論文 Two-Dimensional Loading Tests of Various Types of Steel Girder-Concrete Pier Joints

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ABSTRACT: Composite beam-column connections were investigated under static loading. Five types of composite joints connecting the RC-pier directly to the steel girder were investigated. These types of connections are Shape Steel Leg Inserting, Anchor Bolt, RC Pier Enveloping Main Girder, RC Pier Enveloping Cross Girder, and Capping Pier Head. These connections were investigated by varying such parameters on studs as the locations, and the number. The test results on deflection of the pier, strain of reinforcements in the pier, cracking pattern and the ultimate load-carrying capacities were considered on the basis of the differences of the types and studs.
KEYWORDS: beam-column connections, composite connection, horizontal load-carrying capacity, cracking pattern, studs

1. INTRODUCTION

Rigid-frame continuous steel girders connected with RC-piers are getting further recognition as a rational structural system for high seismic resistance, low noise, and cheap maintenance cost. These are because elimination of expansion joints and bearings by connecting the RC-piers directly to the steel girders. So far connections can be classified as three essential types as pier enveloping superstructure type [1], where part of the superstructure is enveloped by the RC-column, cap type [2], where a cylindrical shell composed in the superstructure covers a pier head, and shape steel leg type [3] where a vertical steel member connected to the superstructure is inserted into pier head. These connections are of composite types connecting steel girders with concrete piers and have been applied to the actual highway bridges constructed in these ten years. For the application of those connections, some experimental studies were carried out to certify the ultimate horizontal strength, toughness of the connection and existence of local failure[1],[2], and [3]. The design details of these connections were complicated and experiments were carried out to insure the safety of the structure, so the safety of the structure was recognized without any local problem. But, the effects of every parts the connection such as studs, reinforcements and stiffeners are not clarified from the test results and on design concepts are not certified to be rational. In this study, five types of the connection are experimentally investigated with simple models consisting of a steel girder and a RC pier column to obtain information on the effects of composing elements for the design of the connections.

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2. THE MODEL SPECIMENS AND TEST PROCEDURES

Fig. 1 shows the typical dimensions of the steel beam and reinforced concrete pier having main and stirrup reinforcements except the details of the connection. For the beam, a H-shape steel beam of 100x200x9x6 mm is used. The RC column has the cross section of 20 cm wide and 24 cm long with ten main reinforcements of 6 mm diameter and 45 mm long are used in the connections. These dimensions were decided with a scale-down factor of 1/12 to an actual bridge.

The test specimen was set upside-down in the test frame as shown in Fig. 2 and the steel beam was pin-supported. By giving a constant vertical load as much as dead weight of super structure, the column was loaded horizontally at the end of the pier. The horizontal load was given with a constant increment and temporally the applied load was unloaded until zero. The connection details of 5 types all are shown in Table 1 and Fig.3. Specimen type F is the shape steel inserting type in which the leg is H-shape steel. The difference in the two specimens is the existence of studs on the flange faces of the leg. Specimen type G is anchor bolt type using anchor bolts to connect the RC-column and the steel beam. The length of anchor bolts is the parameter. Specimen type H is pier enveloping main girder type that the main girder is buried in the concrete column. The stud arrangement for the grip of the girder is changed in two specimens.

Table 1 Specimens types

specimen	stud location on	number of studs	anchor bolt length(mm)	RC under beam flange	cap depth	Styrene foam
F-1	inserted H-beam	12	—	0	—	—
F-2	—	no studs	—	0	—	—
G-1	—	no studs	250	0	—	—
G-2	—	no studs	150	0	—	—
H-1	beam flang, web	24	—	130	—	yes
H-2	beam flang, web	24	—	130	—	No
I-1	box girder,beam flange	30	—	133	—	—
I-2	box girder	24	—	133	—	—
I-3	box girder,beam flange	22	—	100	—	—
J-1	the cup	24	—	130	130	—
J-2	—	no studs	—	130	130	—
J-3	the cup	8	—	80	80	—
J-4	—	no studs	—	80	80	—

Table 2 Ultimate load

Specimen	Ultimate load (KN)	Specimen	Ultimate load (KN)
F-1	24.86	I-2	14.35
F-2	21.82	I-3	17.98
G-1	16.85	J-1	18.13
G-2	18.97	J-2	18.28
H-1-1	20.63	J-3	19.16
H-1-2	19.46	J-4	18.97
I-1	17.15		

