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ULTIMATE SLIP STRENGTH OF PERFOBOND STRIP CONFINED BY CONCRETE COVER

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The ultimate slip strength of a perfobond strip (called "PBL" hereafter) depends significantly on the concrete confinement conditions around PBL hole as well as concrete shear fractures at the hole. If the hole is small, the effect of concrete confinement will still more strongly appear. In this paper, focusing on the concrete confinement due to concrete cover, the ultimate slip strength of PBL with a small hole is investigated experimentally through push-out tests, in which the diameter of PBL hole is set at 30 mm and the thickness of the concrete cover is varied from 0 to 100 mm. Test results show that the concrete separates into two blocks with concrete crack parallel to the PBL plate and that the ultimate slip strength of a 50-mm-thick concrete cover is 34.4 kN, which is about 10 times of the slip strength without concrete cover (3.5 kN). Thus, it can be concluded that thicker concrete cover makes the slip strength remarkably larger, in the case of small-hole PBLs.

Keywords: Push-out tests, Confinement, PBL.

1 INTRODUCTION

PBL proposed by Leonhardt *et al.* (1987), is a shear connector to resist the slippage between different materials in composite structures. In order to design PBL, the evaluation formula of the ultimate slip strength was proposed by Leonhardt *et al.* (1987) etc. and also indicated by the Japanese Standard Specifications for Hybrid Structures (2015). These formulas are formulated by only two parameters, the diameter of the PBL hole and the compressive strength of concrete. Consequently, the ultimate slip strength of PBL is determined by the concrete strength and the area of PBL hole, in the case of without rebar. However, Nakajima *et al.* (2011), and Fujii *et al.* (2014) showed that the ultimate slip strength of PBL depends on the confinement condition of the concrete surrounding PBL hole.

Although PBLs have been used for preventing slip between steel girders and concrete floor slabs in composite girders, in recent years, their use is spreading widely to various composite structures, such as composite slab, the connection between pre-cast members, and so on. In particular, for application to thin composite slabs, PBL with a small hole will be used. Then, its ultimate slip strength should be clarified considering the effect of concrete confinement for economical design.

In this paper, push-out tests of PBL with small-hole of 30 mm diameter are conducted, changing the thickness of concrete cover in order to clarify the effect of the confinement due to concrete cover confinement on the ultimate PBL slip strength.

2 OVERVIEW OF PUSH-OUT TESTS

We made two types of specimens, in which one (A series) has a concrete block inserted a PBL plate with a hole, as shown in Figure 1, the other (B series) has two concrete blocks sandwiching a cross-shape steel column whose two plates have a hole respectively, as shown in Figure 2 (Furukawa *et al.* 2011).

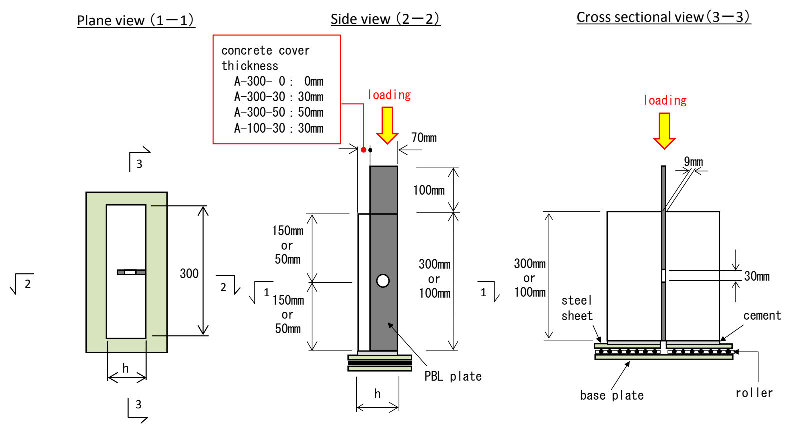

Figure 1. Specimen shape (A series).

