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Bending Behavior of Steel-Concrete Composite Girder with Perfobond Shear Connector Using Super-light Weight Concrete with Steel Fiber Reinforcement

by

Shenghua GUO*, Shinichi HINO**, Kohei YAMAGUCHI***,
Jisun CHOI↑ and Takatomo SONODA↑↑

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Abstract

Recently, the development of the light-weight concrete with short fiber reinforcement is done to simplify the reduction and the structure section of the self-weight. It is possible of lightening about 30 percent using super-light weight concrete compared with normal concrete. On the other hand, there is a reinforcement method of usually having material strength equal with normal concrete by mixing steel short fiber. This study aims at clarify shear strength evaluation of perfobond shear connectors (PBL) using super-light weight concrete with steel short fiber. In this study, it was carried out push-out test and bending test of composite girder using super-light weight concrete with steel short fiber to clarify the presence of a concrete kind and the fiber mixing.

As a result, it was clarified such as: (1) the shear behavior and shear strength evaluation of PBL and (2) applicability of the PBL in composite girder which using super-light weight concrete with steel short fiber.

Keywords: Bending behavior, Shear strength evaluation, Perfobond shear connectors, Super-light weight concrete, Composite girder

1. Introduction

Recenthy, high-raised buildings and big-size infra-structures using reinforced concrete have been. Therefore high strength and lightweight materials are needed. Moreover, weight saving have beneficial effects on environmental problems. Regarding to lightweight material, a super-light weight concrete (SL) using artificial lightweight aggregate could be a good solution. Specific gravity of super-light weight concrete is less

* Graduate Student, Department of Urban and Environmental Engineering
** Professor, Department of Civil and Structural Engineering
*** Assistant Professor, Department of Civil and Structural Engineering
↑ Graduate Student, Department of Urban and Environmental Engineering
↑↑ Graduate Student, Department of Urban and Environmental Engineering

than 1.6. It is expected that use of SL concrete could increase the seismic resistance and economical efficiency by reducing the excessive weight of structures. However, it is weak points against tensile strength and shear strength compared to normal weight concrete. In order to overcome those weak points, adding short fibers into super-light weight concrete was examined. This method was based on the idea that short fibers could increase the tensile strength of concrete.

The short fiber could demonstrate the performances of various each externals steel fiber, vinylon fiber, PVA fiber, etc. In this study, the steel fiber with especially high effect of the strength improvement is targeted.

Moreover, as a connect method of steel and concrete with high slip rigidity, excellent fatigue strength[1)] and workability, PBL is paid to attention. However, it has been researched on shear strength evaluation of perfobond shear connectors using super-light weight concrete with steel short fiber reinforcement. In this study, push-out test and bending test of composite girder using super-light weight concrete with steel short fiber was carried out to clarify the presence of a concrete kind and the fiber mixing was carried out. Based on those test results, the shear behavior and shear strength evaluation of PBL; applicability of the composite girder with PBL using super-light weight concrete with steel short fiber reinforcement was clarified.

2. Push-out Test on PBL Connectors

2.1 Evaluation of shear strength in past research

Shear strength evaluation of PBL have been proposed by Leonhardt[2)], Hosaka[3)]. In this study, the structure of PBL with a reinforce bar through the aperture is targeted. **Eq. (1)** is formulated basically with the push-out test by Hosaka which parameters; apertures number, steel board thickness and reinforcing bar through the hold or not of PBL in normal concrete (N). Moreover, **Eq. (2)** [4)] is a lower bound type of **Eq. (1)**.

On the other hand, push-out test used light-weight concrete by Suzuki[5)] confirmed the shear destruction of PBL is influenced by the kind of aggregate and it is necessary to consider the reduction factor to the equation of normal concrete for evaluate light-weight concrete. **Eq. (3)** evaluates it by multiplying reduction factor 0.7 to $(d^2 - \phi^2) \cdot f'_{cu}$ shows in **Eq. (1)**.

2.2 Definition of shear strength

There are two definitions of the shear strength by the past research as **Fig.1**. The frist is defined shear strength of the PBL with the maximum load (defined as V_{max}) in push-out test and the second is defined with the load up to the relative displacement 10mm (defined as V_{10mm}). V_{max} has possible to ends the test before V_{max} appears by the convenience of test or the penetrated reinforce bar is broken after contact with the steel board of PBL. On the other hand, **Eq. (1)** is formulated basically by many data with V_{10mm}. Moreover, because the penetrated reinforce bar doesn't contact with the steel board of PBL in usual if the relative displacement under 10mm, the shear strength of PBL is evaluated in V_{10mm} in this study.

$$Q_u = 1.45\left\{\left(d^2 - \phi^2\right)\cdot f'_{cu} + \phi^2 \cdot f_{st}\right\} - 26.1\times 10^3 \tag{1}$$

$$Q_u = 1.45\{(d^2 - \phi^2)\cdot f'_{cu} + \phi^2 \cdot f_{st}\} - 106.1\times 10^3 \quad (2)$$

$$Q_u = 1.45\{\,0.7\,(d^2 - \phi^2)\cdot f'_{cu} + \phi^2 \cdot f_{st}\} - 26.1\times 10^3 \quad (3)$$

Q_u : Shear strength per PBL (N)
f'_{cu} : Compressive strength of concrete (N/mm^2)
d : diameter of aperture (mm)
ϕ : diameter of the penetrated reinforce bar (mm)
f_{st} : Tensile strength of the penetrated reinforce bar (N/mm^2)

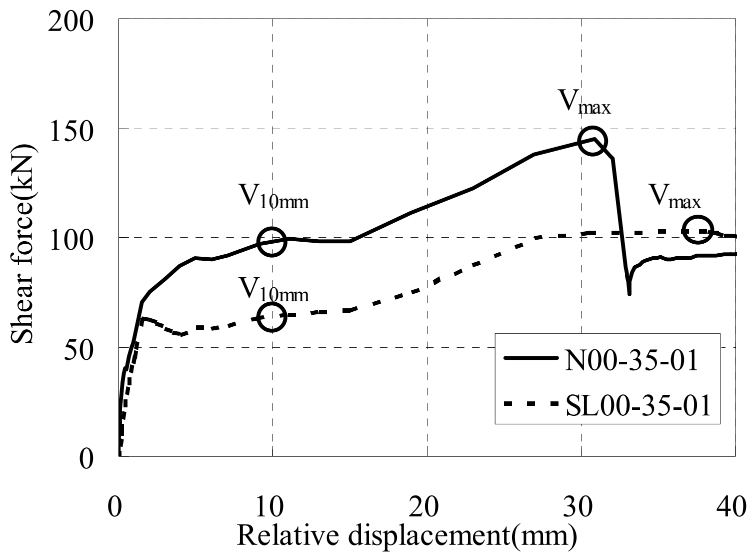


Fig. 1 Definition of shear strength.

