(60) A NEW BEAM TYPE TEST METHOD FOR LOAD-SLIP RELATIONSHIP OF L-SHAPE SHEAR CONNECTOR

Soty ROS[1] and Hiroshi SHIMA[2]

[1] PhD Student, Department of Infrastructure System Engineering
Kochi University of Technology
Kochi, Japan
e-mail: 136004m@gs.kochi-tech.ac.jp

[2] Professor, Department of Infrastructure System Engineering
Kochi University of Technology
Kochi, Japan
e-mail: shima.hiroshi@kochi-tech.ac.jp

A new beam type test method was developed to examine shear force-slip relationship of L-shape shear connector. The specimens were developed by selecting shear connector in a possible steel-concrete hybrid structure and setting it in a location which is most critical to shear force. Two shear connectors were installed in different directions to shear force for each specimen with different sizes and different concrete strength. Split failure which cracks rapidly propagated from head and bottom of shear connector to the loading point was discovered. No break of shear connector in all specimens occurred even shear force was already greater value than the shear strength. The experimental results showed that the direction of shear force on shear connector affects the shear capacity of shear connector. Moreover, the shorter shear connector was found to displace more as compared to the taller shear connector when the same level of shear force is carried. On the other hand, horizontal relative displacement of head of shear connector whose face was opposite direction to shear force was found to have big increment with small increment of shear force after diagonal crack occurred. Last but not least, the new beam type test method was found to be considerably effective in terms of determining shear force-slip relationship and shear force-horizontal relative displacement relationship of L-shape shear connector in steel-concrete hybrid structure

Key words: *Beam type test method, L-shape shear connector, strength of shear connector, shear force-slip relationship, shear force-relative displacement relationship, method effectiveness.*

1. INTRODUCTION

Shear connectors are required in steel-concrete hybrid structure to transfer shear between steel and concrete. Usually, in the design, slip on shear connector is considered as neglectably small, and plane remain plane assumption is applied. However, the design will be more rational by taking shear force and slip on shear connector into account.

Therefore, several test methods were developed to investigate the relationship between shear force and slip on shear connector. Usually, push-out test and direct pull-out test are used for this purpose. Chin Long CHAUH et al.[1)] used direct pull-out test method to study the load-displacement relationship of plate shape shear connector in steel-concrete composite structures. This study found that boundary condition affects the load-longitudinal displacement relationship of shear connector; and the thinner shear connector displaces more as compared to thicker shear connector when equal load is carried. Furthermore, Hiroshi SHIMA et al.[2)] examined the load-slip relationship of headed stud through push-out test and proposed a formula for the relationship. The ultimate slip of headed stud was found to be 0.3 to 0.4 time of stud’s diameter.

However, it is true that the performances of shear connector in push-out test and direct pull-out test are different from those in a real steel-concrete hybrid structures. Therefore, a more rational test method closely represented the real steel-concrete hybrid structure is necessary. Accordingly, a new beam type test method was initiated and developed to study shear force-slip relationship of L-shape shear connector in steel-concrete hybrid structure. This study was carried out to evaluate the effectiveness of the new beam type test method.

2. EXPERIMENT

(1) Originality of specimen

The new beam type test method for shear force-slip relationship of L-shape shear connector was initiated by considering the shear connector in a possible steel-concrete hybrid structure. Accordingly, the specimens were developed by selecting shear connector at the location which is most critical to shear force. Shear span, *a* was selected to form strut and tied with 45^o from the shear connector to the loading point. **Fig.1** illustrates the originality of specimens.

(2) Specimens for experiment

The specimens were developed from the originality of the specimens for the new beam type test method. The heights of all specimens were 3 times of height of shear connector. The steel plates have the same width and thickness, 150mm and 9mm for all specimens. Shear connectors with different sizes, 100x50x9x14mm, 150x75x9x14mm, and 200x90x9x14mm were used for the specimens with different sections, 150x300mm, 150x450mm, and 150x600mm respectively. **Fig.2a, Fig.2b, Fig.2c, Fig.2d,** and **Table.1** give the details of all specimens.

