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EXPERIMENTAL EVALUATION OF PIPE-SHAPE SHEAR CONNECTORS FOR MULTI-BEAM BOX GIRDER BRIDGES

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This study mainly focused on the experimental evaluation of pipe-shape shear connectors for multi-beam box girder bridges. The multi-beam box girder bridges are a structure to the integration with the box girders placed adjacent to each other. They are generally connected by shear keys and loop joints to resist the shear force at their interfaces, and lateral tendons for applying the compression force. However, if the integration effect decreases with time, the relative deflection between adjacent girders occurs and it causes the reflective cracks on the deck along the interfaces. Furthermore, the efficiency of constructing multi-beam box girder bridges decreases when loop joints are used because it is complicated to form the required connections using couplers. Therefore, this study evaluated behavior of pipe-shape shear connectors which are superior in workability and ductility than loop joints by push-out tests and pull-out tests.

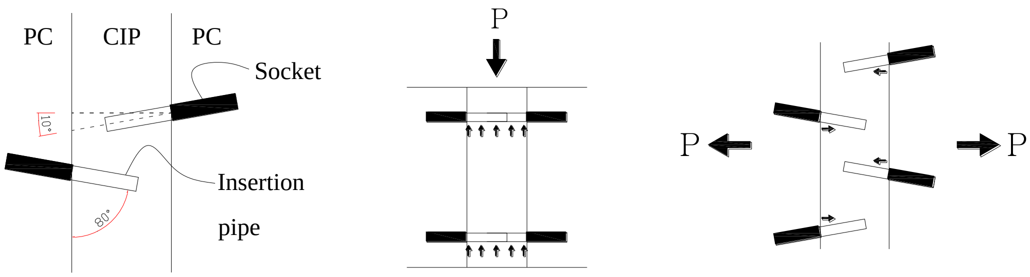
Keywords: Loop joint, Push-out test, Pull-out test, Shear key.

1 INTRODUCTION

In this study, pipe-shape shear connector is proposed. Behavioral characteristics of the newly proposed and existing loop joint were compared by evaluating the shear resistance and pull-out resistance of the proposed pipe-shape shear connector. Push-out tests and pull-out tests were carried out to evaluate the shear resistance and the pull-out resistance of pipe-shape connector.

2 PIPE-SHAPE SHEAR CONNECTOR

Multi-beam box girder bridges were first proposed in the United States in 1950 (Miller *et al.* 1999). The girders are typically connected laterally using either a method involving the use of shear keys and lateral tensile force or a method involving the use of loop joints (PCI 2009, NCHRP 393 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-shape shear connector that would have better constructability and ductility than a conventional loop joint. Figure 1 is a schematic diagram and illustrates the behavioral characteristics of the pipe-shape shear connector developed in this study.



(a) Installation overview. (b) Shear resistance. (c) Pull-out resistance.

Figure 1. Installation overview and mechanical characteristics.

3 SHEAR RESISTANCE OF PIPE-SHAPE SHEAR CONNECTOR

3.1 Details of Experiments

In this study, the behavioral differences with loop joint were assessed through push-out tests presented by Eurocode-4(2007). The characteristics of the reference specimen group and comparison group are shown in Table 1. Figure 2 shows the detail of specimen.

Table 1. Variations of specimens for push-out test.

Name	Diameter (mm)	Length of pipe (m)	No. of pipe	No. of loop joint	Concrete (MPa)	Quantity
D42.7-L200 x 8 (Reference)	42.7 (t=2.3)	200	8	-	45	3
Loop(H16 x 12)	H 16	-	-	12	45	3
D21.7-L200 x 8	21.7 (t=2.3)	200	8	-	45	3
D42.7-L150 x 8	42.7 (t=2.3)	150	8	-	45	3