2.3 Material test

In the material test (Compressive, Tensile, Flexural, Shear strength), the fiber mixing rate (0%, 1.2%) was assumed to be a parameter to normal concrete and super-light weight concrete. **Table 1** shows material type used in super-light weight concrete and **Table 2** shows the proportion of concrete. Concrete strength and Young's modulus of all kinds of specimens are shown in **Table 3**. As for compressive strength, the effect the fiber mixing between N, SL is hardly seen from this table. However, in tensile, flexural and shear strength, it is tends to improve by the fiber mixing remarkably.

2.4 Outline of specimens and push-out test

The parameters of the specimen in push-out test are concrete kind (N, SL), presence (0%, 1.2%) of the steel fiber mixing, and aperture (35mm, 50mm) of PBL as shown in **Table 3**. Here in after, loading test is carried out for three same specimens by the six kinds of specimens. The size of the specimens and the test methods were mainly following "Push-out Test for Handed Stud (Draft)"[6] show in **Fig.3**. Moreover, penetrated reinforce bar D13 SD295 (tensile strength $570N/mm^2$) was arranged in all specimens. The relative displacement between H steel and the concrete block at the penetrated reinforce bar position was measured. The strain gage was patched on the penetrated reinforce bar at 31mm and 125mm away from center two pieces respectively. The loading was repeated by 0.1mm with the relative displacement increment up to relative displacement be in 1mm, 0.5mm up to 10mm, and 5mm after that. No.3 of N00-35 was increased the load monotonically and the evaluation of date not included it. The setup of specimen is shown in **Fig.4**.

Table 1 Material type.

<table>
<tr><th>Material Type</th><th>Detail</th><th>Code</th><th>Property</th></tr>
<tr><td>Cement</td><td>Ordinary portland cement</td><td>C</td><td>Density: 3.16g/cm^3</td></tr>
<tr><td>Normal fine aggregate</td><td>-</td><td>Normal S</td><td>Surface-dry density: 2.55g/cm^3
Water-absorbing ratio: 1.92%</td></tr>
<tr><td>Normal coarse aggregate</td><td>-</td><td>Normal G</td><td>Surface-dry density: 2.90g/cm^3
Water-absorbing ratio: 1.92%</td></tr>
<tr><td>Artificial lightweight fine aggregate</td><td rowspan="2">ASANO Light</td><td>Light S</td><td>Density: 1.89g/cm^3
Water-absorbing ratio: 16.65%</td></tr>
<tr><td>Artificial lightweight coarse aggregate</td><td>Light G</td><td>Density: 1.32g/cm^3
Water-absorbing ratio: 10.92%</td></tr>
<tr><td rowspan="3">Chemical admixture</td><td>High-performance AE water-reducing admixture</td><td>SP</td><td>SF500S
Polycarvone oxidation compound</td></tr>
<tr><td>AE auxiliaries</td><td>AE</td><td>AE-4</td></tr>
<tr><td>Thickener</td><td>B</td><td>Bioporil</td></tr>
<tr><td>Steel fiber</td><td>Dramix</td><td>F</td><td>Density: 7.85g/cm^3</td></tr>
</table>

Table 2 Proportion of concrete.

Type	water-cement ratio (W/C)	kg/m^3							
		W	C	S	G	SP	AE	B	F
N00-35	50.0	213	427	870 (Nomal)	862 (Nomal)	1.08	1.00	0	0
N12-35	50.0	211	422	860 (Nomal)	852 (Nomal)	2.40	0	0	94.0
SL00-35 SL00-50	47.5	233	490	542 (Light)	408 (Light)	0	0	1.00	0
SL12-35 SL12-50	47.5	228	480	531 (Light)	400 (Light)	4.85	0	1.00	94.0

Table 3 Specimen type and material strength of concrete.

(a) Specimen type.

Type (n=3)	Concrete type	Fiver mix rate (%)	Aperture diameter (mm)
N00-35	Normal (N)	0	35
N12-35		1.2	
SL00-35	Super-Light weight (SL)	0	
SL12-35		1.2	
SL00-50		0	50
SL12-50		1.2	

(b) Material strength of concrete.

Type (n=3)	Compressive Strength (N/mm^2)	Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)	Shear Strength (N/mm^2)	Young's Modulus (kN/mm^2)
N00-35	39.8	3.07	5.30	4.68	28.1
N12-35	32.5	3.73	8.28	6.15	26.0
SL00-35	40.2	2.11	3.53	3.42	15.2
SL12-35	41.0	4.37	8.86	5.37	17.4
SL00-50	37.7	2.07	3.23	3.25	14.4
SL12-50	36.1	4.29	6.75	5.01	16.0

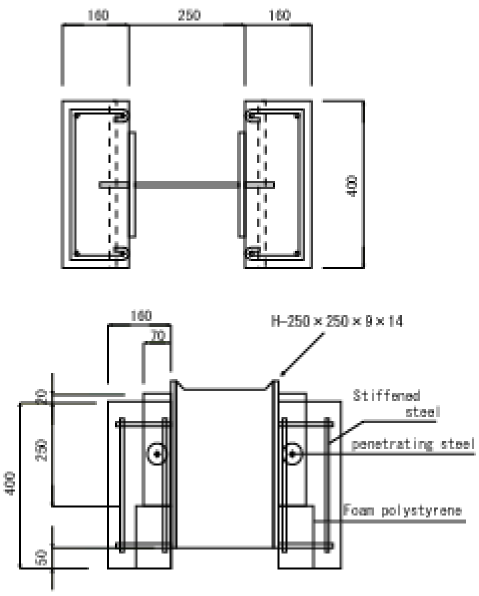


Fig. 3 Push-out specimen. (Unit: mm)

