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Bond performance of light-weight concrete beams with double-layer reinforcement

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ABSTRACT : In order to investigate the bond performance of the beams with double-layer reinforcement using light-weight concrete, an experiment consisting of two parts was carried out. The first part, a cantilever type bond test, shows that the bond splitting strength of the light-weight concrete is 84% of the normal concrete and the double-layer specimens is 79% of the single-layers. The second part is an antisymmetrical loading test of beams where the parameters are the amount of stirrups and the arrangement of the longitudinal bars. The bond stress of the longitudinal bars obtained when the beam failed by bond splitting shows a good relationship with the calculated value multiplied by 0.84. Related with the bond splitting strength of the double-layer reinforcing members, the results obtained from the later part do not show correlation with those results of the first part.

1 INTRODUCTION

The construction of high-rise buildings has become more used nowadays. In that sense, high strength and light weight concrete could represent one of the solution for the multiples problems that high-rise buildings involve. The amount of reinforcement is also increasing, so that the arrangement for longitudinal bars of beams must be multi-layer. Therefore, special consideration will be necessary to avoid the bond splitting failure problems which will appear as a consequence of that.

A definite conclusion about the bond splitting strength of reinforced concrete members with double-layer reinforcement has not been made clear yet. Even though many formulae for calculating the bond splitting strength are given at present, their applicability to members with double-layer reinforcements is unknown.

This research aims to make clear the bond performance of beams with double-layer reinforcements using light-weight concrete with high compressive strength ($360kgf/cm^2$). To realize the objectives of this research, an experiment consisting of two parts was carried out. The first part is a cantilever type bond test, and the second part is an antisymmetrical loading test of beams.

2 CANTILEVER TYPE BOND TEST

2.1 Specimens

The list of the specimens is shown in Table 1, and examples of the specimens is shown in Fig. 1. The specimens are designed in the form of full-scale cantilever type considering as a part of beam. The size of them is 415mm(W) x 715mm(D) x 1000mm(H) and the bond length(l) is 580mm or 485mm. The variables considered here are the number of longitudinal bars (4,6,8 bars : where the 4 bars specimens are single-layer type and the 6 or 8 bars specimens are double-layer type), the amount of lateral reinforcements (p_w=0.0% - 1.2%), and concrete type (light-weight concrete or normal concrete). At the supporting area of resisting force at the free end of the longitudinal bars, they are covered by plastic pipes in order to lose the bond stress between themselves and concrete. And as shown in Fig. 1, in the center of a cross section of the specimen, a large quantity of reinforcement are arranged enough in order to resist the shear force.

Steel bars D29(SD345) were used as longitudinal bars steel bars D13 and D10(both SD295) were used as lateral reinforcement. Light-weight concrete using an artificial light-weight aggregate and normal concrete were used. Their specified concrete strength was 360 kgf/cm^2. Mechanical properties of materials are shown in Table 2.

Table 1. Specimens (Cantilever type bond test)

Speci-mens	Concrete type	Longitudinal bars	Layer type	Lateral reinforcements	p_w (%)
No. 1	Light-weight concrete	4-D29 p_t =0.90%	Single layer	Non reinforcement	0.00
No. 2				2-D10 @120	0.29
No. 3				2-D10 @90	0.44
No. 4				4-D10 @120	0.57
No. 5				2-D10 @60	0.57
No. 6		6-D29 p_t =1.36%	Double layer	Non reinforcement	0.00
No. 7		8-D29 p_t =1.81%			
No. 8				2-D10 @120	0.29
No. 9				4-D10 @120	0.57
No. 10				2-D13 @50	1.22
No. 11	Normal concrete			Non reinforcement	0.00
No. 12				2-D10 @120	0.29
No. 13				4-D10 @120	0.57
No. 14					
No. 15				2-D10 @60	0.57
No. 16				2-D13 @50	1.22
Fixed factor	b×D = 415mm×750mm Specified concrete strength Fc = $360kgf/cm^2$ Bond length l = 580mm (where l = 435mm in No. 10, 16)				