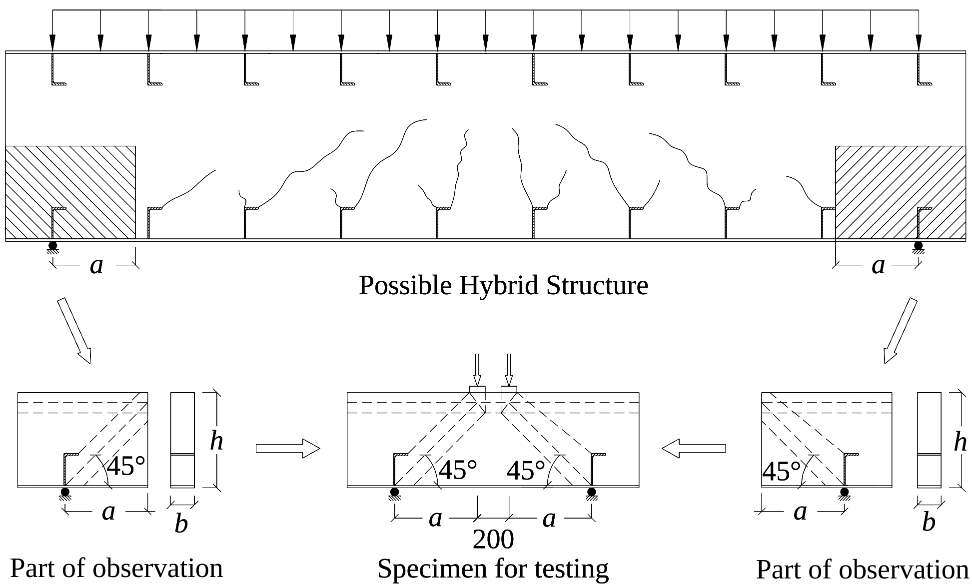

Fig.1 Illustration of originality of specimen

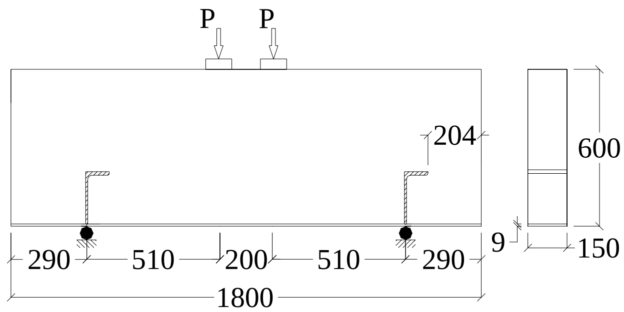

Fig.2a Details of specimen 1&2

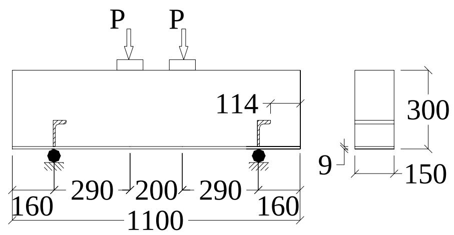

Fig.2c Details of specimen 4

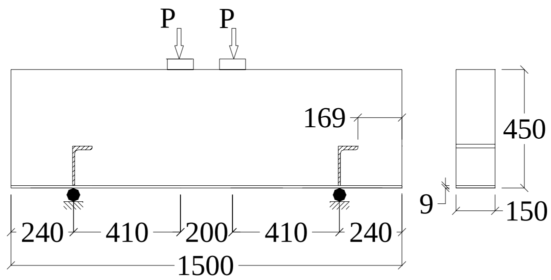

Fig.2b Details of specimen 3

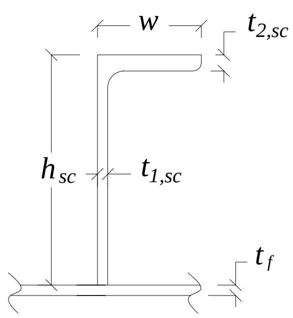

Fig.2d Shear connector and steel plate

Table 1: Details of specimen

Specimen	Sizes of Specimen (mm)			Sizes of shear connector (mm)				Thickness of skin plate	concrete strength f_c'
	a	b	h	h_{sc}	w	$t_{1,sc}$	$t_{2,sc}$	t_f (mm)	(N/mm^2)
S-1	510	150	600	200	90	9	14	9	38.2
S-2	510	150	600	200	90	9	14	9	25.3
S-3	410	150	450	150	75	9	14	9	23.6
S-4	290	150	300	100	50	9	14	9	25.1

Standardized steel, JIS G3101 with grade SM490 and SS400 were used for steel plate and shear connector respectively. The properties of the steels are mentioned in **Table 2**.

Table 2: Characteristics of steel

	Shear Connector	Skin Plate
Tensile yield strength f_y (N/mm^2)	352	370
Ultimate strength f_u (N/mm^2)	448	511
Module elasticity E (kN/mm^2)	202	204

(3) Shear strength of L-shape shear connector

Shear strength of L-shape shear connector is given in "Guidelines for Performance Verification of Steel-concrete Hybrid Structures"[3] of JSCE. The less value calculated from equation (1a) and (1b) is the shear strength of L-shape shear connector.

$$V_{scd} = \left(0.56.h_{sc}.w_{sc}.\left(f_{cd}'\right)^{1/2}.k_1.k_2.k_3 \Big/ \gamma_{b1} \right) \quad (1a)$$

$$V_{scd} = 0.1t_{sco}.w_{sc}.\left(f_{scyd} \big/ \sqrt{3}\right) \big/ \gamma_{b2} \quad (1a)$$

Where: $k_1 = 2.2(t_{sc}/h_{sc})^{2/3} \le 1$;

$k_2 = 0.4(t_f/t_{sc})^{1/2} + 0.43 \le 1$;

$k_3 = ((s_{sc}/h_{sc})/10)^{1/2} \le 1$;