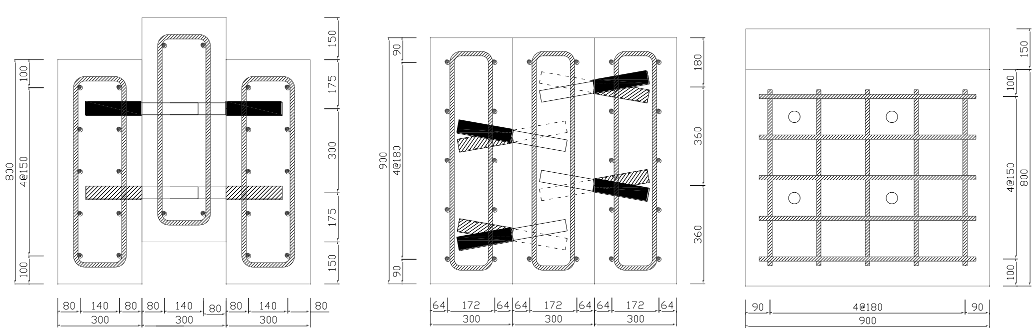
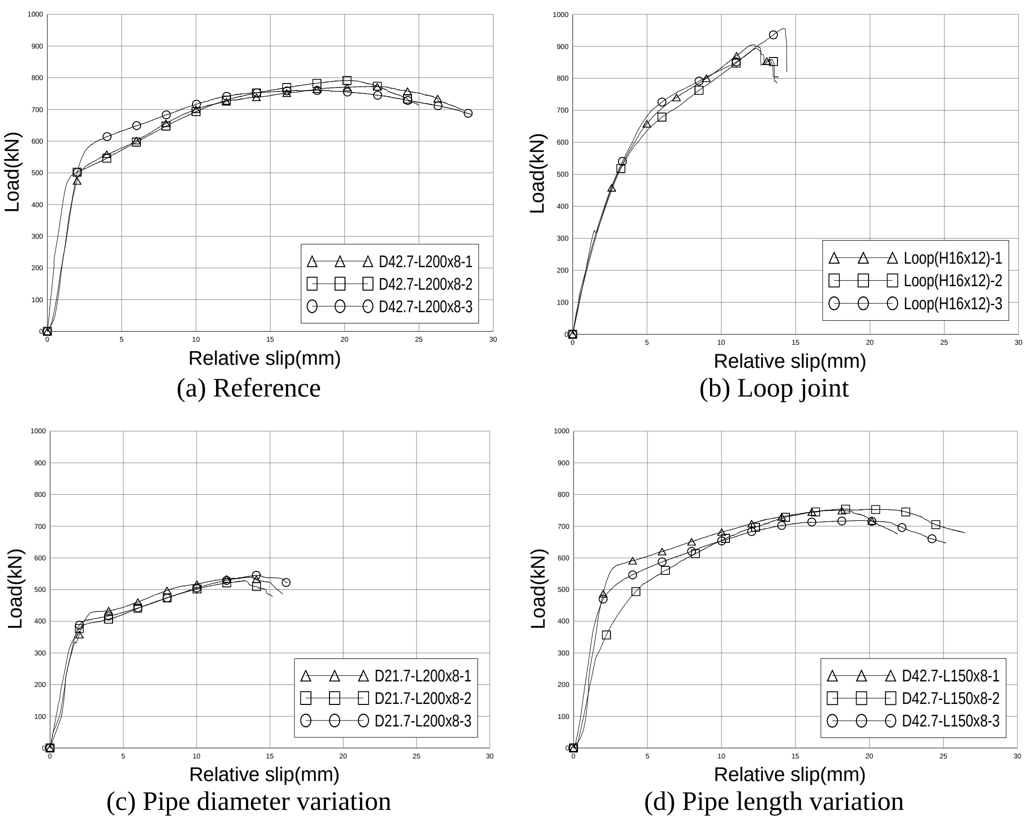


Figure 2. Layout of specimens for push-out test (Reference).

The push-out 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 (δ_{90}) based on P_{RK}, and δ_u/δ_{90} was compared. δ_u/δ_{90} refers to the ratio of slip capacity to the initial relative displacement. The larger the ratio, the bigger the ductility of the shear 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).

3.2 Push-out Test Results

Test results are shown in Figure 3 and Table 2. As shown in Figure 3, diameter of the pipe was concluded to have a significant effect on the shear resistance performance and ductility of pipe-shape shear connectors. However the effect of the length of the pipe on the shear resistance performance of pipe-shape shear connectors is insignificant. As shown in Table 2, P_{max}/P_y was 1.6 on average for the reference specimens 1.5 on average for the loop joint specimens. δ_u/δ_{90} was 2.8 for the reference specimens and 1.4 for the loop joint specimens. This indicates that the pipe-shape shear connector has higher ductility than the loop joint.