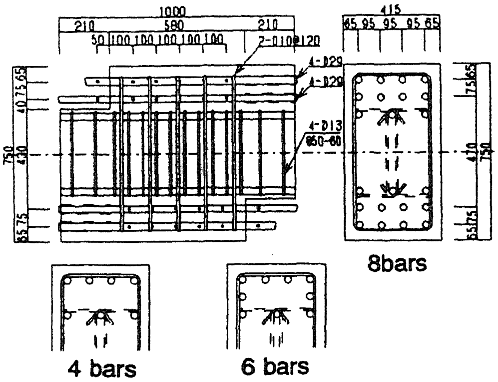

Figure 1. Cantilever type specimens

Table 2. Materials (Cantilever type bond test)

Concrete type	Strength (kgf/cm²)		Young's modulus (kgf/cm²)	Used specimens
	Compression	Splitting		
Light-weight	380	26.9	1.79×10^5	No. 1~10
Normal	368	34.8	2.87×10^5	No. 11~16

Steel bars	Yield stress (kgf/cm²)	Young's modulus (kgf/cm²)	Yield strain (μ)	Tensile strength (kgf/cm²)	Used Specimens
D29	3850	1.86×10^6	2074	6050	No. 1~16
D10	3750	1.88×10^6	1996	5430	Except 10, 16
D13	3610	1.82×10^6	1985	5290	No. 10, 16

2.2 Loading system

In this experiment, the cantilever pull-out type bonding test shown in Fig. 2 is adopted. The longitudinal bars were pulled monotonously with the same tensile loads at the each layer, using 4 oil jacks (100tf). After pulling upper side of the specimen, the specimen was upset and bottom side was pulled in the same style. In the following sentences, the results of the upper side are shown according to adding "T" to the last of the specimens' name and the results of the bottom side adding "B" in the similar way. The load, the displacement at the loaded and at the free end of the longitudinal bars and the strain of the steel bars were measured.

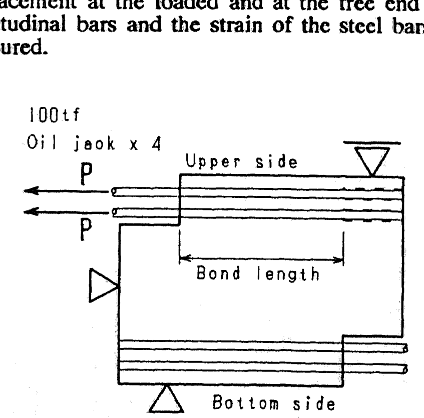

Figure 2. Cantilever type loading system

2.3 Test results and discussions

1. Bond splitting strength of the light-weight concrete

The correlation between the bond splitting strength of the light-weight concrete specimens and that of normal concrete specimens with the same reinforcements is shown in Fig. 3. In this figure a line was drawn from the origin by the method of least square. Thus, the average ratio of the bond splitting strength of light-weight concrete to normal concrete is 84%. Where, there is no much difference between the concrete's compression strength of light-weight and normal concrete (see Table 2), so there is no influence of the compression strength on the bond splitting strength. It seems that the difference is caused by the disparity of the splitting strength between light-weight and normal concrete for the same compression strength.

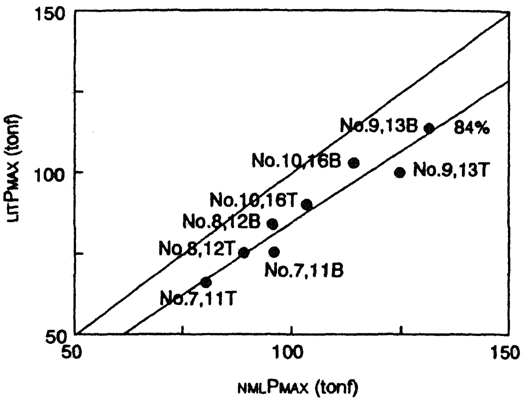

Figure 3. Bond splitting strength of the light-weight concrete specimens

2. Bond splitting strength of the double-layer specimens

The maximum load of the specimens which have 4 longitudinal bars (single-layer) is compared with those