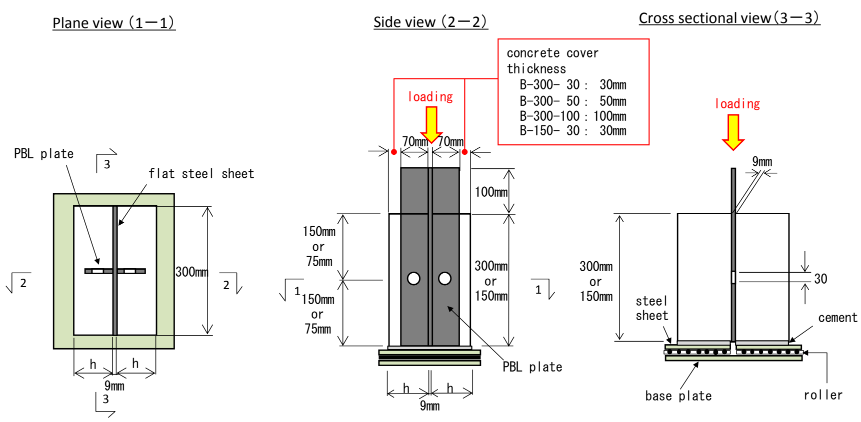

Figure 2. Specimen shape (B series).

Dimensions and material properties of specimens are indicated in Table 1. In the table, concrete cover thickness means the distance from the PBL-plate tip to the concrete surface as shown in Figure 1 and 2. Focusing on the confined effect of concrete cover, in this paper, all specimens have a different concrete cover (0, 30, 50 and 100 mm), respectively, whereas the diameter of PBL hole is the same as 30mm. For the size of the concrete block, the height of almost specimens is set 300mm, but adding to these, the specimens of A-100-30 and B-150-30 are also made, in order to investigate the effect of concrete confinement due to the height of the concrete block. Moreover, the PBL plate surfaces are not processed to remove bonding between concrete and PBL plate, though the bonding force between concrete and flat steel plate at B-series is removed by coating grease.

Before loading, a specimen is placed on the roller support, as shown in Figure 1 and 2, in order to remove the frictional force between concrete block and test bed at the bottom. Then slip load is subjected to the top of PBL plate and increased up to the maximum load. At the fracture, the concrete is divided into two blocks as shown in Figure 3, then, the load decreases rapidly.

If the specimen is set directly on the layer such as gypsum or mortar laid on the test bed, the frictional force appears. Consequently, the frictional force, which works to confine the concrete around the hole, makes the slip strength of PBL enhance significantly (Fujii *et al.* 2014). Readers will notice that this frictional force never appears in the actual structure, except the case of slip test such like a push-out test.

Table 1. Dimensions and material properties.

series	test sample	concrete					PBL plate	
		length (mm)	heigth (mm)	concrete cover thickness (mm)	compressive strength (N/mm^2)	Aggregate diameter (mm)	plate thickness (mm)	yield strength (N/mm^2)
A	A-300-0	70	300	0	62.5	20	9	more than 245
	A-300-30	100	300	30	59.5			
	A-300-50	120	300	50	59.5			
	A-100-30	100	100	30	59.5			
B	B-300-30	100	300	30	72.8	20	9	more than 245
	B-300-50	120	300	50	72.8			
	B-300-100	170	300	100	72.8			
	B-150-30	100	150	30	72.8			

3 RESULTS AND DISCUSSION

3.1 Ultimate Slip Strength

A-300-30

B-300-30

Figure 3. Specimen appearance after failure.

Every specimen were failed by the occurrence of concrete cracks at PBL hole and also of concrete crack parallel to PBL plate in the concrete cover. Consequently, a concrete block sandwiching PBL plate was divided into two pieces, as shown in Figure 3. Ultimate slip strength of PBL obtained from the tests is indicated in Table 2, also those based on three evaluation formulas, where the evaluation formula of Eq. (1) in the table was proposed by Leonhardt *et al.* (1987), Eq. (2) is now being adopted in JSSHS (Japanese Standard Specifications for Hybrid Structures 2015) and Eq. (3) was proposed by Fujii *et al.* (2014).

Table 2. Ultimate slip strength.

series	test sample	[A] experimentally maximum load (kN)	calculated ultimate slip strength (evaluation formula)						concrete properties (N/mm^2)	
			Eq. (1)		Eq. (2)		Eq. (3)			
			① strength (kN)	[A]/①	② strength (kN)	[A]/②	③ strength (kN)	[A]/③	tensile strength	Young's modulus
A	A-300-0	3.5	98.4	0.04	90.0	0.04	3.6	0.97	2.5	2.6×10^4
	A-300-30	18.5	93.7	0.20	85.7	0.22	9.3	1.99	2.5	2.6×10^4
	A-300-50	34.4	93.7	0.37	85.7	0.40	16.1	2.14	2.5	2.6×10^4
	A-100-30	12.2	93.7	0.13	85.7	0.14	5.5	2.22	2.5	2.6×10^4
B	B-300-30	※ 38.3	114.7	0.33	104.9	0.37	12.3	3.11	3.4	4.2×10^4
	B-300-50	※ 42.9	114.7	0.37	104.9	0.41	21.3	2.01	3.4	4.2×10^4
	B-300-100	※ 59.7	114.7	0.52	104.9	0.57	48.1	1.24	3.4	4.2×10^4
	B-150-30	※ 14.7	114.7	0.13	104.9	0.14	8.5	1.73	3.4	4.2×10^4