f_{cd}' : design value for compressive strength of concrete (N/mm^2); h_{sc} : height of shear connector (cm); w_{sc} : width in the direction normal to shear force of shear connector (cm); t_{sco} : a lesser of thickness of shear connector considering welded part and thickness of shear connector itself (cm); f_{scyd} : design value for tensile yield strength of shear connector (N/mm^2); t_f : thickness of steel plate to which shear connector is attached (cm); t_{sc} : thickness of shear connector (cm); s_{sc} : spacing in the direction of shear force of shear connectors (cm); γ_{b1} : member factor which may be 1.3 generally; γ_{b2} : member factor which may be 1.15 generally; γ_c : material factor for calculation of f_{cd}' which maybe 1.3 generally; γ_s : material factor for calculation of f_{scyd} which maybe 1.05 generally.

(5) Experimental conditions

The calculations were made following "Guidelines for Performance Verification of Steel-concrete Hybrid Structures"[3] of JSCE. **Table 3** gives the general experimental conditions of all specimens.

Table 3: Beam type experimental conditions

	S-1	S-2	S-3	S-4
Shear strength of Shear connector $V_{scd.1}$ (kN) from (1a)	240	195	171	154
Shear strength of Shear connector $V_{scd.2}$ (kN) from (1b)	274	274	274	274
Shear Capacity of Specimen V_u (kN)	340	276	237	206

(6) Concrete product

Normal Portland Cement was used to produce the concrete. Water Reduction Agent (WRA) and Air Entrance Agent (AEA) were used in concrete product. The direction of concrete casting was made perpendicularly to the big face of the specimen in order to minimize the cavities around the shear connector. **Table 4** gives the summary of concrete mix proportions.