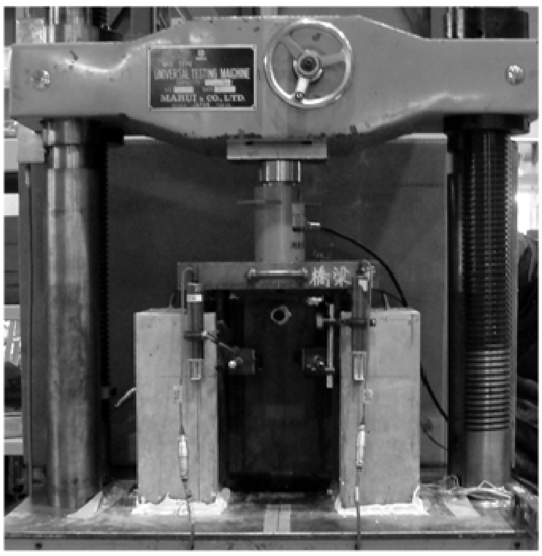


Fig. 4 Setup of specimen.

2.5 Shear strength and slip stiffness

The test result is shown in **Table 4**. The shear strength is converted by one aperture and shown. It is clarified that the difference obviously in the same specimen of the aperture 35mm from the comparison between shear strength V_{10mm} and V_{max} of each type shown in **Fig.5**. Therefore, V_{10mm} is considered as follows. The load keeps increasing with which specimen of the aperture 50mm since V_{10mm}. However, the loading was discontinued because H steel came to contact testing machine before the loading decrease. The maximum load decreases by lightening from SL for aperture 35mm in V_{10mm} was 0.60 times and 0.53 times as N which with the fiber reinforcement or none respectively. Moreover, it is clarified that the effect of the fiber reinforcement is not remarkable like 1.20 times in N and 1.06 times in SL from the comparison with the fiber reinforcement or none. The effect of the fiber reinforcement was hardly seen even in case of the aperture 50mm etc.

Shear strength and slip stiffness (K_{10mm}) are shown in **Table 4**. The slip stiffness is an initial tangent rigidity of the $V_{10mm}/3$ load point in action shear force-relative

Table 4 Results of push-out test.

Type	No.	Aperture diameter (mm)	f'_{cu} (N/mm^2)	V_{10mm} (kN)	V_{max} (kN)	K_{10mm} (kN/mm)	Calculated value(Eq.1) (kN)	V_{10mm}/ Calculated value	V_{max}/ Calculated value
N00-35	1	35	39.8	97.2	145	450	175	0.56	0.83
	2			108	153	216		0.62	0.87
	3			—	—	—		—	—
	Avg.			103	149	333		0.59	0.85
N12-35	1	35	32.5	104	174	647	163	0.64	1.06
	2			112	195	241		0.69	1.19
	3			131	178	400		0.80	1.09
	Avg.			116	182	429		0.71	1.11
SL00-35	1	35	40.2	63.2	102	141	175	0.36	0.58
	2			65.8	103	404		0.38	0.59
	3			58.4	97	1868		0.33	0.56
	Avg.			62.4	101	804		0.36	0.58
SL12-35	1	35	41.0	62.2	121	460	176	0.35	0.68
	2			72.3	120	2240		0.41	0.68
	3			66.3	149	2120		0.38	0.84
	Avg.			66.9	130	1607		0.38	0.74
SL00-50	1	50	37.7	79.2	—	90.4	241	0.33	—
	2			83.1	—	88.3		0.34	—
	3			85.8	—	117		0.36	—
	Avg.			82.7	—	98.5		0.34	—
SL12-50	1	50	36.1	79.4	—	160	236	0.34	—
	2			69.5	—	181		0.29	—
	3			99.0	—	128		0.42	—
	Avg.			82.6	—	156		0.35	—

displacement relation. The result of the slip stiffness from this study and Hosaka[3)] that also used the specimen with penetrated reinforce bar diameter 13mm and aperture 35mm is shown in **Fig.6**. There was a difference in the result, and a clear correlation by super-light weight concrete and fiber mixing was not obtained. K_{10mm} is from 80 to 2300 kN/mm according to the test result. Moreover, the test result is less than the data by Hosaka.

2.6 Load-relative displacement relation

Load-relative displacement relation is shown in **Fig.7**. As for N00-35 and N12-35, it is shown that the load does a continuation increase from **Fig.7 (a)** and **(b)**. Moreover, the load of N00-35-03 and N12-35-03 increases rapidly by the relative displacement about 9mm. It is safe to assume that the penetrated reinforce bar came in contact with the steel board of PBL. The load decrease of SL is remarkably seen from **Fig.7 (c)** in the relative displacement about 2mm. On the other hand, the difference in the curve by presence of fiber mixing with both N and SL was hardly seen, and a clear effect of the fiber reinforcement was not achieved.

2.7 Failure mode of concrete in-aperture

The concrete failure mode inside aperture is shown in **Fig.8**. In the test, the loading was continued until the penetrated reinforce bar came in contact the steel board of PBL. Firstly, concrete upper of the reinforce bar is collapsed with the load increase and became disintegration. Finally, the reinforce bar has come to contact the steel board of PBL as shown in the photograph. Moreover, it is able to confirm that there was coarse aggregate in the aperture from the photograph of aperture 50mm.

