just above a crossbeam connection. With regard to the bending deformation of the upper flange of a main girder, which leads to the separation of a floor slab from the main girder, it is considered necessary to give a certain extent of stiffness to the flange or provide reinforcement at adequate portions, especially in the case of a composite girder. Any contribution to increasing the durability of rationalized plate-girder bridges would be a source of great pride for Nippon Steel.

References

1) Japan Highway Public Corp.: Bridge Construction Section, Design Guideline, Book 2. Jul. 1998
2) Ohgaki, K., Kawaguchi, Y., Yabe, J., Nagai, M.: Design Method for Shear-Connectors of Continuous Composite Two Plate-Girder Bridges. Steel Construction Engineering. 4(15), Sep. 1997
3) Yabe, J., Yamamoto, A., Ohgaki, K., Saito, H.: Simple Analysis Method for the Stresses of Shear-Connector of Continuous Composite Two Plate-Girder Bridges. Kawasaki Heavy Industries Technical Report. (139), (1998)
4) Highway Technology Center: New Tomei Expressway - Investigation and Study of Latest Steel Bridge Technologies, A Follow-up Study of Draft Design and Construction Guideline of Rationalized Plate-Girder Bridges. Mar. 2000
5) Matsui, S., Hiraki, H., Miyoshi, E.: Latest Approval of Headed Studs in West Germany and Calculation Examples. Brides and Foundations. (Sep. 1986)
6) Highway Technology Center: New Tomei Expressway - Investigation and Study Report on Design and Construction of Rationalized Plate-Girder Steel Bridges (Part 3). Mar. 1997
7) Highway Technology Center: Design and Construction Manual of Two Continuous Steel Composite Plate-Girder Bridges Having PC Floor Slabs. Mar. 2002