(5) Measurement set up

Shear force on each shear connector was calculated by dividing the applied load by two because the shear span, a was equal to the armed length. Shear force was also compared to the force calculated from strain value measured by strain gauges mounted on both sides of steel plate near the shear connector, **L11** to **L16** as illustrated in **Fig.3.**

Table 4: Mix proportions of concrete product

Strength (N/mm2)	Slump (cm)	W/C (%)	s/a (%)	Unit weight (kg/m3)					
				W	C	S	G	WRA	AEA
30	8	73	45	155	211	876	1070	2.11	8.4
50	18	46	40	175	378	695	1059	3.78	15.1

Slip distribution between concrete body and steel plate was measured by displacemeters as illustrated in **Fig.4**. Displacemeters **LD7** and **LD8**, on the left side of the specimen were installed to estimate the deflection of the beam type with respect to loads. **Fig.4** shows the locations of the displacemeters for all specimens.

Moreover, horizontal relative displacements between the top and bottom of each shear connector were measured by two displacemeters, **LD11** and **LD12** as illustrated in **Fig.5**. The installations of strain gauges and displacemeters were made symmetrically from left to right side of the specimens.

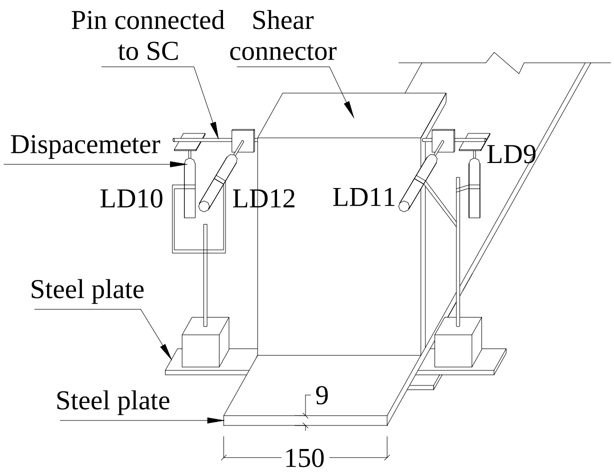

Fig.5 Relative displacement measurement

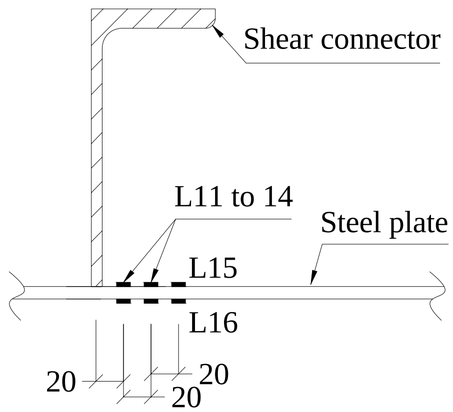

Fig.3 Locations of strain gauges on steel plate and shear connector

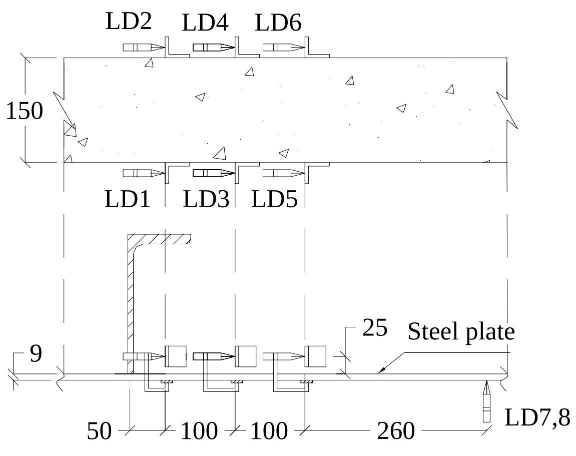

Fig.4 Slip distribution measurement

.