There is little difference by the fiber reinforcement in V_{10mm}. It may be attributable of the penetrated reinforce bar. The fracture mechanism of the concrete inside-aperture without penetrated reinforce bar is shown in **Fig.9**. There is evident that concrete on both sides of the aperture does the shear destruction without penetrated reinforce bar. Therefore, it is clarified that the shear strength of PBL improves as well as shear strength like the material testing value when the fiber is mixed and the penetrated reinforce bar is none though it doesn't clarify by the examination this time. However, when there is a

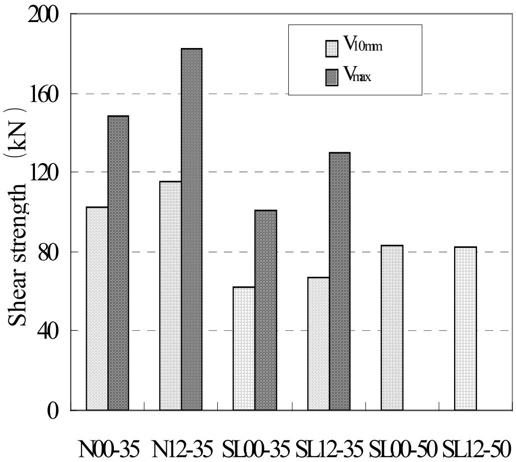


Fig. 5 Shear strength.

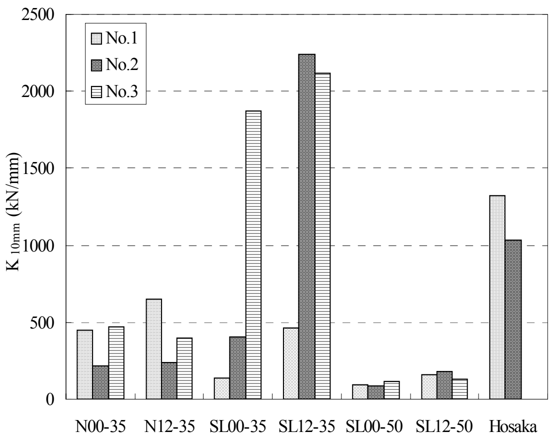
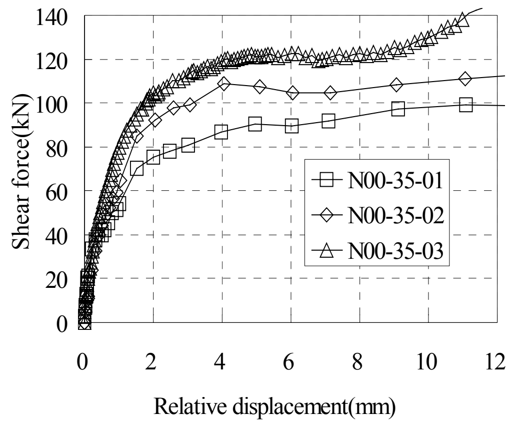
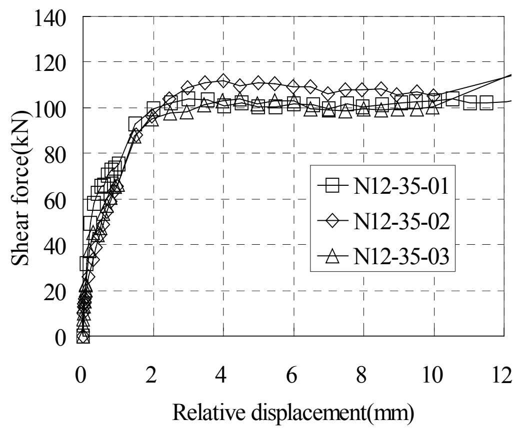


Fig. 6 Slip stiffness.

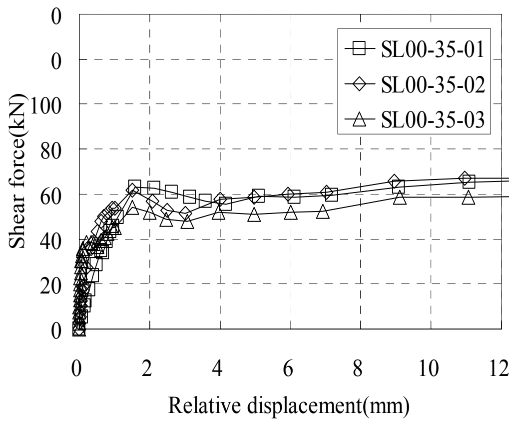
penetrated reinforce bar set, shear force that the concrete inside-aperture and both sides of the aperture receives will distribute by the penetrated reinforce bar. In this time, no the shear fracture but the compressive fracture of concrete upper the penetrated reinforce bar is caused previously.



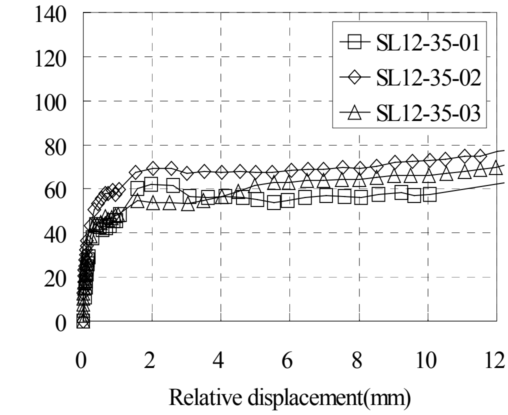
(a) N00-35



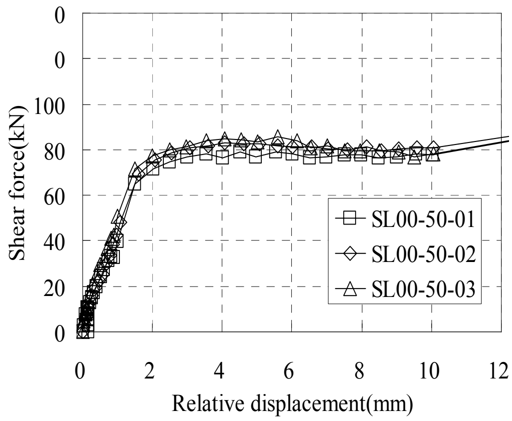
(b) N12-35



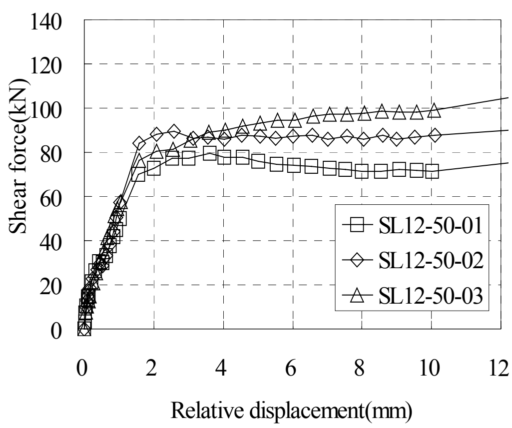
(c) SL00-35



(d) SL12-35



(e) SL00-50



(f) SL12-50

Fig. 7 Load-relative displacement relation.

