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# A study on pipe connector for multi-beam box girder bridges

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## ABSTRACT

This study mainly focused on the evaluation of pipe connector for multi-beam box girder bridges. The multi-beam box girder bridges, which are bridge structures that are formed by connecting box girders together, have been widely used and are being constructed in many places. They are generally connected by shear keys and loop joints. Behavioral characteristics of the newly proposed and loop joint were compared by evaluating the pull-out resistance and ductility of the proposed pipe connector. Pipe connector has higher pull-out resistance and ductility than the loop joint by comparing the experimental results and analytical results.

## 1. INTRODUCTION

Multi-beam box girder bridges constitute about one-six of the bridges built annually on public roads (NCHRP 2009). Lall et al. (1997, 1998) reported that 54% of the box beam bridges built between 1985 and 1990 had developed longitudinal cracks over the shear key. The methods of connecting multi-beam box girders include a method involving the use of shear keys and loop joints to connect girders (PCI 2009). Loop joints are connected to the interface between girders before the girders are placed. After the girders are placed and the formwork is dismantled, the loop joints are connected using a coupler. However, it is inconvenient that a block out is required to protect the coupler before placement of a girder and that the block out must be removed after the formwork is dismantled. This study was conducted to attempt to develop a pipe connector that would have better constructability and ductility than a

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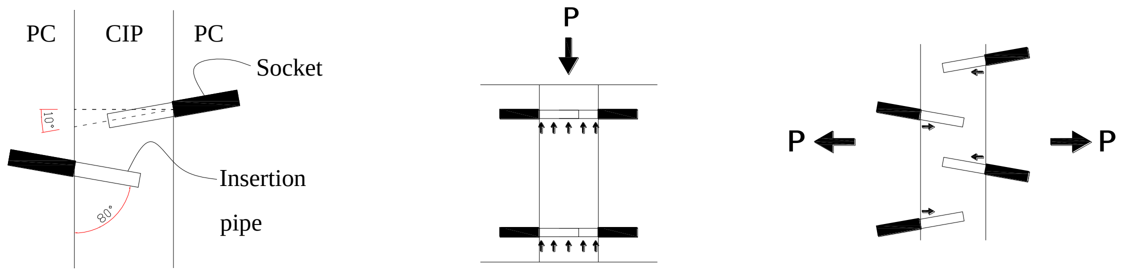
conventional loop joint.

## 2. PIPE CONNECTOR

Fig. 1 is a schematic diagram and illustrates the behavioral characteristics of the pipe connector developed in this study. The pipe connector consists of socket pipe and insertion pipe. A socket for the pipe connector is installed by welding in advance of the formwork for the interface and before placement of a box girder. A pipe connector is inserted into the socket. The pipe connector and the socket are affixed to each other using epoxy mortar. This installation method has considerably improved constructability compared to the conventional placement method for loop joints using coupler connections.




(a) Installation overview (plan view) (b) Shear resistance (front view) (c) Pull-out resistance (plan view)