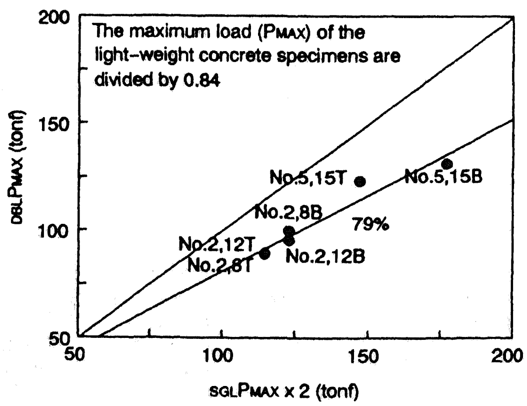

Figure 4. Bond splitting strength of the double layer specimens

of 8 longitudinal bars (double-layer) as shown in Fig. 4. In this examination the maximum loads of the light-weight concrete specimens are divided by the adjustment value 0.84 (see #1). And the loads of the specimens with 4 longitudinal bars are multiplied by 2 in order to fit to compare with what have 8 longitudinal bars in the same stress level. Comparing the strength of the double-layer specimens (8 longitudinal bars) with that of single-layer ones (4 longitudinal bars) in case of the same lateral reinforcements, the ratio between double-layer and single-layer is 79%.

(a) Bond splitting strength of the specimens without the lateral reinforcement

The correlation between the bond splitting strength of the double-layer specimens without the lateral reinforcement with calculated values by a formula[1] of the bond splitting strength are shown in Fig. 5. where the formula was obtained from the experiments of the single-layer specimens. In this examination, to calculate the bond splitting strength from the maximum load, the value of 115mm in the case of 1st layers or the value of 40mm in the case of 2nd layers is subtracted from the entire bonding length (580mm). Because of that, in the specimens, cracks making the angle of 45 degrees with the section of loaded end took place due to the shear force. The concrete from these cracks to the direction of the loaded end is considered not to contribute to rise the bonding strength. And the calculated values of the light-weight concrete specimens are multiplied by 0.84 (see #1).

In this figure, concrete's share of bond splitting strength with 8 longitudinal bars (double-layer) is 94% of that with 4 longitudinal bars (single-layer). This value is bigger than former ratio (79%), so it is considered that the bond splitting strength of the double-layer specimens, in the case where only the support is concrete, makes a little reduction comparing with that of the single-layer specimens.

(b) The increase of the bond splitting strength caused by lateral reinforcements

The correlation between the strength which is supported by the 1st layer longitudinal bar located at the corner of the section and that of at the center of the section is shown in Fig. 6. In this examination, in order to compare the double-layer specimens with the single-layer specimens directly, the specimens of the light-weight concrete are adopted. The horizontal axis of this figure indicates p_w(%) and the vertical axis indicates the increase of the strength. Where the increase is given by the subtraction of the bond splitting strength of the specimens with no lateral reinforcement from that of with lateral reinforcements ($_{EXP}\tau_{MAX} - {}_{EXP}\tau_{co}$) and be normalized by the square root of the concrete' compression strength (σ_B).

In this figure, lines are drawn from the origin by the method of least square. The slope of the line of the longitudinal bar located at the corner of the double-layer specimens is 0.67 which is less than the inclination of that of the single-layer specimens 1.79. Similarly, in the case of the bar at the center the inclination is 0.37, which is less than the inclination 1.03. The average of these ratio of these inclinations are 0.37. Thus, the increase of the strength of the double-layer specimens caused by the lateral reinforcements seems to be smaller than that of the single-layer as well as in the case of the concrete's share of bonding stress. And this value 0.37 is smaller than the ratio of the decline in the case of the concrete's share of bond stress.