2.8 Evaluation of shear strength

Fig.10 shows the relation between shear strength and $(d^2 - \phi^2) \cdot f'_{cu} + \phi^2 \cdot f_{st}$ per aperture. This data is the radical of test result in **Eq. (1).** The Figure below is a close up in the above figure. Here, because the data of **Eq. (1)** was mixed by V_{10mm} and V_{max}, **Eq. (4)** (all data by V_{10mm}) which only by V_{10mm} data was divided from it and compare to the test result. Moreover, the data of **Eq. (4)** include the data not only from **Eq. (1)** and this study but also past research[7), 8), 9), 10)].

Normal concrete (all data of V_{10mm})

$$Q_u = 1.26\left\{\left(d^2 - \phi^2\right) \cdot f'_{cu} + \phi^2 \cdot f_{st}\right\} - 28.3 \times 10^3 \tag{4}$$

(a) N00-35

(b) N12-35

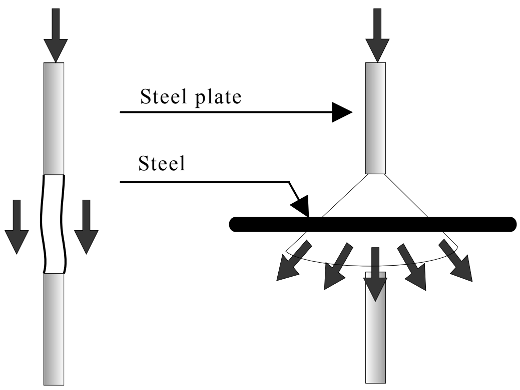
(c) SL00-35

(d) SL12-35

(e) SL00-50

(f) SL12-50

Fig. 8 Failure mode.



(a) Without penetrated reinforce bar. (b) With penetrated reinforce bar.

Fig. 9 Concrete fracture mechanism in aperture.

Table 4 shows the value of test/calculation value of N00-35 (V_{10mm}, No.1 and 2) is 0.56, 0.62. It proves **Eq. (1)** is not appreciable the test result of super-light weight concrete with steel fiber reinforcement. However, the test result of N00-35 can be say appropriate because it more than the lower bound type of **Eq. (4)** (Refer to explanatory notes of **Fig.10**) though it is less than **Eq. (4)** a little. It greatly falls below **Eq. (4)** for SL by both the aperture 35mm and 50mm, and it is thought that it is necessary to multiply the reduction factor by **Eq. (4)** to evaluate it.

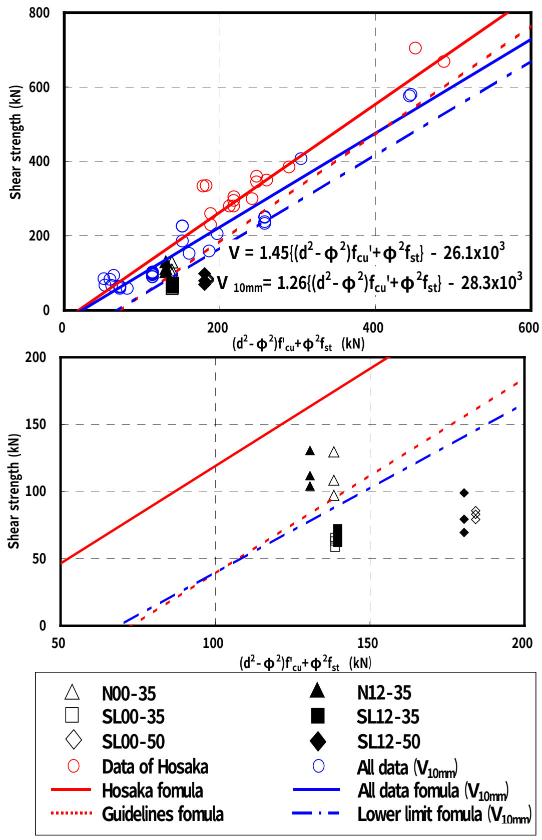


Fig. 10 Evaluation of shear strength.

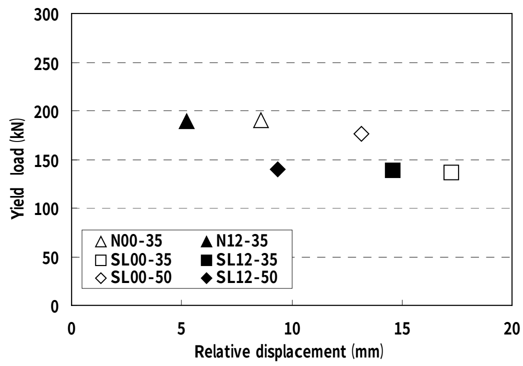


Fig.11 Yield load and relative displacement of penetrated reinforce bar.

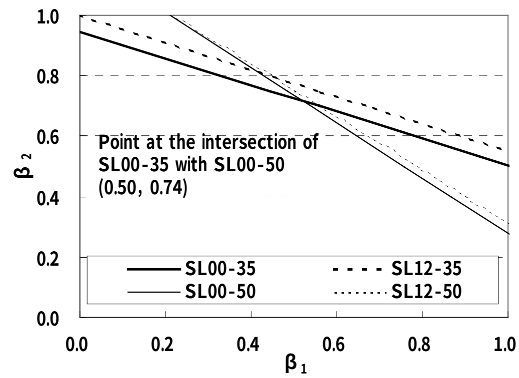


Fig. 12 Reduction factors.

