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# Joints in Hybrid Bridge of Steel Girder and Concrete Pier

## Liaison entre poutre métallique et pile en béton armé dans un pont hybride

## Anschlüsse in aus Stahlträgern und Betonstützen bestehenden Verbundbrücken

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**SUMMARY**

Studies were carried out on joints in hybrid bridge in which steel girders are rigidly connected to reinforced concrete piers with prestressing bars. The fundamental behavior of such joints including stress transfer mechanisms and load carrying capacity was clarified through experiments and analysis. In this paper, the results of the studies are presented with the general features of a highway bridge which was designed based on the results and is now under construction.

**RÉSUMÉ**

On a réalisé des études sur les liaisons dans un pont hybride, dont la poutre est connectée rigidement à la pile en béton armé par des barres précontraintes. On a mis en évidence, par l'expérience et l'analyse, le comportement fondamental de cette liaison qui implique le mécanisme de transmission de contraintes et de force portante. Dans ce rapport, les résultats d'étude sont présentés avec les caractéristiques générales d'un pont d'autoroute au Japon. Ce pont a été calculé sur la base de ces résultats et est en cours de construction.

**ZUSAMMENFASSUNG**

Untersuchungen über die Anschlüsse einer Verbundbrücke, in der Stahlträger mittels Spanngliedern fest mit dem Stahlbetonpfeiler verbunden sind, wurden durchgeführt. Das Verhalten des Anschlusses bezüglich des Mechanismus der Kraftübertragung als auch der Traglast wurden durch Versuche und Analysen geklärt. In diesem Beitrag sind die Ergebnisse der Untersuchungen zusammen mit der generellen Darstellung einer Autobahn-Brücke, die auf Grund dieser Untersuchungsergebnisse entworfen wurde und zur Zeit im Bau ist, dargestellt.

## 1. INTRODUCTION

Rigid frame type bridge, in which steel girders are rigidly connected to reinforced concrete piers, has many merits as compared with the ordinary steel girder, shoe and pier system, because damages originated from local damages in shoes and expansion joints in super structure can be eliminated and smooth riding qualities can be achieved by reducing the number of expansion joints. Though such merits do exist, very few studies have been carried out on design methods for rigid joint in such hybrid bridges. Accordingly, studies on rigid joint in hybrid bridge in which steel girder is connected to reinforced concrete pier with prestressing bars were carried out experimentally and analytically to make clear fundamental behavior of such joint.

This paper describes the results of the experiments and analysis, and discusses stress distribution in such joint, stress transfer mechanism between steel girder and concrete pier, load carrying capacity of such structure and so on, based on the results. Also, the Sasaya Bridge, which was designed based on the results, and is under construction, is introduced as an example of hybrid bridges which have joints of this kind.

## 2. OUTLINE OF THE EXPERIMENT AND ANALYSIS

### 2.1 Specimens

Four specimens were prepared. They are classified into A, B, C and D type according to details of the joints and the dimension of the cross sections. All of them were such ones that a pair of steel plate girders was connected to a reinforced concrete column with four prestressing bars at the center of the girders and the bottom of the column, as shown in Fig.1. At the center of the girders, there is a space surrounded by the webs of the girders, the diaghrams and the bottom plate. This space was filled with concrete, and the prestressing bars were anchored through the filled concrete. Difference among the four specimens is also shown in Fig.1 Stud shear connectors in the A and B type specimens were welded to the diaghrams.In the B type specimen, the outer fibers of the concrete column were cut off at the contact face to the steel girders.

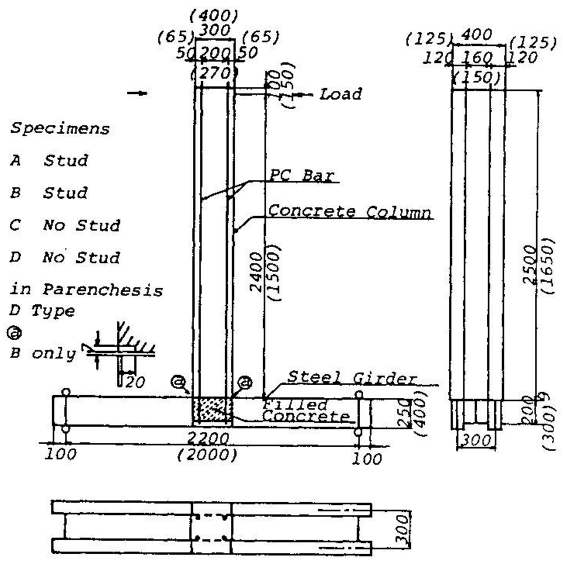


Fig.1 Specimens

### 2.2 Loading program

In the experiments, both ends of the steel girders were fastened to a loading bed through rollers. Horizontal loads were applied at the top free end of the concrete column with an actuator. The applied loads were $10^6$ cycles of reversed load of maximum intensity that did not cause any opening at the contact face between the concrete column and the steel girders (14 kN for the A, B and C type specimens and 30 kN for the D type specimen. Hereinafter the load just causes opening will be referred as the no-opening load), $10^4$cycles of reversed load that caused opening ( 38 kN and 70 kN respectively) and monotonously increased load upto the collapse of the joint.