(6) Loading history

The specimens were loaded and unloaded by monolithic static loading at every 20kN increment until failure. After failure occurred at one side of the specimen that side was fasten by screwing upon two steel plates placed on its top and bottom. Then, loading were continued to make another side of specimen fail. Pushing load was recorded and shear force was calculated by dividing pushing load by two because the shear span was equal to armed length. The average value measured by displacemeters 1 to 6 was defined as the slip

3. RESULTS AND DISCUSSION

(1) Mode of failure

Split failure occurred on concrete plane at left and right shear connectors successively only on specimen 3. No failures took place at the right side of specimen 1, 2 and4. Before failure, in all specimens, flexural crack took place first and crack at head of shear connector forming 45^{o} from shear connector to loading point took place later. Finally, right before failure, a main diagonal crack which was parallel to the crack at head of shear connector occurred at bottom of shear connector and spread rapidly to the loading point. Split failure occurred in all specimens with different loads, 296kN, 210kN, 182kN, and 170kN for S-1, S-2, S-3, and S-4 respectively. **Fig.6a** and **Fig.6b** illustrate the failure mode of the specimens.

Break of shear connectors did not occur for both sides of all specimens even shear forces were already greater value than the shear strength of the shear connectors. It is due to the fact that, the direction of shear force was not perpendicular to the vertical axis of the shear connector. The comparison between experimental results and calculation results were summarized in **Table 5**.

On the other hand, the deflection with respect to applied loads of left and right side of all specimens were depicted in **Fig.7** and **Fig.8** respectively. Even though the values of maximum deflections of all specimens were different, the increment of deflections with respect to load was almost the same for every specimen.

Fig.6a Split failure on left side of specimen 1

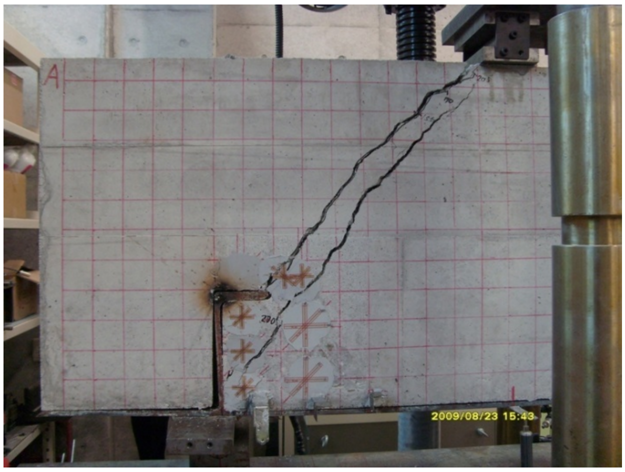

Fig.6b Split failure on left side of specimen 2

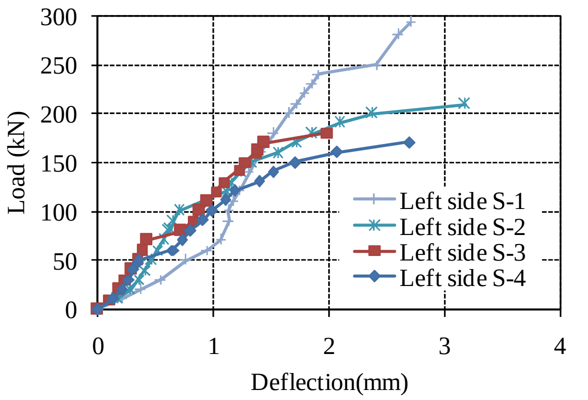

Fig.7 Load-deflection relationship for left side of specimen

Table 5: Summary of experiment's results

		S-1	S-2	S-3	S-4
Experimental Results	Load at flexural crack (kN)	80.0	110.0	80.0	56.0
	Load at crack at head of shear connector (kN)	296.0	155.0	182.5	128.0
	Load at crack at bottom of shear connector (kN)	296.0	200.0	182.5	150.0
	Load at failure (kN)	296.0	210.0	182.5	170.0
Calculation Results	Load at flexural crack (kN)	92	70	47	31
	Shear force when compressive member in concrete in truss analogy collapses V_{u1} (kN)	170	138	118	103
	Shear capacity without shear reinforcement plate V_{u2} (kN)	340	276	237	206