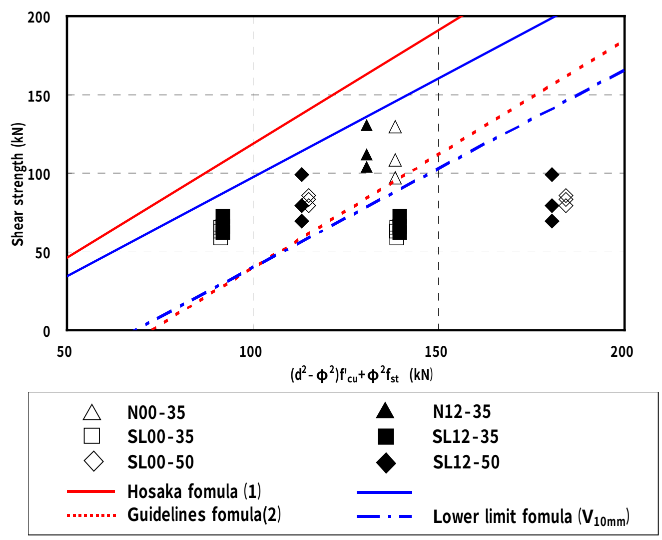


Fig. 13 Evaluation of shear strength.

The relation between the load and the relative displacement when the penetrated reinforce bar yielded is shown in **Fig.11**. As for the relative displacement in this figure, it is clarified that N is less than SL though the yield load is same. Moreover, it is clarified that as the larger mixing of the fiber and the aperture are, the relative displacement will be smaller. This is shown that the degree of monolithically with concrete and the penetrated reinforce bar around the aperture. Because it is surmisable that concrete like SL with small material strength is made disintegration by the low stress easily. When disintegration happens, the force at penetrated reinforce bar becomes small, too. Moreover, to aperture 35mm and 50mm, it is clarified that the reason is that a lot of coarse aggregate enters in the aperture, and concrete strength grew like the confirmation by **Fig.8**. Next, the yield displacement of 1.2% is less than 0% is the influence of material strength by fiber reinforcement. From N and SL like this, it is clarified that the shear strength of PBL used super-light weight concrete with steel fiber reinforcement could not only evaluates by paragraphs of concrete, but also multiply the reduction factor to the penetrated reinforce bar. Then, it proposes the expression to multiply reduction factor β_1 and β_2 by $(d^2-\phi^2)\cdot f'_{cu}$ of concrete and $\phi^2 \cdot f'_{cu}$ of penetrated reinforce bar in this study respectively. Because the effect of the fiber reinforcement was not seen in the result of this study, the average of V_{10mm} with N00-35 and N12-35 is assumed to be an average of N here. The value of β_1 and β_2 equal the calculation value by examination value/proposal type of SL and examination value/calculation value by **Eq. (4)** of N respectively.

The relation between β_1 and β_2 is shown in **Fig.12**. Four segments of SL00-35, SL12-35, SL00-50, and SL12-50 can be shown from the result of this study. β_1 and β_2 concentrates on about 0.7 and 0.5 of intersection in these lines respectively. Because the smallest value of intersection by line SL00-35 and SL00-50 among four segments is (0.50,0.74), it is assumed the reduction factor of super-light weight concrete as β_1 =0.50 and β_2=0.74. The shear strength equation evaluated with V_{10mm} of normal and super-light weight concrete is shown as follows.

For super-light weight concrete

$$Q_u = 1.26\left\{\beta_1\left(d^2-\phi^2\right)\cdot f'_{cu} + \beta_2\phi^2\cdot f_{st}\right\} - 28.3\times10^3 \qquad (5)$$

$\beta_1=0.50,\ \ \beta_2=0.74$

The calculation result (SL00-35, SL12-35, SL00-50, SL12-50) by **Eq. (5)** is shown in **Fig.13**. In this figure, the calculation value of SL00-35 and SL12-35 move from horizontal axis about 140 to about 90; SL00-50 and SL12-50 move from horizontal axis about 180 to about 120 within the range of **Eq. (4)** lower bound type. It shows that the shear strength of PBL with super-light weight concrete could appreciable by **Eq. (5)** as well as normal concrete by **Eq. (4)**

3. Bending Test on Composite Girder

3.1 Outline of specimens and bending test

To confirm the applicability of the proposal valuation **Eq. (5)**, bending test of composite girder with super-light weight concrete and steel short fiber reinforcement was carried out.

Parameter of the specimen is aperture interval (70mm, 140mm two type) of PBL as shown in **Fig.14** and **15**. Because the effect of fiber reinforcement is not remarkable by the above-mentioned, the steel fiber mixing presence of specimen in bending test is only in 1.2%. The material factor by material test of concrete and steel are shown in **Table 5**. In this test the steel girder (200×200×8×12mm, SS400) is be used. The material factor of the steel girder and reinforce bar (D13, SD295) are also shown in **Table 5**. The loading situation is shown in **Fig.16**.

3.2 Design value

The calculation result of the shear strength with the composite used the data of push-out test above-mentioned is shown in **Table 6**. In this calculation, the material strength of concrete and steel was defined in 30N/mm^2 (compressive strength) and 400N/mm^2 (yield strength of steel girder and bar). To satisfy the horizontal shear force *Ha* between slab and steel beam at design load, the aperture interval of PBL was designed with 70mm. Moreover, aperture interval of Type 2 was designed in twice of Type 1 with 140mm for test the completeness.

Design load was calculated by Design Code foe Steel Structural (Part B Composite structure)[11] as **Eq.6**.