※ half of the loading load

Leonhardt *et al.* (1987):

$$V=1.4\times d^2\times\beta_{wn} \tag{1}$$

where, V: ultimate slip strength [N], d: diameter of PBL hole [mm], and β_{wn}: compressive strength obtained from cubic concrete specimen based on ISO 1920-3 [N/mm^2]. Since the compressive strength f'_c is usually used based on the test result of a cylindrical specimen according to JIS A 1132 in Japan, the compressive strength β_{wn} is given by changing from cylindrical to cubic compressive strength using the relationship of $f'_c / \beta_{wn}=0.8$.

JSSHS (2015):

$$V=\frac{1.6\times d^2\times f'_c}{\gamma_b} \tag{2}$$

where f'_c: compressive strength of a cylindrical specimen [N/mm^2], and γ_b: member factor (=1.0).

Fujii *et al.* (2014):

$$V=V_{int}+2.5\times T_c \tag{3a}$$

$$V_{int}=2\times(\pi\times\frac{d^2}{4}+(n-1)\times A_s)\times\tau_{ct} \tag{3b}$$

In Eq. (3), V_{int}: the pure shear strength under the condition without concrete confinement [N], this condition corresponds to the specimen without concrete cover in this paper. T_c: the maximum confined force caused by the concrete cover, that is the maximum resistance force resisting the splitting force which causes concrete block dividing into two blocks. n: the ratio of the elastic modulus E_s/ E_c for concrete E_c and rebar E_s, A_s: the cross-sectional area of rebar set through -PBL hole [mm^2] (=0 in this paper), and τ_{ct}: shear strength of concrete, which Fujii *et al.* (2014) adopts tensile strength of concrete [N/mm^2].

Exactly speaking, Fujii *et al.* (2014) indicated confinement factors not only the cover but also other factors, that is: rebar set through PBL hole, rebar set perpendicular to PBL plate in the cover, and the friction force along the boundary between block and test bed at the bottom as mentioned above, in the case of push-out test. By the way, Fujii *et al.* (2014) made the evaluation formula Eq. (3) of ultimate slip strength based on the following assumptions:

(1) When slip force (shear force) V is subjected to PBL, the slip force will produce the splitting force T at the hole, as shown in Figure 4, as well as a shear force which corresponds to V_{int} in Eq. (3). Then, the splitting force will be larger as the slip force increases.
(2) The splitting force will make concrete fracture at the hole, consequently, the concrete is broken to two pieces, as shown in Figure 4.
(3) If confinement force, which prevents the above concrete fracture, exists, it will make the ultimate slip strength enhance up to when the splitting force exceeds the confinement force.

For the confinement force due to the concrete cover in the push-out test, the concrete sandwiching the PBL plate can be regarded as a rigid frame consisted of the cover and both sides concrete, as shown in Figure 3. The maximum confinement force T_c can be calculated as the fiber stress reaches to the tensile strength of the concrete at the top of the PBL plate in Figure 3, by using beam theory. Then, the ultimate slip strength becomes larger as the concrete height becomes higher by the reason of bigger inertial moment and cross-sectional area of the cover concrete.

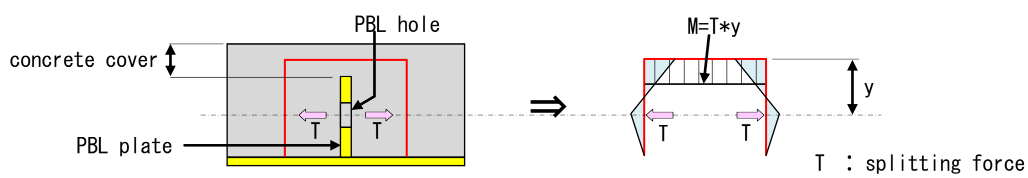

Figure 4. PBL model used by Fujii *et al.* (2014).

