AN EXPERIMENT OF BOND-SLIP RELATION UNDER REPEATED LOAD

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1. INTRODUCTION

Bond between concrete and deformed-bar of RC members strongly influences the structural performance under various kinds of loading. So, many studies on bond-slip relation have been done by using various methods of loading and specimens. The purpose of our experiment is to investigate the bond-slip relation by low-cycle repeated load (let's say as range of 10^0 to 10^1), and check if the repeated load of significant level worsens the ultimate bond strength or not.

The following notations will be used: P_{max}: Maximum load in simple monotonic loading, $P_{0.2}$ or $P_{0.3}$: Load when first slip becomes 0.2mm or 0.3mm and is used as upper control during repeated loading for designated cycles, $P_{max,r}$: Maximum load in final pullout after the designated cycles of repeated loading and "r" implies residual, τ_{max}: Bond strength corresponding to P_{max}, and $\tau_{max,r}$: Bond strength corresponding to $P_{max,r}$.

2. EXPERIMENTAL PROGRAM

Mixed condition for the concrete is: the maximum size of aggregate (crushed lime stone) = 20mm, W/C = 60%, s/a = 46%, unit quantity of water and cement = 169kg and 282kg, respectively.

The specimens have cross section of 100mm x 100mm, in which one D10 or D16 re-bar is embedded at the center with the bonded length of 2ϕ (ϕ: diameter of re-bar), 3.1ϕ or 5ϕ. Two unbonded sections with length of 50mm each were provided. Concrete was cast when the re-bar and a surrounding steel form lied horizontally.

In the study, the monotonic pullout test was performed at first to valuate the P_{max} as well as bond-slip relation, and afterward, the cyclic load by $P_{0.2}$ or $P_{0.3}$ was carried out up to designated number and final pull-out was then performed to measure $P_{max,r}$.

3. EXPERIMENTAL RESULTS

Table 1 and **2** show the types of specimens and their results. The numbers of specimens for each test were 3 to 1. However, Table 1 selectively shows the results of best fit among them, because the entire shape of the curve and

Table 2 Variance of τ_{max}(MPa)

Data No.	Individual Values			Average
1	**8.1**	9.0	7.1	8.1
4	**8.2**	8.2	10.4	9.0
7	**6.2**	7.0	6.3	6.5
10		**8.5**		8.5
14	**11.3**	11.1	13.1	11.8

Note: underlined data appeared in the Table 1

Table 1 Summary of Experimental Results

Data No.	Diameter	Bond Length	Loading method	Compressive strength (MPa)	Tensile Strength (MPa)	τ_{max} (MPa)	$\tau_{max,r}$ (MPa)	τ_{max} or $\tau_{max,r}$ ÷ f_t	Slip at $\tau_{max,r}$ (mm)	Slip at final stage (mm)	P_{max} or $P_{max,r}$ (kN)	$P_{0.2}$ or $P_{0.3}$ (kN)	P_{max} or $P_{max,r}$ ÷$P_{0.2}$ or $P_{0.3}$	$P_{max,r}$ ÷P_{max}
1	**D10**	2 ϕ (20mm)	Mono.	27.9	2.4	8.1		3.38	0.70		4.87	3.95	1.23	1.00
2			$P_{0.2}$ X 5				7.9	3.30	0.40	0.31	4.76	4.30	1.11	0.98
3			$P_{0.2}$ X 20				7.5	3.13	0.63	0.34	4.50	3.53	1.27	0.92
4		2 ϕ (20mm)	Mono.	20.1	2.2	8.4		3.77	0.55		5.02	4.77	1.05	1.00
5			$P_{0.3}$ X 5				8.2	3.69	0.60	0.44	4.91	4.62	1.06	0.98
6			$P_{0.3}$ X 20				8.4	3.78	0.65	0.53	5.04	4.65	1.08	1.00
7		5 ϕ (50mm)	Mono.	24.5	2.0	6.2		3.03	0.70		9.30	7.40	1.26	1.00
8			$P_{0.2}$ X 5				5.9	2.90	0.66	0.29	8.90	6.90	1.29	0.96
9			$P_{0.2}$ X 20				6.2	3.05	0.80	0.57	9.40	8.23	1.14	1.01
10		5 ϕ (50mm)	Mono.	20.1	2.2	8.5		3.85	0.73		12.82	10.00	1.28	1.00
11			$P_{0.3}$ X 5				8.7	3.93	0.89	0.36	13.08	10.88	1.20	1.02
12			$P_{0.3}$ X 20				8.7	3.91	0.69	0.49	13.02	11.22	1.16	1.01
13			$P_{0.2}$ X 302				8.0	3.60	1.10	1.04	12.00	10.29	1.17	0.93
14	**D16**	3.1 ϕ (50mm)	Mono	33.3	3.4	11.3		3.36	0.51		28.12	24.09	1.17	1.00
15			$P_{0.2}$ X 5				11.2	3.34	0.73	0.315	27.98	20.66	1.35	0.99
16			$P_{0.2}$ X 5 *				8.9	2.64	0.57	0.415	22.15	23.96	0.92	0.79

Note : * … Splitted failure (others are pull-out failure).