Fig. 1 Installation overview and mechanical characteristics of pipe connectors

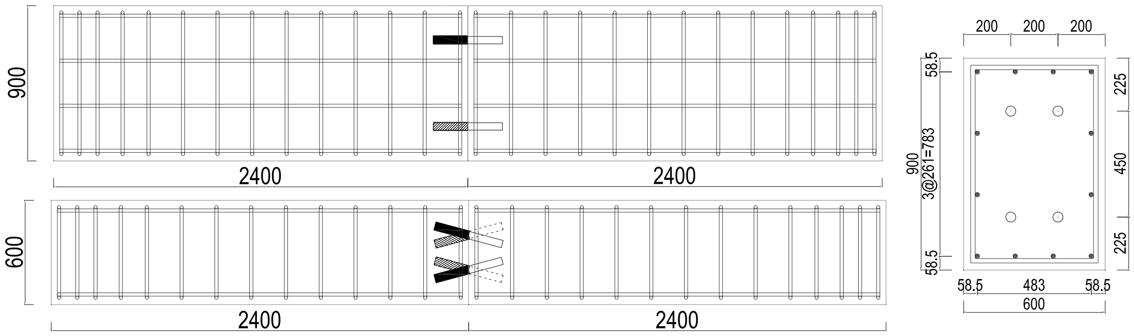
## 3. PULL-OUT RESISTANCE OF PIPE CONNECTOR

### *3.1 Details of Experiments*

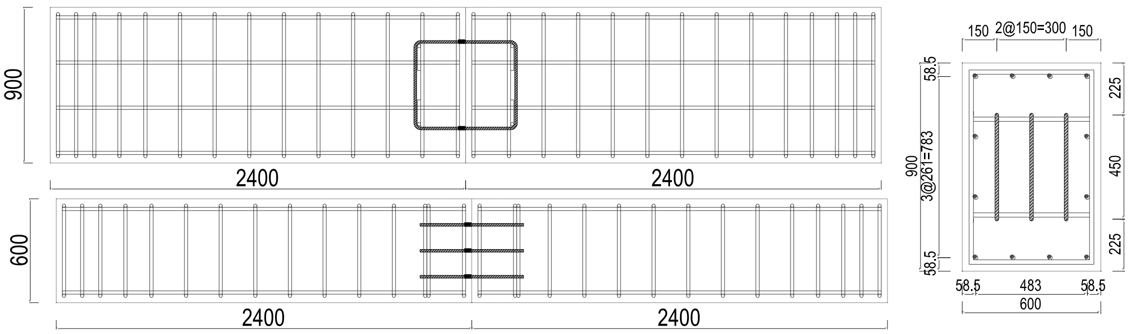
In this study, various design variables which can affect pull-out resistance such as pipe insertion angle, pipe length, and connector type were set as variables to evaluate the pull-out resistance of the pipe connector. Table 1 shows the characteristics of the reference specimen group and comparison group. Fig. 2 shows the detail of specimen. For each variable condition, specimens with the same specifications were manufactured. Pure bending tests were carried out to evaluate the pull-out resistance performance of the pipe connectors. The bending moment is calculated as a function of the load applied, and the pull-out force acting on the connector is calculated from the bending moment. Fig. 3 shows the test set-up of the pull-out test.

Table 1 Variations of specimens

| Name | Diameter (mm) | Length of pipe connector (mm) | Insertion angle (°) | No. of connector | Concrete (MPa) | Quantity |
|---|---|---|---|---|---|---|
| L200-A15 (Reference) | 42.7 (t=2.3) | 200 | 15 | 4 | 45 | 3 |
| Loop-H16 | - | - | - | 6 | 45 | 3 |
| L200-A10 | 42.7 (t=2.3) | 200 | 10 | 4 | 45 | 3 |
| L150-A15 | 42.7 (t=2.3) | 150 | 15 | 4 | 45 | 3 |




(a) Pipe connector (Reference)



