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Residual strength of Y-type perfobond rib shear connectors to cyclic load on highway bridge

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ABSTRACT

The plastic slip amplitude of Y-type perfobond rib shear connectors under cyclic loading is estimated. Load range of cyclic loading test was determined 30kN to 300kN in according to Korea Highway Bridge Specifications. The Y-type perfobond rib shear connectors are embedded in RC slab like the typical push-out test specimen. Under repeated loading, the Y-type perfobond rib shear connectors experience initial plastic slip. However, it remains almost unchanged up to 1.3 million cycles. The residual strength as well as stiffness of Y-type perfobond rib shear connector also remains unchanged even the system endures some permanent plastic slip.

1. INTRODUCTION

The steel-concrete composite structures are widely adopted for bridges. Because the shear connecting systems provide the sound structural performance and efficiency in both construction cost and workability in construction sites. The most normally utilized sort of shear connector is headed stud shear connector. The headed stud shear connectors have good workability such as fast welding and easy arrangement of reinforcement. However, stud shear connectors have fatigue problem at connector's root (Ahn et al. 2007) and can not experience the large relative slip between the steel-concrete (Shariati et al. 2012). To improve the disadvantages of stud shear connectors, perfobond rib shear connector has been developed (Zeller 1987). Recently, various types of shear connectors have been introduced (Shariati et al. 2012). Kim et al. (2013) suggested the shear capacity evaluation model for the Y-type perfobond rib shear connectors, in which the conventional perfobond rib shear connectors have been modified to improve the performance such as shear resistance, vertical resistance, ductility and workability for transverse rebar placement. In this study, the permanent

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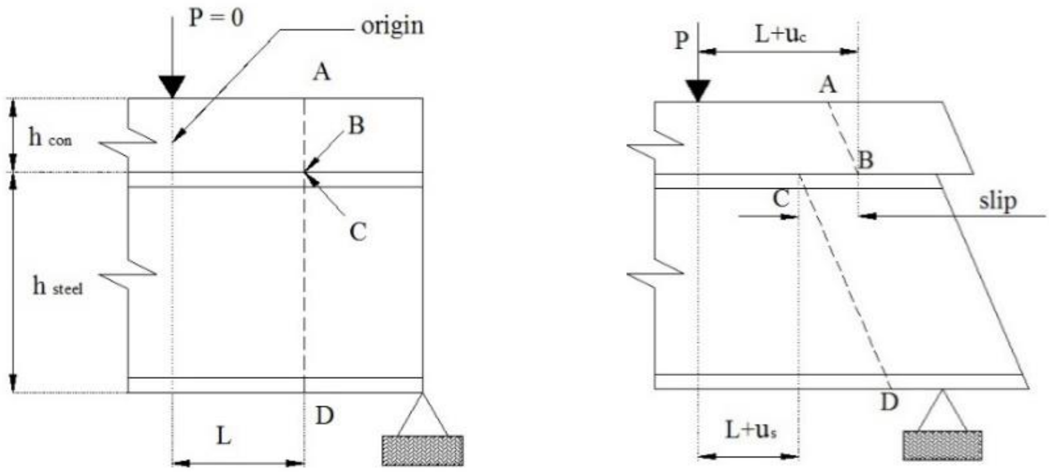
relative slip of Y-type perfobond rib shear connectors under cyclic loadings is evaluated.

2. BEHAVIOR OF SHEAR CONNECTORS UNDER CYCLIC LOADING

2.1 Plastic slip in composite beam

The cyclic loadings can cause permanent slip in connecting part of the shear connectors embedded in the Reinforced Concrete(RC) slab deck. Fig. 1(a) shows the composite girder without loadings, and Fig. 1(b) shows the composite girder under loading. Before loading, point B and C have same distance L. When the force P is applied point B moves $L + u_c$ and point C moves $L + u_s$. The difference between point B and C is called the slip. When slip is completely prevented, it is called the "full composite action". However, in practice certain amount of slip is unavoidable. Therefore, the full composite action is very difficult to achieve. This slip may cause additional deflection, bending stress, and degrading stiffness of connecting part.