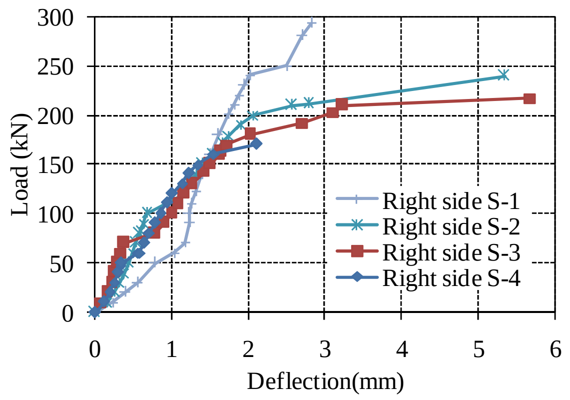

Fig.8 Load-deflection relationship for right side of specimen

(2) Shear force-slip relationship

It is obvious that through this new beam type test method, the relationships between average shear force and average slip were established. **Fig.9a, Fig.9b, Fig.9c,** and **Fig.9d** give the experimental results of the relationships of S-1, S-2, S-3, and S-4 respectively.

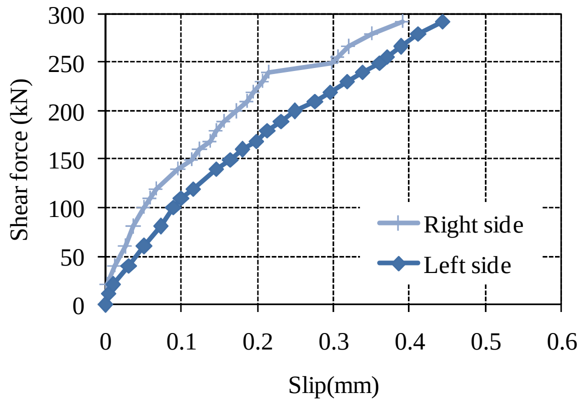

Fig.9a Shear force-slip relationship of shear connectors in S-1

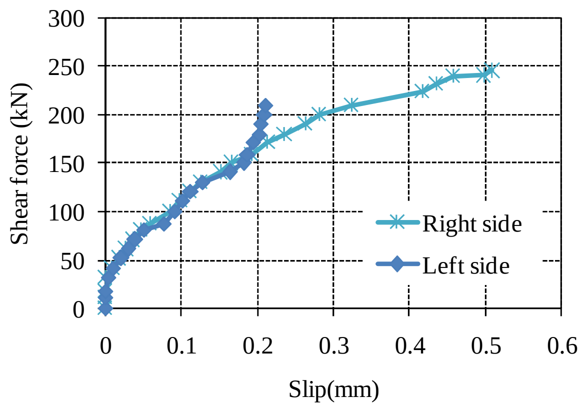

Fig.9b Shear force-slip relationship of shear connectors in S-2

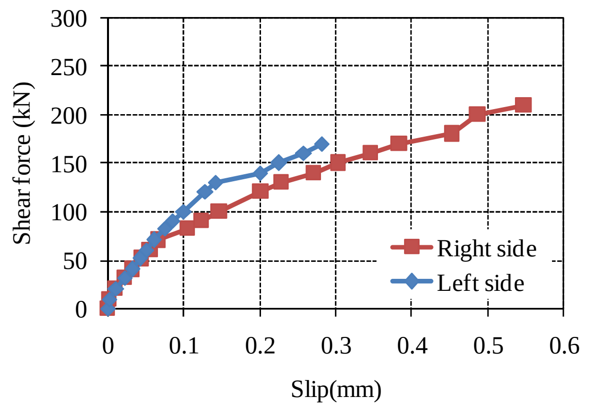

Fig.9c Shear force-slip relationship of shear connectors in S-3

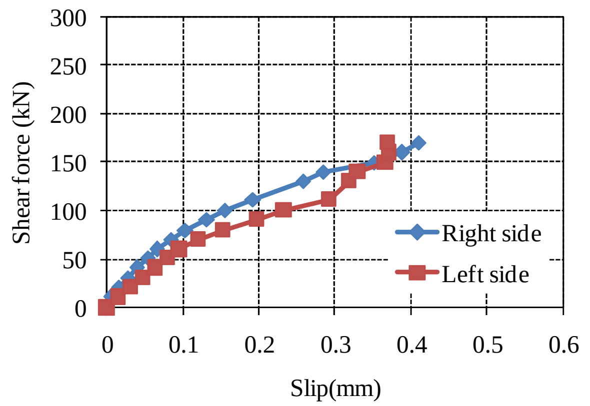

Fig.9d Shear force-slip relationship of shear connectors in S-4

Unfortunately, the ultimate slip of all shear connector was not able to determine because no break of shear connector occurred. However, slip values at failure of specimen was recorded. Slip values measured at left side specimen S-1, S-2, S-3, and S-4 were found to be 0.44mm, 0.21mm, 0.28mm, and 0.37mm respectively. On the other hand, the slip value at failure at the right side specimen was observed only on specimen S-3 which failed at 218kN with 0.54mm of slip. It was due to the fact that there were no failures occurred at the right side of three other specimens. However, the value of shear forces and slips reached for three other specimens were also recorded. The maximum slip recorded of specimen S-1, S-2, and S-4 were 0.39mm, 0.51mm and 0.41mm with the shear forces 296kN, 245kN, and 170kN respectively.