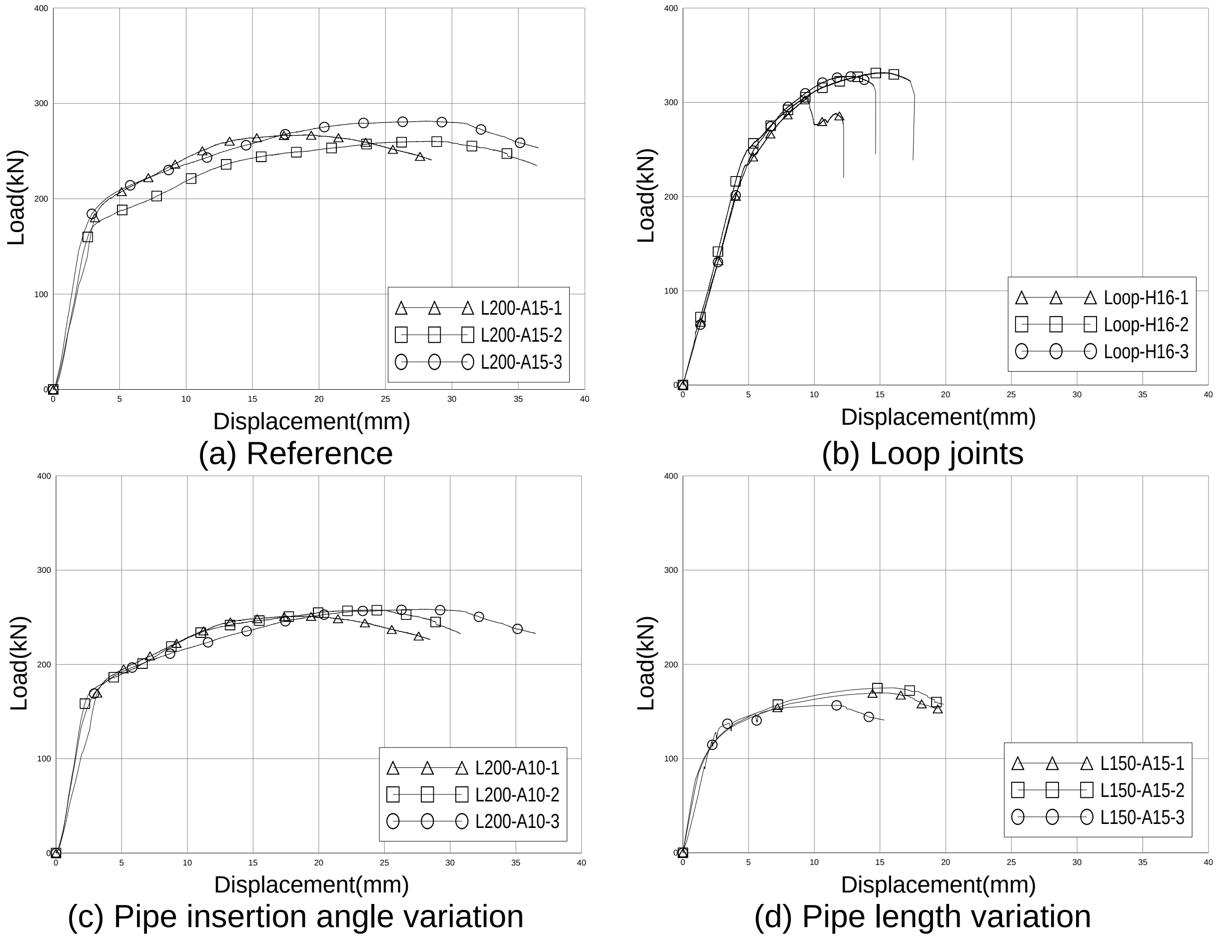

(b) Loop joint

Fig. 2 Layout of specimens (Unit:mm)

Fig. 3 test set-up

### *3.2 Test Results*

The test results were evaluated on the basis of the results of the relative displacement caused by loading. Evaluation of results was performed by Kim et al. (2013) proposed method. Kim et al. (2013) proposed the initial relative displacement ($\delta_{90}$) based on $P_{RK}$, and $\delta_u/\delta_{90}$ was compared. $\delta_u/\delta_{90}$ refers to the ratio of slip capacity to the initial relative displacement. The larger the ratio, the bigger the ductility of the connector compared to the initial stiffness. A safety factor is calculated using the ratio of the maximum load ($P_{max}$) to the yield strength ($P_y$). Test results are shown in Fig. 4 and Table 2. As shown Fig. 4, length of the pipe has a large effect on the pull-out resistance performance of pipe connectors. However 5 ° change in the pipe insertion angle does not have much effect on the pull-out performance of pipe connectors. As shown in Table 2, $P_{max}/P_y$ was 1.5 on average for the reference specimens and 1.3 on average for the specimens with loop joint. $\delta_u/\delta_{90}$ was 2.8 on average for the reference specimens and 1.9 on average for the loop joint specimens. This indicates that pipe connectors, which exhibit higher ductility than loop joints at the similar level of $P_{max}/P_y$, can ensure a higher safety factor after yield strength than loop joints.