(a) Composite girder without loading (b) Composite girder under loading

Fig. 1 Slip in composite girder

2.2 Slip of the stud shear connector

Hanswille et al. (2006) proposed some equations related to the fatigue behavior of the stud shear connectors based on the results of the 71 push-out tests presented in the earlier companion papers. Hanswille et al. (2006) reanalyzed push-out tests to determine the fatigue life of stud shear connector embedded in solid RC slabs and developed empirical expressions to predict the fatigue life and the residual static strength after high cycle pre-loading.

Hanswille et al. (2006) has proposed Eq. (1) through (5) for evaluating the plastic slip of stud shear connectors based on the results of the push-out tests presented in the earlier companion papers. According to the equations, the plastic slip is affected by the load range, load cycles and shear resistance.

$$\delta_{pl,N} = C_1 - C_2 \cdot ln\left(\frac{1}{N_i/N_f} - 1\right) \geq 0, \qquad for\ 0 < N_i/N_f < 0.9 \tag{1}$$

$$\delta_{pl,N} = 0, \qquad for\ \ N_i/N_f = 0 \tag{2}$$

$$C_1 = 0.104 \cdot e^{3.95 \cdot \frac{P_{max}}{P_{u,0}}} \tag{3}$$

$$C_2 = 0.664 \cdot \frac{P_{min}}{P_{u,0}} + 0.029 \tag{4}$$

$$\delta_i = \left\{-\frac{ln\left(1 - P_i/P_{u,N}\right)}{3.25}\right\}^{\frac{1}{1.46}} - \delta_{pl,N} \tag{5}$$

where, $\delta_{pl,N}$ (mm) is the plastic slip, P_{min} (kN) is the minimum load, C_1 and C_2 are the empirical parameters, N_i is the load cycles, N_f is the fatigue life, $P_{u,N}$(kN) is the residual strength, $P_{u,0}$(kN) is the shear resistance, P_{max}(kN) is the maximum load and ΔP(kN) is the load range.

3. CYCLIC LOADING TEST

Cyclic loading tests are conducted over 650 thousand cycles for all specimens (Y-type-A, B, C). The cyclic loading tests has been continued up to 1.3 million cycles with the specimen, that has resulted in the maximum slip after 0.65 million cycles (Y-type-B). The load range of cyclic loading test is selected in accordance with the Korean Highway Bridge Specification (KHBS) (MOCT 2010).

3.1 Fabrication of specimens

In this study, a total of four specimens are fabricated according to the standard push-out test specimen presented in Eurocode-4 (CEN 2007) to evaluate the relative slip of Y-type perfobond rib shear connector. The design variables of specimens are as follows : the concrete strength is set to 30 MPa, the Y-shaped angle is set to 60 degrees and the number of ribs is set to four. The diameter of dowel holes is 40 mm and the thickness of the rib is 10 mm. The transverse rebar have a diameter of 16 mm. Table 1 summarizes the design variables of the specimens.

A 70 mm long styrofoam is attached at the bottom end of the rib of the shear connector to prevent concrete from pouring in. Also, to remove the adhesive force caused by the chemical bonding between the concrete and steel rib, grease is applied to the steel rib before pouring the concrete. Fig. 2 shows the details of specimen.

Table 1 Design variables of specimen

Design variables	
Compressive strength of concrete	30 MPa
Number of ribs	Four
Thickness of RC slab	280 mm
Width of RC slab	600 mm
Length of RC slab	750 mm
Diameter of dowel hole	40 mm
Diameter of transverse rebar	16 mm

3.2 Determination of load range for cyclic loading tests

The load range of the cyclic loading test is estimated based on the design dead load and live load in accordance with the KHBS (MOCT 2010). According to the Korean Highway Bridge Manual(KHBM) (MOCT 2008), the general span length of a composite girder bridge is 25m to 45m. Therefore, the span length of bridge is determined as 40m in this study. The minimum shear force of 30kN per meter is generated by a dead load, and the maximum shear force of 200kN per meter is generated by live load and dead load. In order to consider the ultimate condition, the maximum load is set to 1.5 times the shear force. Finally, the load range for the cyclic loading test was set as shown in Table 2.