Keywords: *Bond-slip relation, Deformed-bar, Low-cycle repeated loading, Residual slip, Ultimate bond strength*
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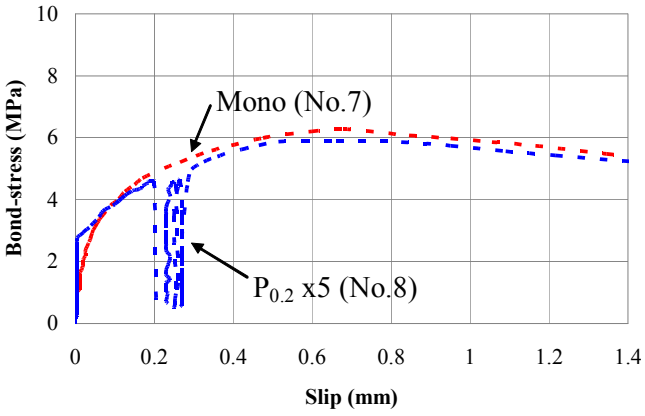

Fig. 1 Bond-slip Relation(D10, Bond 5ϕ, $P_{0.2}$ x5)

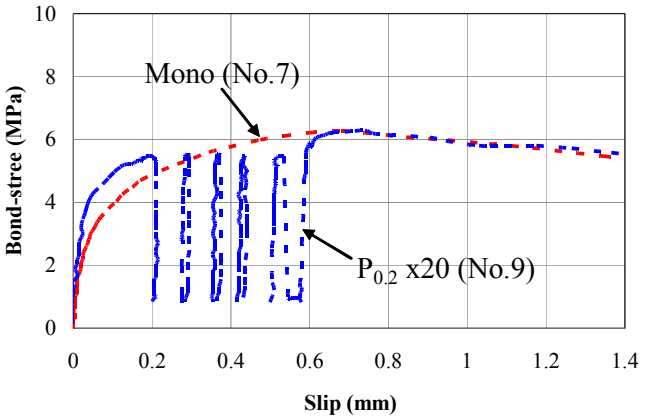

Fig. 2 Bond-slip Relation(D10, Bond 5ϕ, $P_{0.2}$ x20)

the peak value between the two loading methods (monotonic and repeated loadings) are expected to be near each other. The strength of concrete is also given in Table 1, and main reason of the variance is the age of concrete at the experiment.

In such destructive tests which seem to be strongly influenced by the tensile strength of concrete (f_t), some scatter is unavoidable. The ratios of $\tau_{max,r}$ or τ_{max} divided by f_t are distributed from 2.64 to 3.93 as being showed in the Table 1.

Fig. 1 ~ 3 shows typical curves of bond-slip relation under monotonic loading and repeated loading for 5ϕ specimen. For example No.8 data in Fig. 1, $P_{0.2}$ was given 5 times and then the final pullout was conducted to lead the specimen into so-called pullout destruction. The path of bond-slip relation finally agreed with the path of monotonic loading (No.7), and any significant drop of the peak bond strength was not found, as being reported in [1]. This tendency was common to almost of all cases.

However in Fig. 3 where repeated cycles reached 302 and residual slip exceeded 1.0mm, $\tau_{max.r}$ becomes obviously smaller than τ_{max} (ratio=0.93). This means that the residual bond strength is affected by repeated loading,

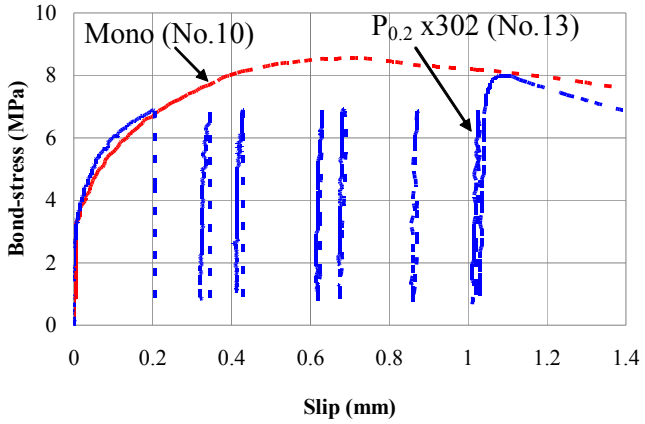

Fig. 3 Bond-slip Relation (D10, Bond 5ϕ, $P_{0.2}$ x302)

even though such phenomenon was not reported in [1]. This loading condition (1/1.17 P_{max} was given 302 times), however, was very severe compared with actual circumstances. In other words, the current design specification [2] that the bond strength is to be calculated with $0.28\ f'_{ck}{}^{2/3}$ (but less than or equal to $4.2N/mm^2$) is safe enough at least for one directional loading. Only No.16 showed spitted failure with less $P_{max,r}$ than $P_{0.2}$ (ratio=0.92). This splitted failure occurred at the final pullout after $P_{0.2}$ was given 5 times

The results of bonded length of 2ϕ indicated somewhat wider scatter, partly because the number of lugs of deformed-bar embedded in 2ϕ length could change from 2 to 3.

The ratios of $P_{max,r}$ to $P_{0.2}$ or $P_{0.3}$ in Table 1 seem to drop parallel to increasing loading cycles, particularly the tendency is more visible for the 5ϕ specimens. The ratio of $P_{max,r}$ to P_{max} also indicates the decreasing residual bond strength in accordance with the increase of loading cycles. However, the ratios of a few specimens do not show such decrease.

4. CONCLUSION

Our experiments give the following conclusions;

(1) Although there were a few exceptions, the path of bond-slip relation which observed in the repeated loading finally agreed with the path of monotonic loading, and no significant drop of the residual bond strength was confirmed.

(2) The current design specification regarding to the bond strength seems to be safe enough against low cycle repeated one directional loading.

REFERENCE

[1]B.H. Oh, et al, “Realistic Models for Local Bond Stress-Slip of Reinforced Concrete under Repeated Loading”, J. of Structural Eng. of ASCE, Feb. 2007 pp.216~224

[2]Japan Society of Civil Engineers, “Standard Specification for Concrete (2007, Structural Design)” (written in Japanese)