### 2.3 Analysis

The stresses and the deflections at each part of the specimens were analyzed based on the elementary beam theory and two dimensional FEM, and compared with the experimental results. In the analysis, it was assumed that entire section of the concrete column is effective and contribution of the prestressing bars can be neglected. At the joint, section of the filled concrete was transformed to the steel's one using the Young's modulus ratio and the effect of the stud shear connectors was neglected. In the FEM analysis, the prestressing force was considered to be an external load.

## 3. RESULTS AND DISCUSSION

### 3.1 Distribution of vertical stress in the joint under the no-opening load and stress transfer mechanism

Distribution of vertical stress in the joint was as shown in Fig.2 and 3. As shown in these figures, compressive stress takes the maximum value at the point where the compression fiber of the concrete column contacts to the flanges of the steel girders, decreasing in downward direction and being almost uniform in transverse direction. This fact shows the compressive force carried by the concrete column is transferred to the joint directly across the contact face and distributed in the longitudinal direction. As the result, the webs of the steel girders carries a part of the compressive force even the portion out of the joint.

Tensile stress, also as shown in the figures, distributes in longitudinal direction symmetrically to compressive stress, but in transverse direction, it decreases towards the outer portion. This is probably due to the fact that the tensile force carried by the concrete column is transferred at first to the bottom of the filled concrete through the prestressing bars and then transferred to the webs and diaghrams.

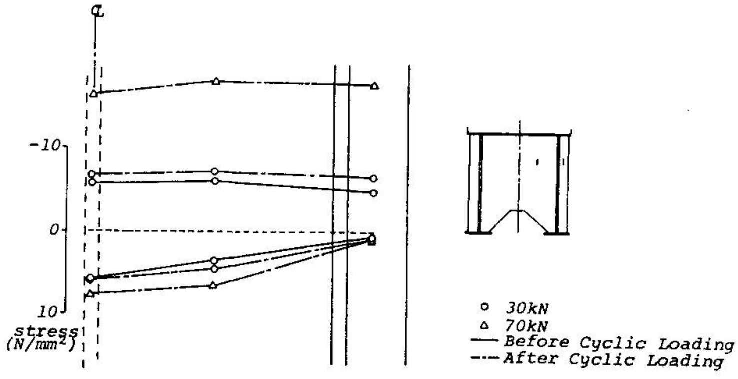


Fig.2 Vertical stress in transverse direction

The stress shown in Fig.3 was nearly equal to the one calculated assuming bending moment transferred from the concrete column is carried by the section which consists of the filled concrete, webs and diaghrams. This fact shows that vertical stress near contact face in joint can be roughly predicted based on the same assumption.

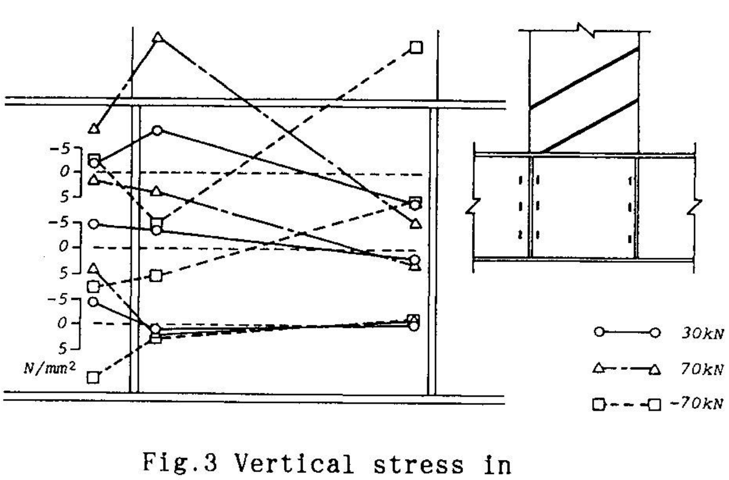


Fig.3 Vertical stress in longitudinal direction

The vertical stress distribution in the type A specimen was almost exactly equal to the one in the type C specimen.