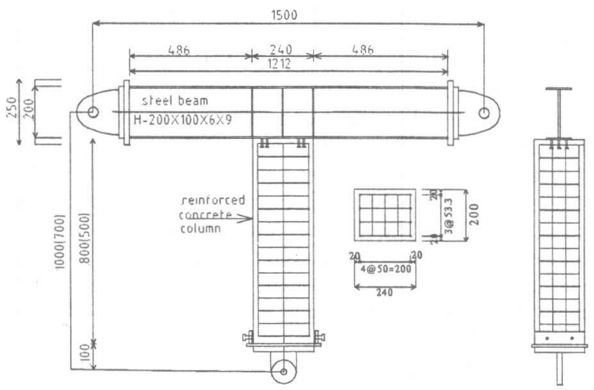

Fig. 1 General test specimen

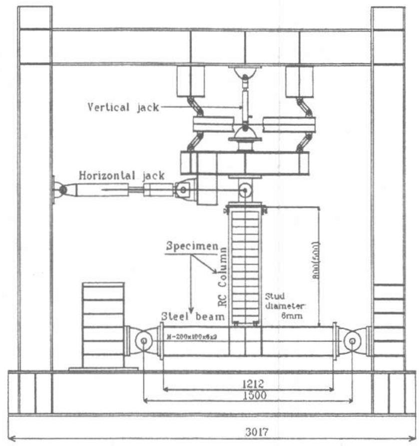

Fig. 2 Experiment setup

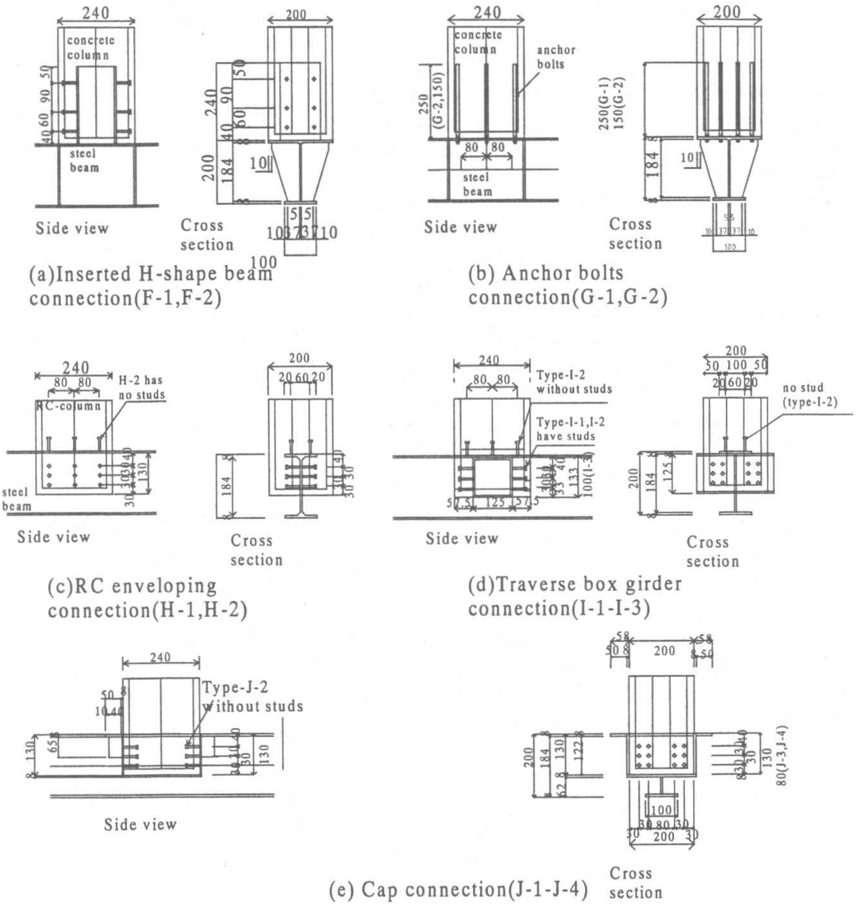

Fig. 3 Composite joint details

Specimen type I is pier enveloping cross girder type where the RC column is gripping the transverse box beam and main studs are welded to the beam webs. The parameters are the stud numbers on the transverse girder, existence of studs on main girder flange and the depth of transverse girder. Specimen type J is cap type where the superstructure has a steel cup covering the top of the RC column. The parameters are the depth of the cap and existence of studs inside of the cap.

The concrete for piers was mortar because the specimens were small. The compressive strength and elastic modulus of the concrete were 27 N/mm^2 and 18.3 kN/mm^2, respectively. The tensile strength of the studs 497 N/mm^2.

At each loading step, displacements of the pier, strains of reinforcements, and concrete surfaces strains were measured. Cracking of concrete was observed and traced with pencils.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

In the rigid flame continuous bridge system, the connection parts of the steel girders and concrete piers should be designed as stronger than the concrete piers. Also, dangerous local failure should be protected by arranging studs or stiffening by reinforcements as hoop reinforcements.