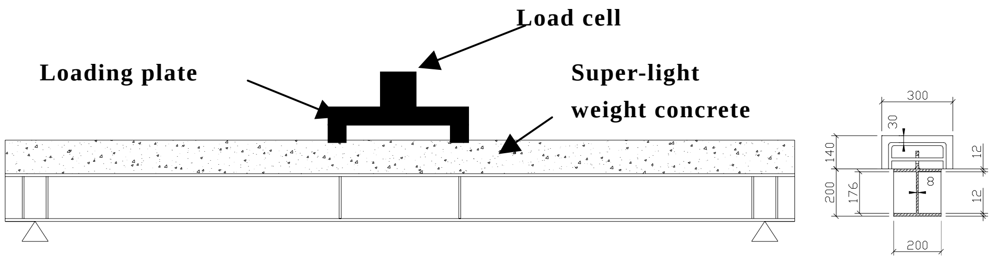


Fig. 14 Details of composite girder. (mm)

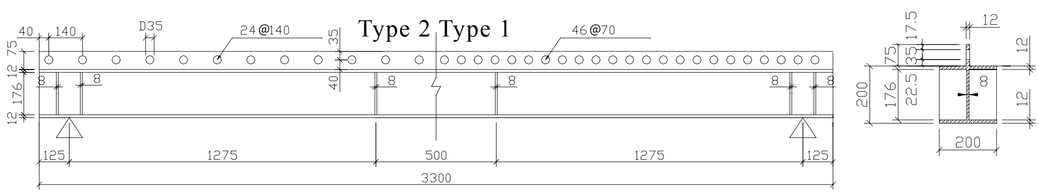


Fig. 15 Details of steel girder. (mm)

Table 5 Material strength.

Material	Compressive strength (N/mm^2)	Yield strength (N/mm^2)	Tensile strength (N/mm^2)	Flexural strength (N/mm^2)	Shear strength (N/mm^2)	Young's modulus (kN/mm^2)
Steel	-	349	-	-	-	210
Bar(D13, SD295)	-	329	487	-	-	210
Concrete	44.5	-	4.52	7.70	6.82	15.6

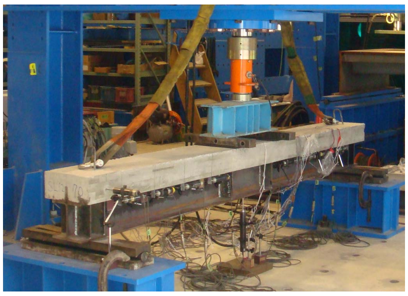


Fig. 16 Setup of specimen.

Table 6 Calculation result based on Eq. 6

		Specimen type	Allowable load of steel girder: *Pd*	Yield load of steel girder: *Py*	Ultimate load of steel girder: *Pu*
Shear strength by PBL (kN)	Design by expectation value	Type 1	172	-	414
		Type 2	86.2	-	207
	Design by material strength	Type 1	231	-	361
		Type 2	116	-	180
Moment strength (kN)	Design by expectation value	-	168	294	348
	Design by material strength	-	160	391	487
	Test result	Type 1	172	397	461
		Type 2	171	390	441

$$H_F = a_c \cdot A_c \cdot S_v / I \quad \text{(kN/mm)} \tag{6}$$

H_F : Horizontal shear force between slab and steel beam at design load. (kN/mm)
a_c : Distance between centroids of slab and composite girder. (mm)
A_c : Effective cross-sectional area of slab. (conversed in steel). (mm^2)
I : Second moment of area. (conversed in steel) (mm^4)
S_v : Shear force. (kN)

3.3 Test results

3.3.1 Load-deflection relation

Load-deflection curve obtained from test and calculation is shown in **Fig.17**, and the moment strength of each stage by calculated and the test is shown in **Table 5**. The deflection is a value measured in the steel girder bottom flange at the center of composite girder span, and the calculation was calculated as a complete composite beam by Design Code foe Steel Structural (Part B Composite structure)[11)]. From **Fig.17** and **Table 5,** the rigidity and moment strength of both types are almost corresponding to the calculation value, and the rigidity of Type 2 was able to be confirmed be on the decrease than Type 1 with an increase of the load but enough. Moreover, the maximum moment strength of

Type1 and Type2 are 0.95 and 0.91 times than the ultimate load of the calculation respectively, and able to confirmed that both types had yield strength enough.

3.3.2 Load-relative displacement relation

Fig.18 shows the position of relative dislocation is measured. Moreover, the data of the measurement position of No.4-7 is shown in **Fig.19**. From this figure, it confirms that the relative dislocation by maximum strength of Type2 is 4.4 times of Type2 as 0.5mm and 2.2mm respectively and the effect of PBL of the slip resistance is remarkable.

Fig.20 show the relative dislocation distribution of the distance from center of composite girder span. It is confirmed that almost the same value of relative dislocation at each measurement position on composite beam span.

3.3.3 Strain distribution

The strain distribution in specimen span central section is shown in **Fig. 21**. From **Fig. 21**, it is confirmed that as the load comes to about 400kN, Type 2 tends to be non composite by the progress of slip between the concrete slab and the steel beam, but the same tendency is not seen in type 1. It is clarified that type 1 can be treated as a complete composite beam.

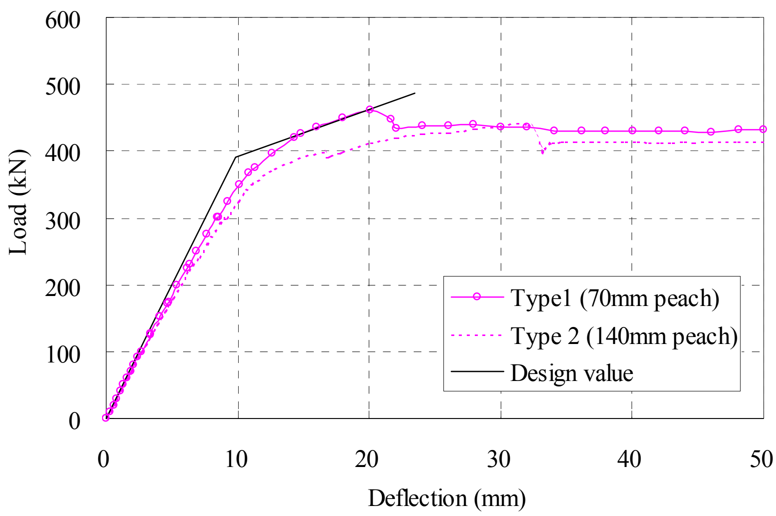


Fig.17 Load-deflection curve.