Ultimate slip strengths obtained from tests are indicated in Table 2, and also calculated by each evaluation formula are shown to compare. From the test results, it is noticed that the ultimate strength of PBL grows big, as the concrete cover becomes thicker. Moreover, when the concrete cover exists, the higher height of the concrete block gives bigger ultimate slip strength, comparing A-300-30 with A-100-30 or B-300-30 with B-150-30. On the other hand, when the cover does not exist such as the specimen A-300-0, ultimate slip strength does not change and is almost the same as A-300-0 even if the concrete height varies, although this fact could not enough show here. These phenomena are obviously caused by the confinement effect depending on the concrete cover. As for Eq. (1) and Eq. (2), it is noticed that the ultimate slip strength is determined only by the diameter of PBL and compressive strength of concrete. Therefore, the ultimate slip strength becomes consequently the same value for each series in Table 2, because these equations cannot take the confinement effect into account. Adding to this, also noticed that the ultimate slip strengths based on both equations are significantly larger than test results. This reason is probably that these evaluation equations were built by regression analysis based on the experimental data, which must have contained several confinement effects. In contrast, Eq. (3) can show the tendency of the phenomena due to confined effect, as indicated in Table 2. However, the value of ultimate slip strength has significant difference between test results and the evaluated values by Eq. (3), without the case of without concrete cover.

Thus, the confinement force effects largely on the ultimate slip strength of PBL, for example, when the specimens of concrete strength at the same level is compared, the ultimate slip strength of the specimen A-300-50 (cover-thickness=50 mm) was approximately 10 times higher than that of A-300-0 (without cover). Consequently, it can be concluded that the confined effect must be evaluated correctly in the evaluation formula.

4 CONCLUSIONS

Focusing on only the concrete confinement of the concrete cover, ultimate slip strength of PBL with a small hole was investigated by conducting push-out tests. Since the ultimate slip strength depends clearly on the confinement condition of concrete, the friction force at the bottom, one of the confinement factors, was removed completely by the roller in this paper. Test results were compared with three evaluation formulas having been proposed. Conclusions are as below:

(1) Ultimate slip strength becomes larger as concrete cover becomes thicker. This fact is clearly due to the confined effect caused by the cover. When the cover is 50 mm, the slip strength (34.4 kN) is about 10 times of that without cover (3.5 kN). Thus, ultimate slip strength is significantly affected by the concrete confinement.

(2) For ultimate slip strength, test results are far smaller than that obtained by both Leonhardt *et al.* (1987) and Japanese Standard Specifications for Hybrid Structures. Especially in the case without concrete cover, the test result is about 1/25 of them. This reason is that their evaluation formulas are tacitly taken confined effects into account because they are derived from a regression analysis of experimental data, many of which contain several concrete confinements.

(3) When the specimen has no concrete cover, the ultimate slip strengths are almost the same between the test and Fujii *et al.* (2014). But, in the case with concrete cover, the remarkable difference is recognized between them. Though Fujii *et al.* (2014) can show the tendency of the confinement phenomena due to the cover, their evaluation formula should be improved more in the future.

(4) Ultimate slip strength increased as the concrete height of specimen becomes larger. This phenomenon is also caused by the concrete confinement of the cover and can be explained also by the concept of Fujii *et al*. (2014).

References

Fujii, K., Doukan, Y., Iwasaki,H., Himukai, M., Mori, K., and Yamaguchi,S., Ultimate Shear Strength of Perfobond Strip, *Journal of Japan Society of Civil Engineers*, Japan Society of Civil Engineers, A1, 70(5), 53-68, May, 2014.

Furukawa, Y., Fujii, K., Doukan, Y., and Yamaguchi,S., *On Pushes Tests Slip Strength of PBL Under Dimensional Parameters*, The 9th Symposium on Research and Application of Hybrid and Composite Structures, Japan Society of Civil Engineers, 58-65, November, 2011.

Japanese Standard Specifications for Hybrid Structures, *2014 Design*, Japan Society of Civil Engineers, 74-77, 581-584, March, 2015.

Leonhardt, F., Andrä, W., Andrä, H., and Harre, W., Neues, Vorteilhaftes Verbundmittel für Stahlverbund-Tragwerke mit hoher Dauerfestigkeit, *Beton-und Stahlbetonbau*, 325-331, December, 1987.

Nakajima, A., Hashimoto,M., Koseki, S., and Suzuki, Y., *Evalution of Shear Strength of Perfobond Strip Based on Restrained Push-Out Test*, The 9th Symposium on Research and Application of Hybrid and Composite Structures, Japan Society of Civil Engineers, 49-57, November, 2011.