Figs.4 and 5 are test results about strain of main reinforcement in the pier and RC-pier displacement. The displacement was measured at the cross section 64cm apart from the flange of the steel beam and the strain was measured at the cross section near the failed cross section. The failed section of piers was almost the flange face section except Type F which failed at the cross section of the tail of the inserted leg. In Table 2, the ultimate loads of all specimens are listed. The Type F showed higher ultimate load than the others due to the difference of failed section as described above. Secondly, Type G developed higher ultimate load due to larger diameter of anchor bolts than the main reinforcements. The remained specimens resisted up to almost the same ultimate load.

From results of strain shown in Fig.4, all specimens can be said that they failed by yielding of main reinforcements. By comparing the results of Figs. 4 and 5, the followings can be detected: In the F type, F-2 specimen showed slip between concrete and steel leg at the 18 kN and it showed a sudden decrease of load resistance at 22 kN which also due to slip. In the G type, G-2 specimen occurred a sudden decrease of load resistance due to shorter length of the anchor bolts. In the H type, H-2 specimen showed early load decrease. The phenomena seems to be due to early local cracking of the pier at the contacting face section of steel beam. In H-1 specimen, the inner surface of the upper flange was covered with 10mm thick styrene between flanges. Flange can carry a part of uplift force in tension side. In the J type, J-1 had longer cap depth and many studs in the inside, so the RC-column was connected effectively to the steel cap which could be seen from large strain of the reinforcements comparing to thos of J-3, and J-4. Also, to find out more differences of the specimens, the detailed cyclic results of the displacement were plotted in Fig.6. The specimens of J-1 and J-2 which have deeper caps have developed bending cracks at about 6kN. On the other hand,. in the specimen J-3 and J-4 cracking load became higher as 12 and 14 kN. Due to characteristics of concrete crack, large displacement and strain have occurred in the specimens J-1 and J-2 than in the specimens J-3 and J-4 after cracking. But, it can be seen that the inclination of reloading curve of the displacement is almost the same in all specimens. From the results, the connecting effect of the cap type is almost the same even though the depth of caps are different.

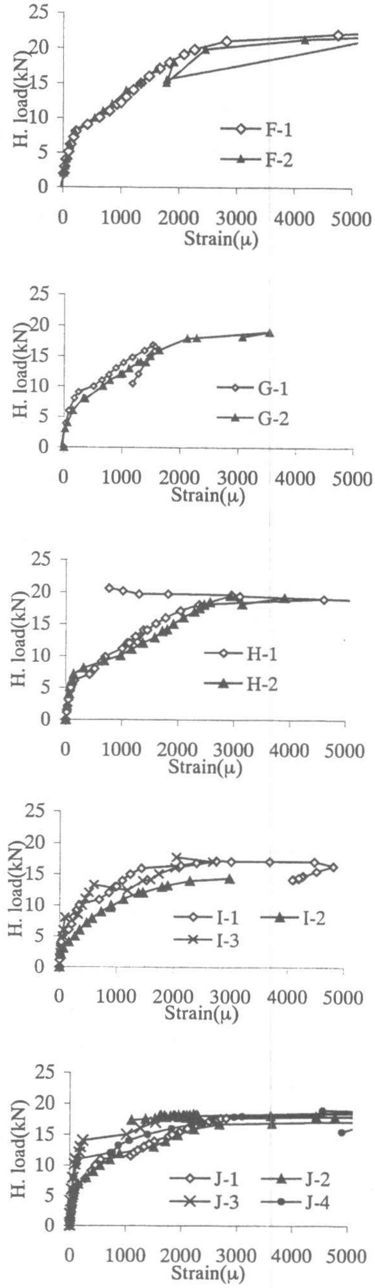

Fig. 4 Reinforcement strain

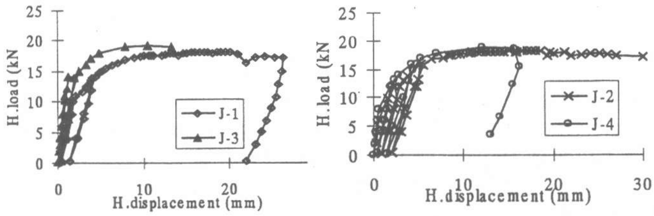

Fig. 6 Cyclic load-displacement of type J

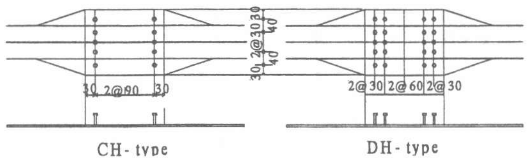

Fig. 7 Arrangement of studs on the steel girder flange of the previous experiment of type CH and DH specimens