Table 2 Load range for cyclic loading test

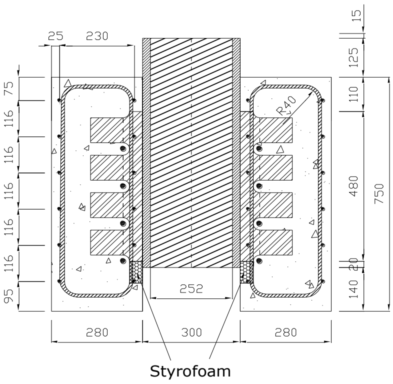
Minimum load	Maximum load	Load range
30 kN	300 kN	30 ~ 300 kN

3.2 Determination of load range for cyclic loading tests

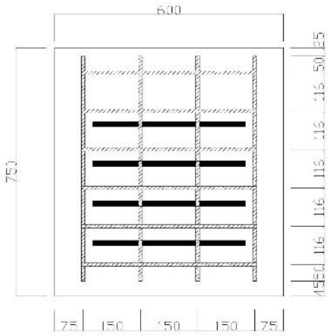
A total of 650 thousand cycles are applied to the specimens. The cyclic loading tests has been continued up to 1.3 million cycles with the Y-type-B specimen, that has resulted in the maximum slip after 0.65 million cycles. Table 3 shows the load range and the number of cycles for the residual strength tests. During cyclic loading tests, slip and stiffness are measured every 10 thousand cycles. A L-shaped angle is attached at middle of the RC slab and four 50 mm Linear Variable Differential Transformer(LVDT)s are installed to measure the slip between the concrete and steel. Fig. 3 shows the set-up of the cyclic loading tests.

Table 3 Load range and cycles for cyclic loading test

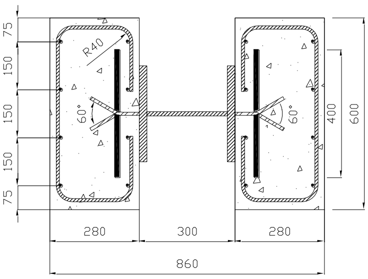
Category			Note
Load range	30 ~ 300 kN		Refer to KHBS (MOCT, 2008)
Cycles	650×10^3	Y-type-A Y-type-B Y-type-C	Frequency : 1 Hz
	1.3×10^6	Specimen that has resulted in the maximum slip after 650×10^3 cycles	



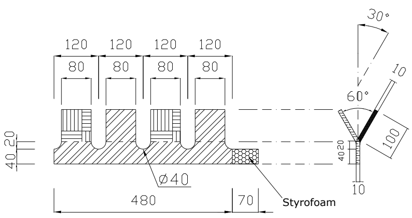
(a) Front view(unit : mm).



(b) Side view(unit : mm).



(c) Plain view(unit : mm).



(d) Details of connector(unit : mm).

Fig. 2 Layout of specimen

Fig. 3 Test set up of cyclic loading test

4. RESULT OF CYCLIC LOADING TEST

The results of the cyclic loading tests are shown in Table 4 and Fig. 4. During the additional 650 thousand cycles, the slip of the Y-type-B connector increased by 0.01 mm. The slip of the Y-type-A specimen increased up to 70 thousand cycles and then increased slowly from 70 thousand cycles to 500 thousand cycles. It remained almost unchanged afterwards. In the Y-type-B specimen, the slip increased sharply at 70 thousand cycles and then remained relatively constant up to 1.3 million cycles. The slip of the Y-type-C specimen increased up to 100 thousand cycles and remained almost unchanged thereafter.

The Y-type-B specimen is taken as a representative specimen of Y-type perfobond rib shear connectors. The characteristics of the stud shear connector follow the equations proposed (Hanswille et al. 2006). The numerical value of load range and shear resistance in the equations are the same as that of the Y-type perfobond rib shear connector. Therefore, the characteristics of stud shear connector can be compared with Y-type perfobond rib shear connector.