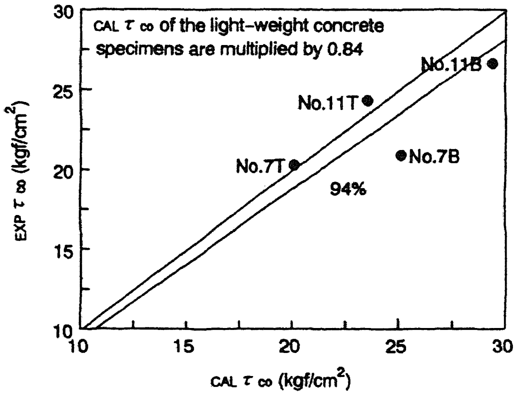

Figure 5. Bond splitting strength of the double layer specimens without lateral reinforcement

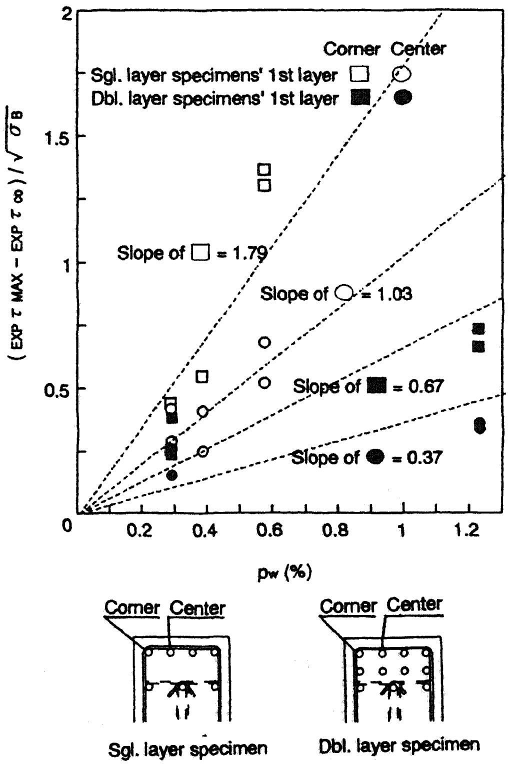

Figure 6. The increase of the bond splitting strength caused by lateral reinforcements

3 ANTISYMMETRICAL LOADING TEST OF BEAMS

3.1 Specimens

The list of the specimens is shown in Table 3, and the arrangement of the reinforcement is shown in Fig. 7. The specimens are designed in the form of 1/3 scale beams at lower floor of about 20 stories building. The variables considered here are the arrangement of longitudinal bars and the amount of lateral reinforcement (p_w=0.56% - 0.84%). The size of the specimens is 175mm(b) x 270mm(D) x 1080mm(L) and the ratio of the shear span to the depth (M/QD) is 2.0.

Eight steel bars D10(SD345) were used as longitudinal bars, and steel bars D5(SD295) was used as stirrups. Light-weight concrete using an artificial light-weight aggregate was used. Its specified concrete strength was 360 kgf/cm^2. Mechanical properties of materials are shown in Table 4.

Table 3. Specimens (Antisymmetrical loading test)

Speci-mens	Longitudinal bars			stirrups	
	1st layer	2nd layer	p_t(%)		p_w(%)
No.1	6-D10	2-D10	1.35	3-D5 @60	0.56
No.2				3-D5 @40	0.84
No.3	4-D10	4-D10	1.39	3-D5 @60	0.56
Fixed factor	Concrete type = Light-weight concrete b×D = 175mm×270mm, Span L = 1080mm(M/QD=2) Specified concrete strength Fc = 360kgf/cm^2				

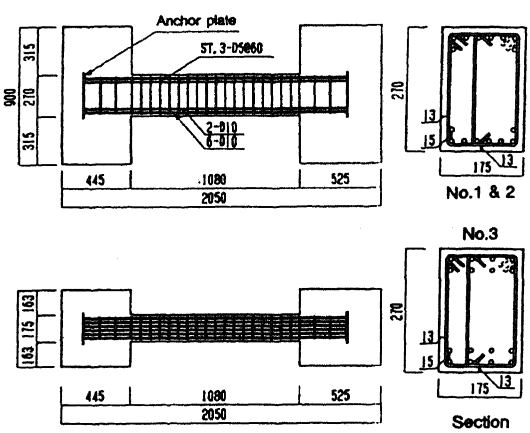

Figure 7. Beam specimens

Table 4. Materials (Antisymmetrical loading test)