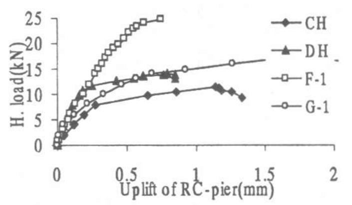

Fig. 8 Up lift of Rc-Pier

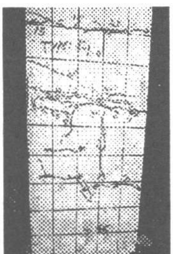

Photo 1 Loading face of specimen type F-1

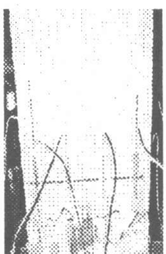

Photo 2 Loading face of specimen

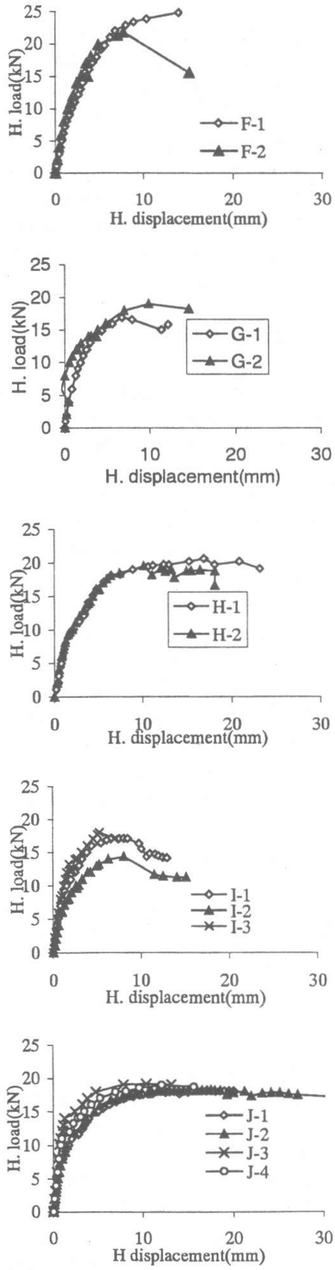

Fig. 5 Load-displacement curves.

Experimental results using only studs on the flange to connect steel beam and concrete pier as shown in Fig. 7, the load carrying capacity were almost double of the ones of the previous study [4]. there, the reinforcement did not yield due to tensile failure of concrete at near the stud heads or cone failure of the studs. Therefore, crack at the failure section was opened largely as shown in Photo.2 and uplifting or separation of the RC-pier from the steel beam in the previous was much greater than the present study as shown in Fig. 8.

The crack pattern in the present study which is shown in Photo.1 is of uniform distribution over the loading face of the RC pier. Therefore, the crack width at the bottom section nearest to flange was not so large until the ultimate load. This is a proof that good anchoring of the RC-pier to the steel girder was achieved by the composite connections.

4. CONCLUSIONS

In the present research, basic investigation of beam-column composite connections in the integral bridge was carried out. The five types of composite connections of simple structures were examined to get fundamental resisting mechanisms. Fourteen specimens were tested by two-dimensional loading condition.

From these experimental results, the following points can be pointed out:

1. All the connections resisted over the yielding strength of the RC column which is one of the main members in the structural system. Therefore all types of the connections seem to be useful for connection methods.
2. The reinforcement in the RC-pier yielded in the tension side and those in the compression side developed about 40-60% of the yield strain without buckling.
3. The shape steel leg Type can be said to have high resisting strength. When there is no stud on the leg, slip between the leg and concrete pier is apt to occur and ductility seems to drop by the slip.
4. The cap type connections have showed favorable behaviors in this study without slip of RC pier from the cap even in shallow cap. Also, in this type of connection, effect of studs is small.

Now alternative horizontal loading tests with same types specimens are under investigation. For the tests, more clear differences are expected by changing parameters on the details of the connections.

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References

1. Shigeyuki MATSUI et al."A Study on the Design for Rigid Connection of Steel Girder and RC Pier in Hybrid Frame Bridge", Annual Conference of Kansai Branch, JSCE, Osaka, March 1997, Vol.43A, pp.1367-1374(in Japanese)
2. Masahiko YOSHIDA et al. "Investigation on A Design Method of Corner part of Composite Frame Bridges" Japanese Highway Bridges standard, 1996,pp.7-12(in Japanese)
3. Nobuhito Okubo et al." Design and Experimental Study on Structural Properties of A Steel –Concrete Hybrid Bridge", Developments in Short and Medium Span Bridge Engineering'98, pp 1789-1800.
4. Shigeyuki MATSUI et al." Basic Investigation on Beam-Column Composite Connection in the Mixed Bridge System" Steel Structure Symposium, Tokyo, 18-19, November, 1999, pp 209-216.