(a) Reference (b) Loop joints

(c) Pipe insertion angle variation (d) Pipe length variation

Fig. 4 Load-relative slip relationships

Table 2 Results of pull-out test

| Specimens | No. | P (kN) | | $P_{pull}$ (kN) | | $\delta_{90}$ (mm) | $\delta_u$ (mm) | $\delta_u/\delta_{90}$ | $P_{max}/P_y$ |
|---|---|---|---|---|---|---|---|---|---|
| | | max | yielding | max | yielding | | | | |
| L200-A15 (Reference) | 1 | 267.2 | 190.1 | 534.5 | 380.2 | 9.7 | 28.5 | 2.9 | 1.4 |
| | 2 | 260.5 | 166.0 | 521.0 | 332.0 | 12.6 | 36.4 | 2.9 | 1.6 |
| | 3 | 281.6 | 180.0 | 563.1 | 359.9 | 13.7 | 36.4 | 2.7 | 1.6 |
| | Avg. | 269.8 | 178.7 | 539.5 | 357.4 | 12.0 | 33.8 | 2.8 | 1.5 |
| Loop-H16 | 1 | 304.7 | 231.6 | 609.4 | 463.2 | 7.1 | 12.2 | 1.7 | 1.3 |
| | 2 | 331.7 | 242.1 | 663.5 | 484.3 | 8.6 | 17.5 | 2.0 | 1.4 |
| | 3 | 327.8 | 240.7 | 655.5 | 481.4 | 8.0 | 14.7 | 1.8 | 1.4 |
| | Avg. | 321.4 | 238.1 | 642.8 | 476.3 | 7.9 | 14.8 | 1.9 | 1.3 |
| L150-A15 | 1 | 169.6 | 102.2 | 339.2 | 204.4 | 6.9 | 19.4 | 2.8 | 1.7 |
| | 2 | 175.1 | 96.5 | 350.1 | 192.9 | 7.3 | 19.8 | 2.7 | 1.8 |
| | 3 | 156.5 | 126.2 | 312.9 | 252.4 | 4.2 | 15.3 | 3.7 | 1.2 |
| | Avg. | 167.0 | 108.3 | 334.1 | 216.6 | 6.1 | 18.2 | 3.1 | 1.5 |
| L200-A10 | 1 | 251.6 | 178.1 | 503.1 | 356.2 | 9.7 | 28.5 | 2.9 | 1.4 |
| | 2 | 258.0 | 162.0 | 516.0 | 323.9 | 10.7 | 30.8 | 2.9 | 1.6 |
| | 3 | 258.7 | 154.7 | 517.4 | 309.4 | 13.8 | 36.5 | 2.6 | 1.7 |
| | Avg. | 256.1 | 164.9 | 512.2 | 329.8 | 11.4 | 31.9 | 2.8 | 1.6 |

## 4. FINITE ELEMENT ANALYSIS FOR PIPE CONNECTOR

### *4.1 Analysis Method*

Finite element models for pull-out specimens with pipe connector were developed to estimate the pull-out resistance using the ABAQUS. The pipe connector must be constructed of at least two in order to demonstrate the performance of the pull-out resistance. Thus, the finite element analysis of pull-out is examined the performance, it is composed of two pipe connectors. The results of the analysis were compared with the results of the experiment by applying a multiplication. The finite element mesh of specimens is presented in Fig. 5.