Concrete type	Strength (kgf/cm^2)		Young's modulus (kgf/cm^2)	Used specimens
	Compression	Splitting		
Light-weight	380	29.3	1.99x10^5	No.1~3

Steel bars	Yield stress (kgf/cm^2)	Young's modulus (kgf/cm^2)	Yield strain (μ)	Tensile strength (kgf/cm^2)	Used position
D10	3780	1.78x10^6	2130	5460	Logitudinal
D5	3860	2.05x10^6	1880	4330	stirrups

3.2 Loading system

The specimens were loaded cyclicly using the antisymmetrical loading system shown in Fig. 8. The loading cycle is twice of R=+-1/200, +-1/100, +-1/50, +-1/33, once of R=+-1/20, and R=+1/15. The load, the relative displacement between the upper and the lower stub and the strain of the steel bars were measured.

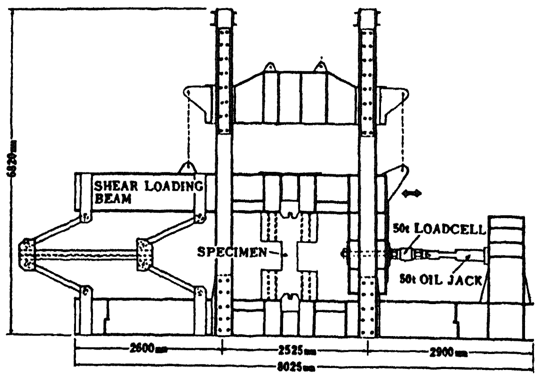

Figure 8. Antisymmetrical loading system

3.3 Test results and discussions

1. Failure pattern

Main results of this test is shown in Table 5. One beam failed by bond splitting (No.1) and the others failed by concrete compression (No.2 and No.3). The crack patterns and the load-displacement curves are shown in Fig. 9. The curve of the specimen No.1 which failed by bond splitting is poor one, and the decrease of the strength is seen at the large displacement. The curves of the specimens No.2 and No.3 show good ductility. The difference of the failure mode makes the clear difference of the curves.

Comparing the curves of the specimens with the same stirrups between No.1 and No.3, the curve of specimen No.3 show better ductility than No.1. So it is possible to improve the ductility of beams and prevent the bond splitting failure of beams by the change of the arrangement of longitudinal bars.

Table 5. Main results of antisymmetrical loading test

Speci-mens	Maximum load (tonf)		Ultimate displacement*2		Failure mode
	exp.	cal.*1	(mm)	(rad)	After bending yield
No.1	9.89	8.65	49.9	(1/22)	Bond splitting
No.2	10.34		65.1	(1/17)	Concrete compression
No.3	9.30	8.42	56.9	(1/19)	Concrete compression

*1 $Q = 0.9\Sigma a_t \cdot \sigma_y \cdot d / (L/2)$

*2 The displacement when the load became less than 80% load of the maximum on the skelton curve