(a) Reference (b) Loop joint

(c) Pipe diameter variation (d) Pipe length variation

Figure 3. Load-relative slip relationships of push-out test specimens.

Table 2. Results of push-out test.

Specimens	No.	P_{max} (kN)	P_y (kN)	P_{RK} (kN)	δ_{90} (mm)	δ_u (mm)	δ_u/δ_{90}	P_{max}/P_y
D42.7-L200 x 8 (Reference)	1	773.3	488.2	696.0	9.8	28.0	2.9	1.6
	2	792.0	405.9	712.8	11.0	25.0	2.3	2.0
	3	761.2	551.9	685.1	8.2	28.5	3.5	1.4
	Avg.	775.5	482.0	698.0	9.6	27.2	2.8	1.6
Loop(H16 x 12)	1	906.0	579.2	815.4	9.4	13.5	1.4	1.6
	2	894.3	552.2	804.8	9.8	14.6	1.5	1.6
	3	956.1	648.8	860.5	11.3	14.4	1.3	1.5
	Avg.	918.8	593.4	826.9	10.2	14.2	1.4	1.5
D21.7-L200 x 8	1	539.5	394.3	485.6	7.3	15.9	2.2	1.4
	2	528.3	338.0	475.5	8.1	15.2	1.9	1.6
	3	546.0	376.8	491.4	9.1	17.3	1.9	1.4
	Avg.	537.9	369.7	484.1	8.2	16.1	2.0	1.5
D42.7-L150 x 8	1	750.2	535.4	675.2	9.6	21.9	2.3	1.4
	2	754.8	395.1	679.3	11.2	26.4	2.4	1.9
	3	718.6	462.3	646.7	9.5	25.2	2.6	1.6
	Avg.	741.2	464.3	667.1	10.1	24.5	2.4	1.6

4 PULL-OUT RESISTANCE OF PIPE-SHAPE SHEAR CONNECTOR

4.1 Details of Experiments

In this study, various design variables which can affect pull-out resistance such as pipe insertion angle, pipe length, and shear connector type were set as variables to evaluate the pull-out resistance of the pipe-shape shear connector. Table 3 shows the characteristics of the reference specimen group and comparison group. Figure 4 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-shape shear 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.

Table 3. Variations of specimens for pull-out test.

Name	Diameter (mm)	Length of pipe (m)	Insertion angle(°)	No. of pipe	No. of loop joint	Concrete (MPa)	Quantity
L200-A15 x 2 (Reference)	42.7 (t=2.3)	200	15	8	-	45	3
Loop(H16 x 3)	H 16	-	-	-	12	45	3
L200-A10 x 2	21.7 (t=2.3)	200	10	8	-	45	3
L150-A15 x 2	42.7 (t=2.3)	150	15	8	-	45	3

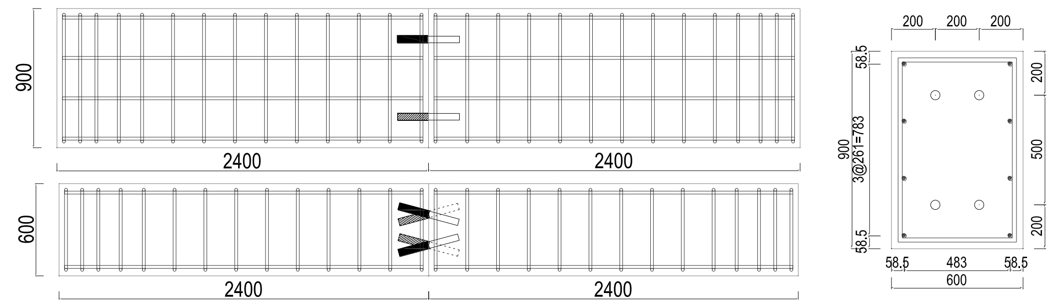
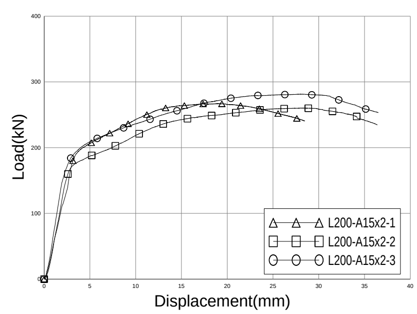


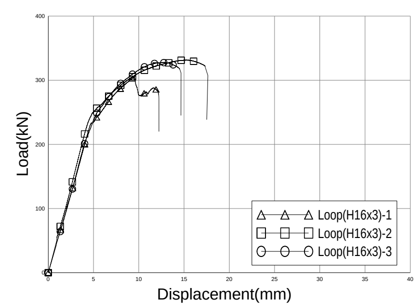
Figure 4. Layout of specimens for pull-out test (Reference).