This results suggests that the stud shear connectors did not play any significant role in stress transfer. However, it does not mean stud shear connectors are not needed in actual structures, because the experimental result was more or less owing to relatively high rigidity of the joint as compared with the one in actual joint.

### 3.2 Distribution of flexural stress under the no-opening load

Flexural stress was distributed along the upper and lower flanges of the steel girders, as shown in Fig.4. It can be recognized from this figure that the measured stresses agree well with the values obtained from the elementary beam theory as well as FEM analysis except the point adjacent to the joint, where the values obtained from FEM are higher a little than the others. This result shows that the elementary beam theory is very useful to predict flexural stress along flange of steel girder. A little high stress obtained from FEM shows some stress concentration could occur at outermost corners of joint, but in actual situation, it is considered to be reduced owing to creep of concrete.

Flexural stress within the joint was as shown in Fig. 5, and good agreement was observed among the measured and analyzed values except the type B specimen, again showing the usefulness of the elementary beam theory. In the type B specimen, the effect of cut off at the contact face of the concrete column was reflected, and a little higher stress was observed at inner portion of the joint and a little lower stress at outer portion.

### 3.3 Effect of reversed cyclic loading

Even after $10^6$ cycles of reversed load below the no-opening load were applied, no significant change was observed in the stress distribution shown in Figs. 2 to 5 nor any fatigue cracks occurred in the steel girders. Furthermore, stress range in prestressing bar is considered to be very small, if load is below the no-opening load. Consequently, there is no fear of fatigue in joint of this kind if opening does not occur under service load.

### 3.4 Effect of opening at the joint

Some change in the stress distribution described in 3.2 and 3.3 was observed when load exceeded the no-opening load and opening was occurred at the contact face. Firstly, the symmetry observed in the distribution of vertical stress in longitudinal direction became no longer observed, and compressive stress became larger than tensile stress, as the dotted lines shown in Fig.3. This is simply because the area of compression zone was decreased due to opening. Secondly, decrease of vertical tensile stress in transverse direction became more severe, as shown in Fig.2, and at the outermost portion near the contact face, the stress became even compressive. This is because the tensile force, which was transferred to the bottom of the filled concrete, forced the filled concrete to

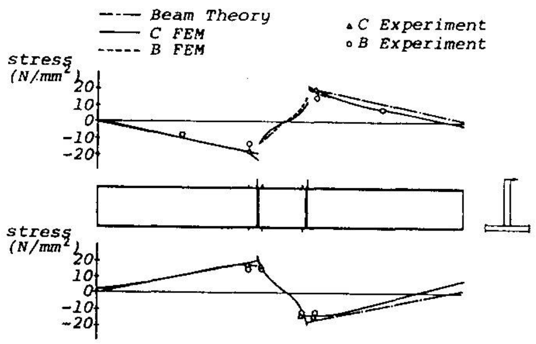


Fig.4 Flexural stress

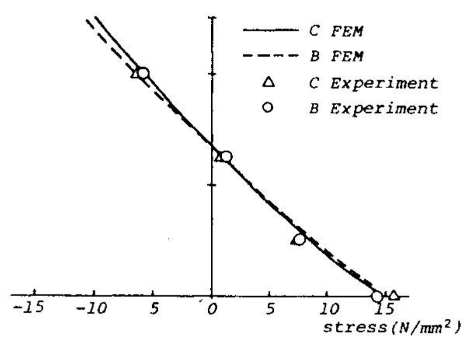


Fig.5 Flexural stress within joint

move upward direction and the flanges at the contact face to deform in a convex shape. To analyze these phenomena accurately, three dimensional FEM which can simulate opening should be used instead of two dimensional one.

Even load is lower than the no-opening load, opening could occur if complete contact between the flanges of the steel girders and the end face of the concrete column can not be attained due to, for example, some irregularity, and it was recognized that opening of this kind caused the same phenomena as above, though the degree was less significant. Consequently, if joint of this kind is so designed that opening is not allowed under service load, special precaution is needed in construction to achieve complete contact.

The stress distribution described at the beginning of this section was not changed significantly even after $10^4$ cycles of reversed load higher than the no-opening load was applied. This fact shows that joint of this kind can tolerate several times repetition of severe load such as earthquakes.

### 3.5 Behavior of the joint at failure

All specimens reached their ultimate states due to crushing, initiated by yielding of the prestressing bars, of concrete in the compression zone adjacent to the joint, and the ultimate moments at the joints coincided well with the ones of the concrete columns. At the ultimate states, no significant change was observed in the joints. This shows that hybrid structure of this kind is good enough in practical use.