On the other hand, there seems to be no much different between the curves of shear force-slip relationship of both shear connectors in every specimen. Therefore, the performance of shear connector with respect to shear force of shear connectors with different direction to shear force seems to be similar. However, from the results of the experiments it was discovered that, with the same concrete strength and the same thickness as well as height of shear connector, the right side specimens could resist more shear force than the left side. It was due to the fact the distance from head of shear connector at the left side was closer to the loading point than that of the right side shear connector. Similarly, the left side specimens with shear connectors whose faces were opposite direction to shear force failed at lower value of slip compared to the right side one.

By plotting shear force-slip relationships of all left side shear connectors in one graph, **Fig.10** and all right side ones in another graph, **Fig.11** the effect of height of shear connector on shear force-slip relationships can be understood. Left side shear connectors in specimen S-1, S-2 and S-3 whose height were 200mm, 200mm and 150mm respectively behaved similarly with the same level of shear force **Fig.10**. However, left side shear connector of specimen S-4 whose height was 100mm behaved differently because at the same level of shear force, slip value was greater than other shear connectors. On the other hands, it can be concluded that with the same concrete strength and shear connector thickness, the shorter shear connector allowed greater value of slip as shown in curve S-2, S-3 and S-4 of **Fig.10**.

The effect of height of shear connector for the right side ones could be also understood from the form of the curves of shear force-slip relationships, **Fig.11**. Similarly, with the same thickness of shear connector and level of shear force, the shorter shear connector gave greater values of slip.

In short, the results from this experiment proved that the new beam type test method was considerably effective in terms of determining shear force-slip relationships.