4.2 Pull-out Test Results

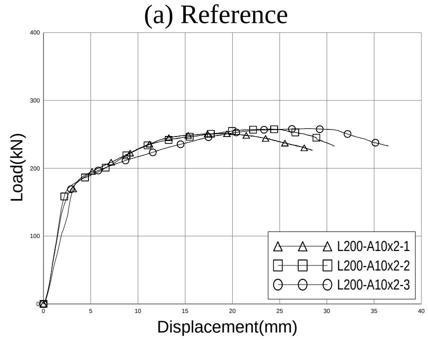
Test results are shown in Figure 5 and Table 4. As shown Figure 5, length of the pipe has a large effect on the pull-out resistance performance of pipe-shape shear connectors. However 5° change in the pipe insertion angle does not have much effect on the pull-out performance of pipe-shape shear connectors. As shown in Table 4, P_{max}/P_y was 1.5 on average for the reference specimens and 1.3 on average for the specimens with loop joint. δ_u/δ_{90} was 2.8 on average for the reference specimens and 1.9 on average for the loop joint specimens. Therefore, it was concluded that pipe-shape shear 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.



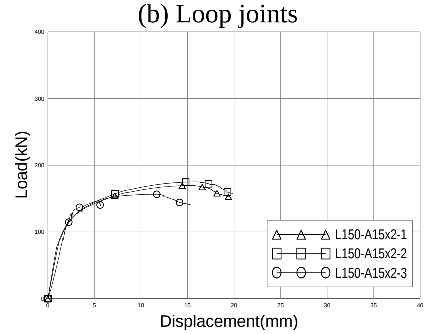
(a) Reference



(b) Loop joints



(c) Pipe insertion angle variation



(d) Pipe length variation

Figure 5. Load-relative slip relationships of pull-out test specimens.

Table 4. Results of pull-out test.

Specimens	No.	P(kN)		P_{pull}(kN)		δ_{90} (mm)	δ_u (mm)	δ_u/δ_{90}	P_{max}/P_y
		Max	Y	Max	y				
L200-A15 x 2 (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 x 3)	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 x 2	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 x 2	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

5 CONCLUSIONS

In this study, push-out tests and pull-out tests were conducted on the pipe-shape shear connector to propose a new shear connector with improved workability and high ductility that can be applied to various types of precast concrete structures. The results of the push-out tests and pull-out tests indicated that the pipe-shape shear connector has better ductility and safety than the loop joint. Also, through the evaluation of behavioral changes of the pipe-shape shear connector, it was found that the pipe diameter has effect on the shear resistance of pipe-shape shear connector. When the pipe length increased, the pull-out resistance and ductility of the pipe-shape shear connector increased. This shows that the pipe length improves the pull-out performance and ductility. Therefore the pipe-shape shear connector demonstrated more idealized behavior than the loop joint, by achieving higher ductile behavior and safety.

References

CEN, Eurocode-4: *Design of composite steel and concrete structures part1-1: General rules and rules for buildings*, European Committee for Standardization, Brussels, 2007.

Henry G. Russell, *National Cooperative Highway Research Program synthesis 393-Adjacent Precast Concrete Box Beam Bridges: Connection Details*, Transportation Research Board, 2009.

Kim, S.H., Choi, K.T., Park, S.J., Park, S.M., and Jung, C.Y., Experimental shear resistance evaluation of Y-type perfobond rib shear connector, *Journal of Constructional Steel Research*, 82, 1-18, 2013.

Miller, R. A., Hlavacs, G. M., Long, T., and Greuel, A., Full-Scale Testing of Shear Keys for Adjacent Box Girder Bridges, *PCI Journal*, 44(6), 80-90, Nov–Dec, 1999.

PCI, *The State-of-the-Art of Precast Prestressed Adjacent Member Bridges*, Precast/Prestressed Concrete Institute, Chicago, 2009.