## 4. A PRACTICAL EXAMPLE -THE SASAYA BRIDGE-

On the basis of the results described in 3, the Sasaya Bridge, a rigid frame bridge where steel girder is connected to bridge piers rigidly with prestressing bars, is under construction on the Sakata route of Tohoku Transverse express way. This bridge is the first prototype bridge, to which such a structure is applied, in Japan. The super structure of the Sasaya bridge is a three span continuous girder which is connected rigidly to the two middle supports (see Fig.6). The difference from ordinary steel plate girder is that box type cross girders are arranged at the middle supports.

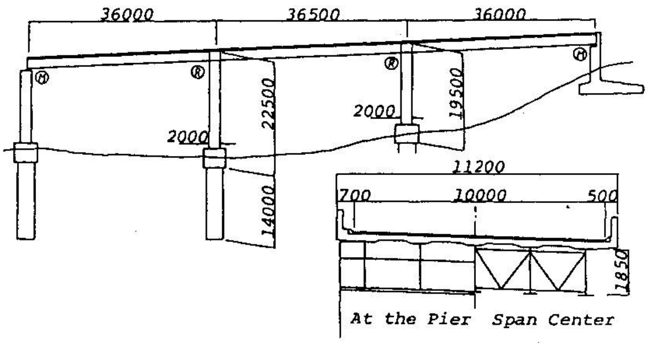

Fig.6 The Sasaya Bridge

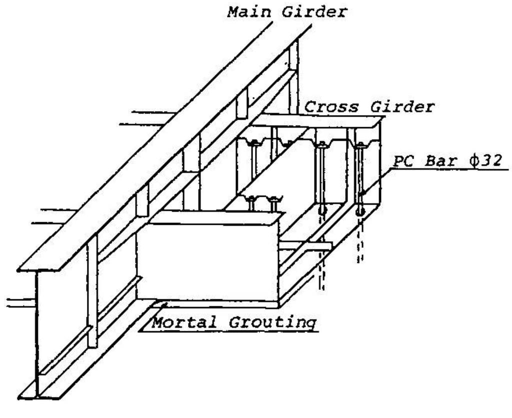

Fig.7 Structure of joint

### 4.1 structural analysis

Since the elementary beam theory was found to be useful for predicting flexural behavior, the main structure of the Sasaya bridge was analyzed as a two dimensional rigid frame, and then, since load distributing action of each girder can not be treated by frame analysis, two dimensional grid girder theory was applied to analyze this action. After that, three dimensional frame analysis was carried out to check the results of two dimensional frame and grid analysis. It was confirmed from the analysis that the results given by the two dimensional analysis were satisfactorily accurate.

### 4.2 Structure of the joints

Structure of the joints is as shown in Fig 7. In order to achieve rigid connection between the main girders and the piers, the prestressing bars embedded in the piers are tensioned and anchored to the concrete placed in the box-like spaces in the cross girders. The magnitude of the prestress is such that no tensile stress is caused at the contact face under ordinary service load.

### 4.3 Test on non-shrinkage mortar grouting

In order to assure reliability of the entire structure, it was considered to be important to obtain complete contact between the piers and the cross girders, because the joints were designed as described in 4.2. Accordingly, it was planned to grout no-shrinkage mortar into the spaces between the piers and the cross girders, and the experiment was carried out using a high quality no-shrinkage agent with nonmetal aggregate to confirm the reliability of the grouting and establish grouting method.

Excellent grouting efficiency of the mean filling rate of 99% was obtained when rather soft mortar, whose consistency measured with the funnel specified by Japan Society of Civil Engineers was 7 s, was grouted through head difference, and strength test on cored specimens showed average strength of 63.2 $N/mm^2$, which was much higher than the design strength of concrete of the piers, 35.0 $N/mm^2$.

As for the construction, the election of the main girders will begin in April, 1990, and complete in October, 1990. The construction works will be reported in the Symposium accordingly.

## 5. CONCLUSION

The followings may be concluded from the results of the experiments and analysis reported herein.

(1) The tested joints have practically satisfactory performance and can resist reversed cyclic loads of $10^6$ cycles below the load which just causes opening and of $10^4$ cycles over the load.

(2) The elementary beam theory is very useful to predict stress in entire structure including joints.

(3) In compressive stress, stress transfer mechanism is very simple and can be analyzed by two dimensional FEM even after opening occurs. However, in tensile stress, it is rather complicated and three dimensional FEM is needed to analyze the mechanism, particularly after opening occurs.

(4) Opening could occur even below the load which does not cause tensile stress at the contact face if some irregularity exists. Opening of this kind also causes the same phenomena as opening due to higher load does.

(5) The Sasaya Bridge, a hybrid bridge designed based on the results described above and under construction, is introduced.