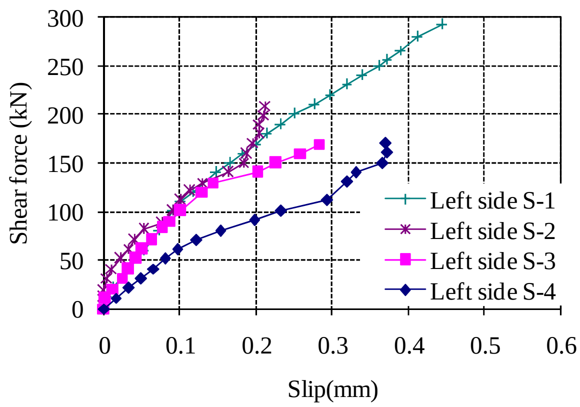

Fig.10 Shear force-slip relationship of all left sides shear connectors

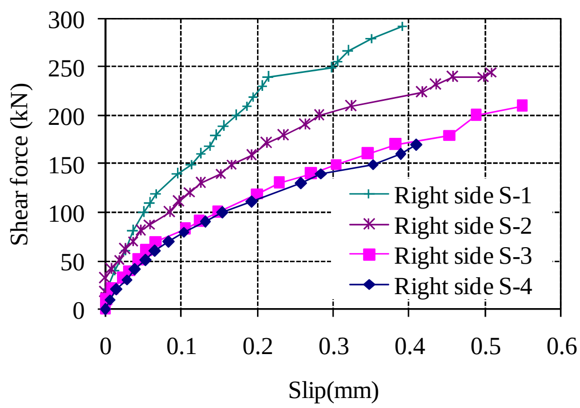

Fig.11 Shear force-slip relationship at right side of all specimens

(2) Performance of shear connector

The behavior of shear connector with respect to shear force can be clearly understood by observing on the relationship between shear force and horizontal relative displacement of shear connector at left sides of specimen S-2, S-3, and S-4 which were shown in **Fig.12.**

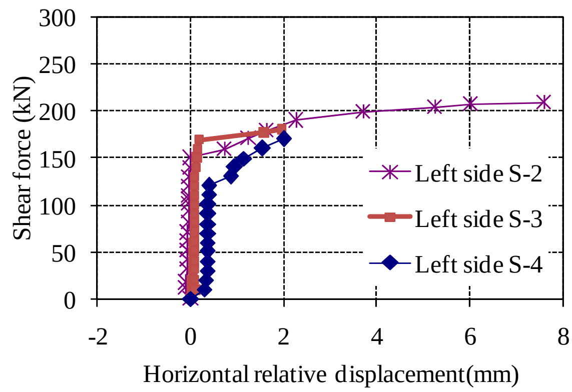

Fig.12 Shear force-horizontal relative displacement relationship of head of all shear connectors on the left side

It was observed that the horizontal relative displacement of all shear connectors suddenly increased when first diagonal crack occurred. It is believed that the suddenly increment of horizontal relative displacement was due to the sudden decrease of stiffness between concrete and shear connector. Moreover, the value of horizontal relative displacement of S-2, S-3 and S-4 at failure was 7.6mm, 1.9mm, and 2mm respectively. From the experimental results, it was discovered on shear connector at the left side of specimen S-2 that after diagonal crack occurred, head of shear connector still relatively displaced with respect to shear force until failure of specimen with greater value of relative displacement, 7.4mm compared to other shear connectors in other specimens, **Fig.12**.

4. CONCLUSION

The following conclusions can be derived from this study.

(1) Split failure which cracks rapidly propagated from head and bottom of shear connector to the loading point was found in the new beam type test method.

(2) The direction of shear force on shear connector was found to have effects on the shear capacity of shear connector in steel-concrete hybrid structure.

(3) The shorter shear connector displaces more as compared to the taller shear connector when the same level of shear force is carried.

(4) Horizontal relative displacement of head of shear connector whose face was opposite direction to shear force was found to have big increment with small increment of shear force after diagonal crack occurred.

(5) The new beam type test method was found to be considerably effective in terms of determining shear force-slip relationship and shear force-horizontal relative displacement relationship of L-shape shear connector in steel-concrete hybrid structure. However, the design of specimen and measurement should be improved in order to obtain the ultimate slip of the shear connector.

ACKNOWLEDGMENT: The author would like to express his gratitude to the organizers of Special Scholarship Program (SSP Program) for the financial support in this research. The author also would like to express his grateful thanks to all members of concrete laboratory of Infrastructure System Engineering Department, Kochi University of Technology (KUT) for their assistances during the experimental work.

REFERENCES

1) Chauh, C.L., Shima, H. and Virach, R.: Load-Dosplacement Relationship of Plate Shear connector in Steel-Concrete Composite Structures, *Proc. Of JSCE*, No. 433/V-15, pp.223-229, August 1991.
2) Guidelines for Performance Verification of Steel-Concrete Hybrid Structures, No.2, Hybrid Structure Series, Japan Society of Civil Engineers, 2006.
3) Shima, H. and Watanabe, S.: Formulation for Load-Slip Relationships of Headed Stud Connector, *Proc. Of fib2009*, 2009.6.22-24, London.