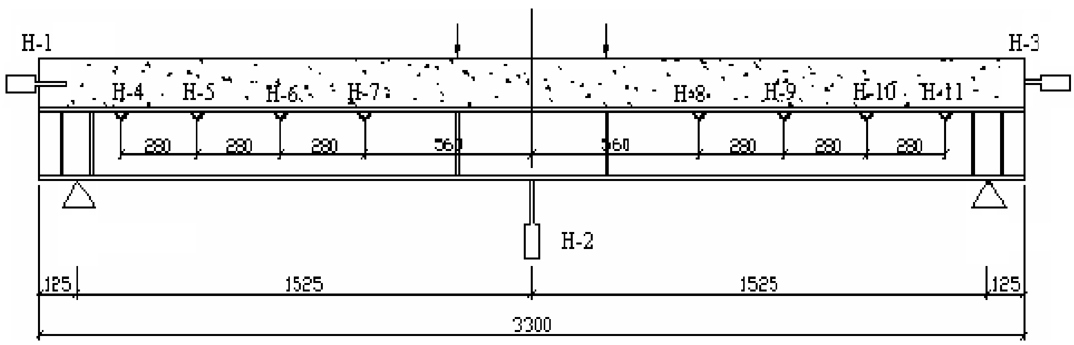


Fig. 18 Measure position of relative dislocation

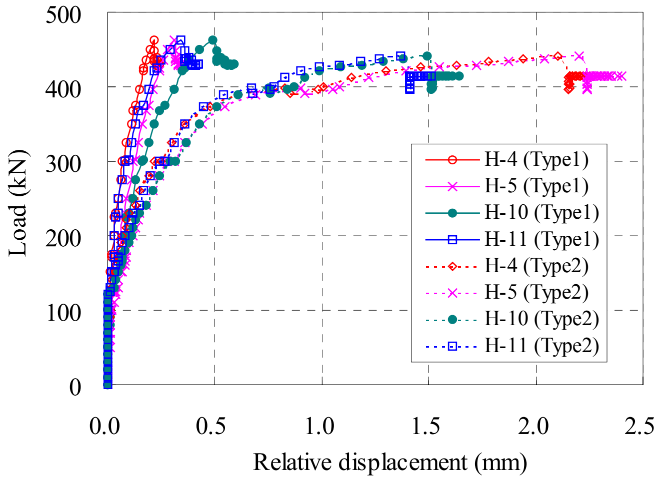


Fig. 19 Load-relative displacement

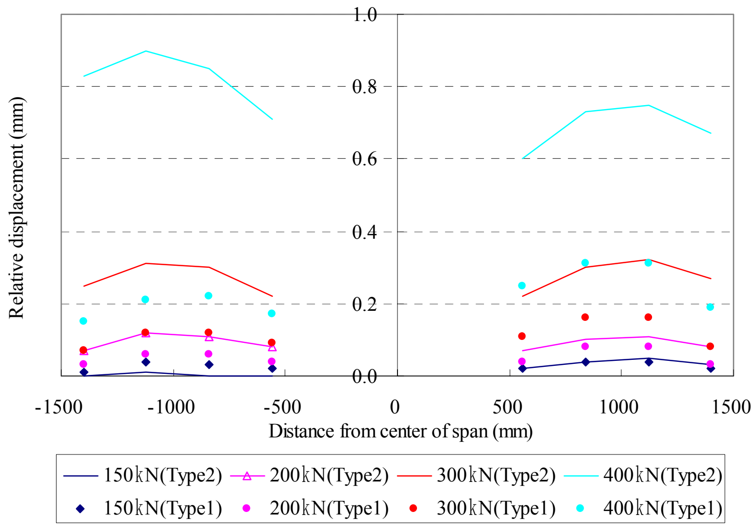
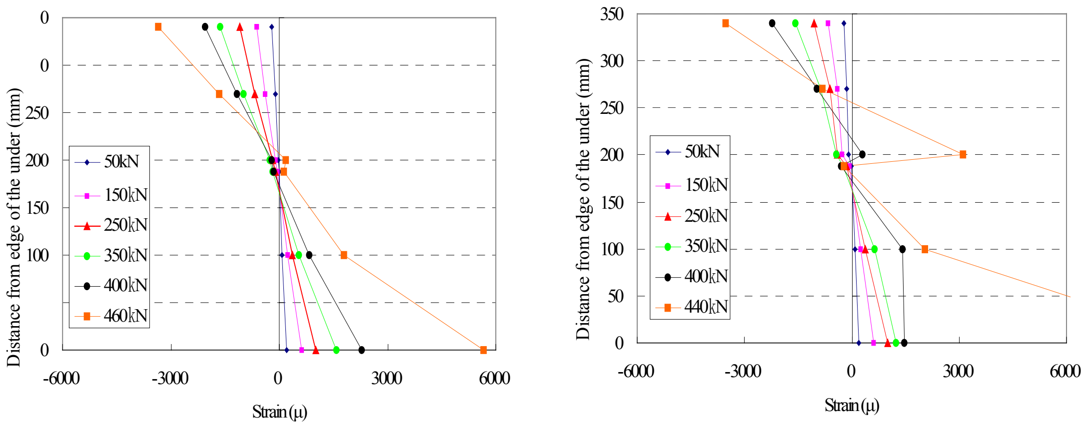


Fig. 20 Relative displacement distribution



(a) Type 1

(b) Type 2

Fig. 21 Strain distribution

4. Conclusion

The following conclusions were clarified in this study.

(1) The shear strength of PBL with super-light weight concrete decreases more than that uses normal concrete by about 40 percent regardless of the fiber mixing or none.

(2) The improvement of the shear strength by the fiber mixing could hardly be expected regardless of a concrete kind. It is verified that there is the compressive fracture of concrete upper the penetrated reinforce concrete but not shear fracture cause the shear fracture of PBL by the influence of penetrated reinforce bar.

(3) The shear strength of PBL used super-light weight concrete with steel fiber reinforcement was evaluated adequately by multiplied the reduction factor which considered the maximum shearing force of relative displacement 10mm to paragraph of concrete and penetrated reinforce bar.

(4) The bending strength evaluation method existing can be applicable with good accuracy to the composite girder by PBL used super-light weight concrete with steel short fiber reinforcement clarified by bending test.

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