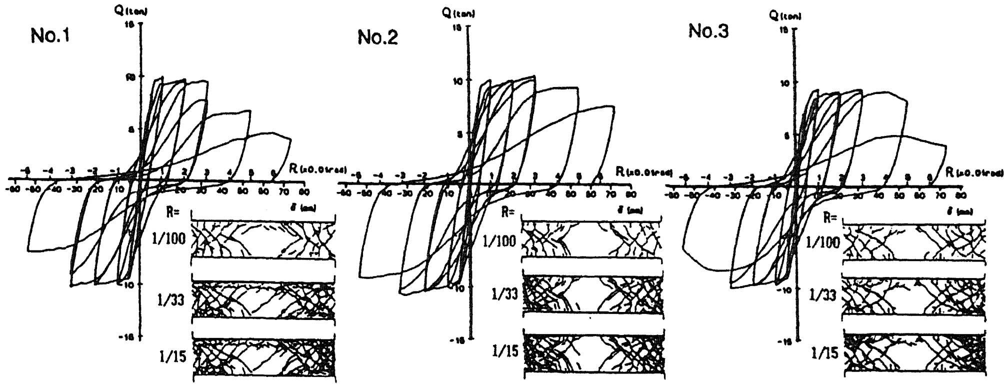

Figure 9. Load – displacement curves and clack patterns

2. Bond stress – displacement curves of longitudinal bars

Bond stress – displacement curves of the beams are shown in Fig. 10. The bond stress is calculated from the data obtained from two strain gages which were placed on the corner bars at the points which located 270mm (1.0D) from the both beam ends, by using Ramberg–Osgood model in calculating the stresses from the strains. In Fig. 10, solid and dotted lines show the stress of the first layer bars and that of the second layer bars, respectively.

The calculated value obtained from the formula[1)] multiplied by 0.84 (23.3 kgf/cm^2) gives approximately the experimental maximum bond stress value of the first layer bars of specimen No.1. The coefficient 0.84 is applied to take into account of the bond splitting strength of light–weight concrete. The measured stress of the second layer bars is higher than that obtained from the first layer in the positive displacement. Because of that, a splitting line occurred along the first layer line, where the length of the splitting line is smaller, so the bond stress of the first layer reduced.

On the other hand, the obtained bond stress of the specimen No.2 is about 30 kgf/cm^2, this value also shows a good relationship with a calculated value. And the bond stress of the second layer is the same to that of the first layer, because of not occurring the bond splitting failure.

The bond stress of the specimen No.3 is larger than the stress of No.1 and No.2, because of the difference of the arrangement of the longitudinal bars comparing to specimens No.1 and No.2. And the bond stress of the second layer is about 60% of that of the first layer.

Thus, the obtained bond stresses of the beams loaded antisymmetricaly show a good relationship with the failure modes and the arrangement of the longitudinal bars. But those do not show correlation with the results of the cantilever type bond test.

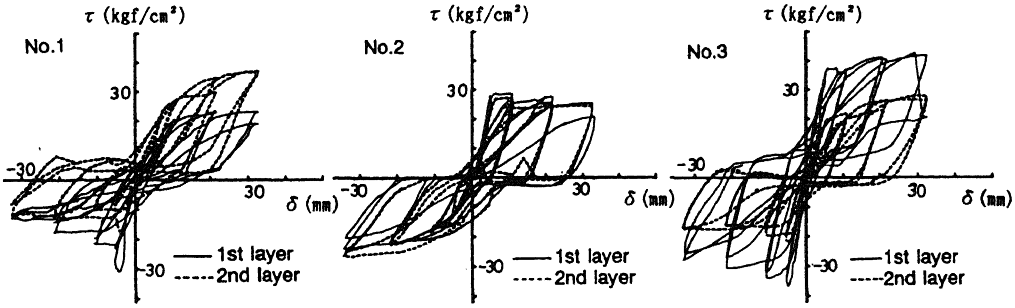

Figure 10. Bond stress – displacement curves of longitudinal bars

4 CONCLUSIONS

1. From the results of both test, cantilever type bond test and antisymmetrical loading test of beams, the bond splitting strength of light–weight concrete is 84% of normal concrete.

2. The bond splitting strength of the members with the double–layer reinforcement is 79% of the single–layer reinforcement in case of cantilever type bond test. However in case of antisymmetrical loading test of beams, the obtained bond stresses of the longitudinal bars show a good relationship with those values calculated using the single–layer reinforcing formulation.

3. It is possible to improve the ductility of beams and prevent the bond splitting failure of beams by the change of the arrangement of longitudinal bars.

4. The bond stress obtained from the beam which failed by bond splitting reduces at the first layer, where the splitting line occurred.

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