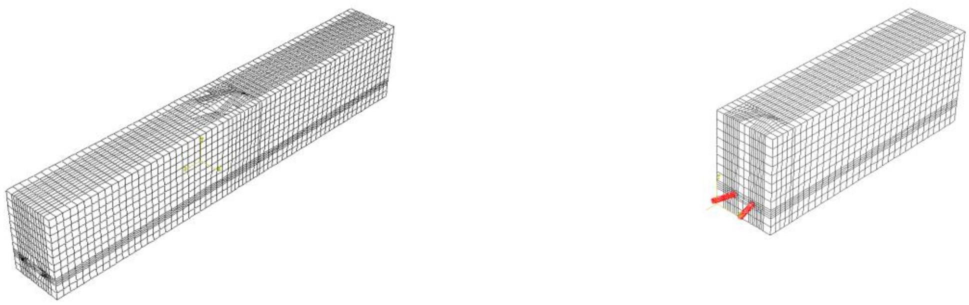


Fig. 5 Finite element mesh

Concrete and steel pipe connector are modeled with solid element and shell element, respectively. Shell elements are analyzed by changing the attribute for each thickness of the pipe, and are applied to offset the top side so as not to be combined with concrete elements. Concrete damaged plasticity model is used to model the concrete material. This material is suitable for the material with different yield strength in tension and compression. Classical metal plastic model is applied to steel that shows the stress-strain relationship of bi-linear characteristic with respect to compression and tension. In this study, the basic behavior of the pipe connector specimen is assumed to exhibit a linear behavior before the yield stress. After the yield stress, it is assumed to exhibit a perfect plastic behavior.

*4.2 Validation of analytical model*

The analytical model is validated by comparing them with the pull-out test results. The load-relative slip characteristics obtained from the finite element analysis are shown in Fig. 6, and also plotted are the pull-out test results for reference specimens (D42.7-T2.3). Table 3 summarizes the results from the experimental tests and the finite element model. The analytical model had an ultimate load of 512.8 kN. $\delta_u/\delta_{90}$ was 4.6 for the analytical model. This seems to be caused by the epoxy mortar used for pipe adhesive are separated from the socket, when pull-out force acts. The reason seems to be that the oil was not completely removed the pipe inside at the time of the specimen production. However, the overall shape and the maximum pull-out resistance of the load–relative displacement were interpreted to an appropriate level. Therefore, the analysis results were valid.

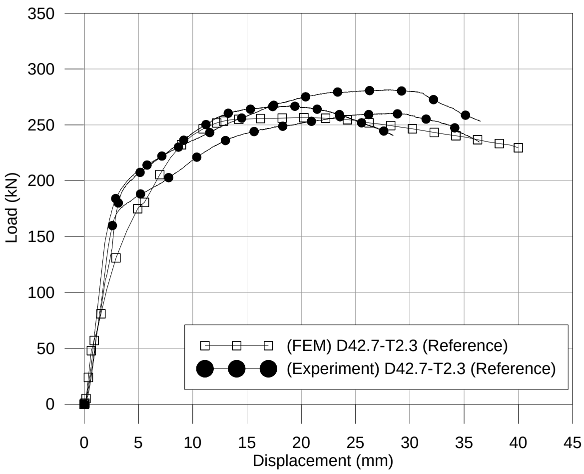



Fig. 6 Load-relative slip characteristics

Table 3 Results of pull-out test and numerical analysis

| Name | No. | $P_{max}$ (kN) | $P_{RK}$ (kN) | $\delta_{90}$ (mm) | $\delta_u$ (mm) | $\delta_u/\delta_{90}$ |
|---|---|---|---|---|---|---|
| D42.7-T2.3 (Reference, experiment) | 1 | 267.2 | 534.5 | 9.7 | 28.5 | 2.9 |
| | 2 | 260.5 | 521.0 | 12.6 | 36.4 | 2.9 |
| | 3 | 281.6 | 563.1 | 13.7 | 36.4 | 2.7 |
| | Avg. | 269.8 | 539.5 | 12.0 | 33.8 | 2.8 |
| FEM | - | 256.4 | 512.8 | 8.5 | 39.2 | 4.6 |