Under repeated loading, the specimen Y-type-A and C experience slightly large slip in the early stage and the slips are always lower than stud shear connectors. The early stage slip of Y-type-B specimen is greater than that of the stud shear connector, but it remains almost unchanged up to 1.3 million cycles. The stud shear connectors undergoes gradual increasing slip even though the permanent slip in the beginning stage is smaller, but it becomes larger than specimen Y-type-B after half million cycles. Fig. 5 shows the relationships between the slip and the loading cycles for the Y-type perfobond rib shear connector and the stud shear connector.

Table 4 Results of cyclic loading tests

Cycles ($\times 10^3$)	Specimens	Slip
650	Y-type-A	0.37 mm
	Y-type-B	0.39 mm
	Y-type-C	0.24 mm
1,300	Y-type-B	0.40 mm

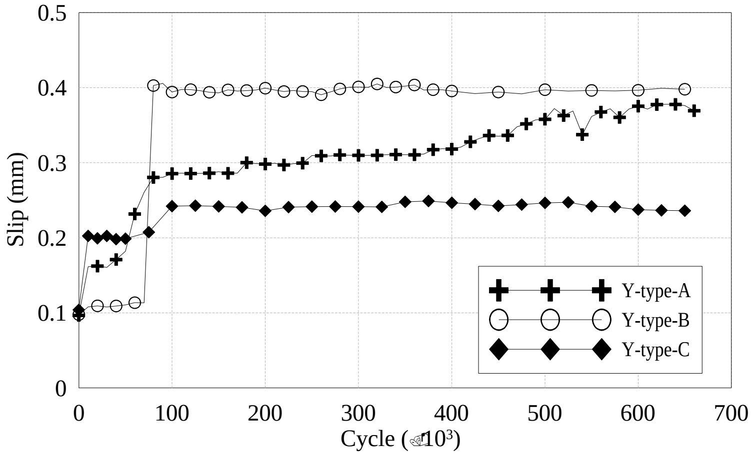


Fig. 4 Slip-loading cycle relationships of Y-type perfobond rib shear connectors

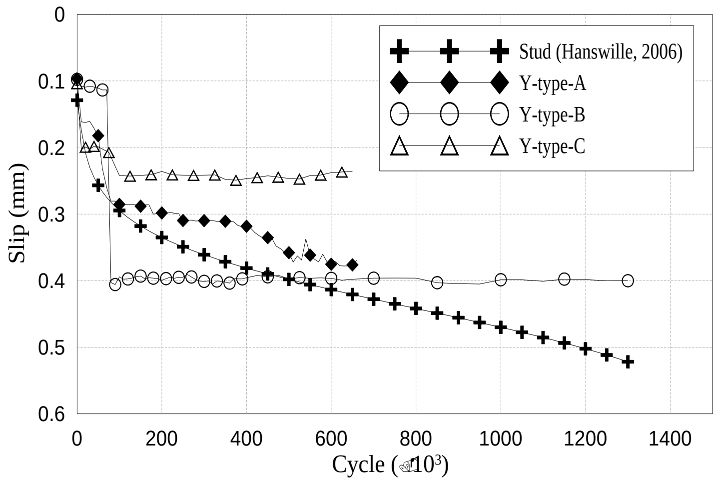


Fig. 5 Slip-loading relationships of Y-type perfobond rib shear connectors and stud shear connectors

5. CONCLUSION

The relative slip amplitude of Y-type perfobond rib shear connectors under cyclic loading is estimated. Under the repeated loadings, the permanent plastic slips between the Y-type perfobond rib shear connectors and RC slab are monitored. It is found that the Y-type perfobond rib shear connectors provide smaller permanent plastic slip than the stud shear connectors. Even though the plastic slip of the Y-type perfobond rib shear connector increases sharply in the initial stage, it remains unchanged upto 1.3 million cycles. The plastic slip in the system with the stud shear connectors increases gradually and becomes larger after about 0.5 million cycles.

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