The numerical simulations are used to evaluate the effects of more assorted variable. The variables are determined as follows; the pipe diameters (60.5 mm, 89.1mm), the pipe thickness (2.3mm, 3.2mm). The analytical models are compared with the experimental results of reference specimen and loop joint specimen. Fig. 7 shows the load-slip curves. Table 4 summarizes all results from the experimental tests and the numerical model. In Fig. 7, The loop joint specimen has ultimate load it is higher than the reference specimen. However, the ultimate loads of the pipe connector specimens are gradually increased as the pipe diameter and thickness increase. Therefore the pipe connectors were seemed to be superior to the loop joints in terms of ensuring the load-carrying capacity of the connections in which they were used.

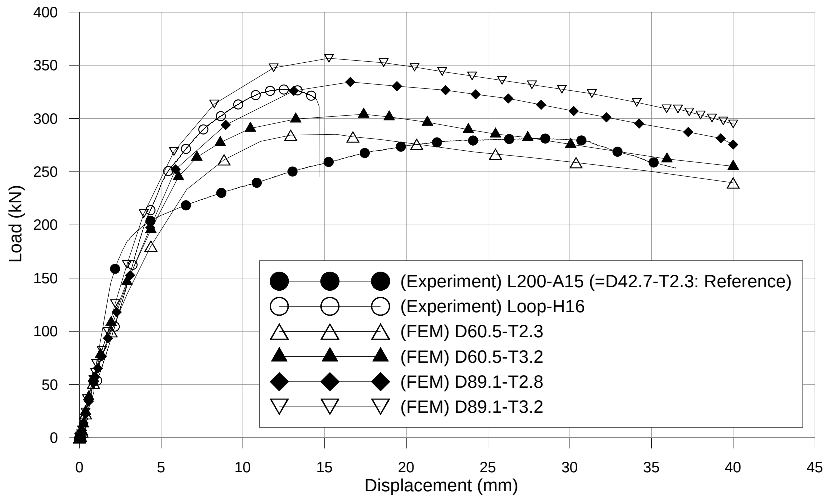



Fig. 7 Comparison of experimental and analytical results

Table 4 Pull-out behavior characteristic of experimental and analytical results

| Name | $P_{max}$ (kN) | $P_{RK}$ (kN) | $\delta_{90}$ (mm) | $\delta_u$ (mm) | $\delta_u/\delta_{90}$ |
|---|---|---|---|---|---|
| D42.7-T2.3 (Reference, experiment) | 256.4 | 512.8 | 8.7 | 38.5 | 4.4 |
| D60.5-T2.3 | 285.1 | 570.2 | 7.2 | 31.4 | 4.4 |
| D60.5-T3.2 | 304.0 | 608.0 | 8.1 | 32.2 | 3.9 |
| D89.1-T2.8 | 334.3 | 668.6 | 9.6 | 33.1 | 3.4 |
| D89.1-T3.2 | 356.6 | 713.2 | 9.3 | 32.3 | 3.5 |
| Loop-H16 (Loop joint, experiment) | 356.6 | 713.2 | 9.3 | 32.3 | 3.5 |

## 5. CONCLUSION

In this study, pull-out tests and numerical analysis were conducted on the pipe-connector to propose a new connector with improved workability and high ductility that can be applied to various types of multi-beam box girder bridges. The results of the pull-out tests indicated that the pipe connector has better ductility and safety than the loop joint. Also, through the evaluation of behavioral changes of the pipe connector, it was found that the pipe length increased, the pull-out resistance and ductility of the pipe connector increased. This shows that the pipe length improve the pull-out performance and ductility. The results of the finite element analysis indicated that the pull-out resistance is gradually increased as the pipe diameter and thickness increase. In addition, the pipe connector has ultimate pull-out resistance those are higher than the loop joint as the pipe diameter and thickness increase. From this study, the pipe connector demonstrated more idealized behavior than the loop joint, by achieving higher ductile behavior and safety.

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