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Pull Out Strength of An Anchor Bolt Embedded in Cracked Concrete

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ABSTRACT : Many headed studs are embedded in RC shear walls in nuclear-related facilities in order to fast some equipments and pipings. The purpose of this paper is to present basic experiment data and to decide the criteria for designing a headed stud embedded in a shear wall under earthquake. Pull out strength of a headed stud due to cone failure of concrete with and without cracks was examined. Tests results show that the pull-out strength decrease due to cracks running through the stud, but it almost recovers when the cracks are closed again by a external compressive load. Relation between recovery rate and magnitude of compressive stress is empirically formulated.

1.INTRODUCTION

In nuclear facilities, a lot of anchor bolts are embedded in concrete walls in order to provide supports for equipment, pipes, etc. The walls are forcibly deformed due to shear force, and under biaxial states of stress during an earthquake. The cyclic external force due to the earthquake often produce cracks in the wall which keep open and close during an earthquake. The purpose of this paper is to study the cone failure of concrete and to propose the criteria for designing the headed studs embedded in the shear walls under the above complicated situations. Extensive research works have been performed by R.Eligenhausen, on the pull-out strength of the fasteners under static load, therefore the information are partly not enough when the object installing the fasteners is limited to the shear wall during an earthquake. Moreover during an earthquake, the walls are in biaxial states of stress, where the cracks are in opened and closed state.

In this paper, based on experimental work the pull-out strength of a stud embedded in a concrete plate under the following five situations is discussed.

(1) without cracks
(2) with a single open crack running through a stud
(3) with two cracks orthogonal with each other running through a stud
(4) with a single closed crack due to compression
(5) with a closed crack and an open crack orthogonal with each other

As to the pull-out strength of Anchor bolt, following two formulas were used.
" Design Recommendation for Composite Construction " published in Architectural Institute of Japan. The formula is as follows;

$$P = Ac\sqrt{\sigma_B} \quad \cdots\cdots\cdots\cdots \quad \text{Eq. (1)}$$

Where, P : pull-out strength due to cone failure of plain concrete, σ_B: compressive strength of concrete and Ac : effective area of cone failed surface which is given by the following equation,

$$Ac = \pi\ h\,(h+D) \cdots\cdots\cdots\cdots\cdots \text{Eq. (2)}$$

in which, h: embedment depth and D: diameter of a stud.

And the pull-out strength presented by R.Eligenhausen, which is given by the following equation.

$$P = k\sqrt{\sigma_B} \times h^{1.5} \cdots\cdots\cdots\cdots\cdots \text{Eq. (3)}$$

where, k is the empirical coefficient (=15.7 kg/cm)

2. EXPERIMENT

2.1 Specimen

In all, Forty two specimens as listed in Table 1 were prepared. The situation (1) mentioned in the above section corresponds to the specimens of series No.1, No.4, No.7,and No.10. The situation (2) corresponds to the series No.2 and No.11, the situation (3) corresponds to the

Table 1 List of specimens

Name of specimen	symbol	Age at test (days)	Concrete: Compressive strength σ_B (kg/cm²)	Concrete: Splitting tensile strength σ_T (kg/cm²)	crack width: dx (mm)	crack width: dy (mm)	Compressing force (t)	crack width After Compression: dx (mm)	crack width After Compression: dy (mm)	Pexp (t)	Pexp (t): Ave.
No.1-a										3.40	
b		52			-	-	-	-	-	3.32	3.23
c										2.97	
No.2-a					0.26					2.42	
b		54	388	41.2	0.33	-	-	-	-	2.03	2.27
c					0.17					2.36	
No.3-a					0.19	0.17				1.73	
b		55			0.34	0.19	-	-	-	1.47	1.66
c					0.35	0.24				1.78	
No.4-a										3.21	
b		90			-	-	-	-	-	2.86	3.05
c										3.09	
No.5-a					0.07		17.0	0.01		3.39	
b		91	346	29.0	0.27	-	17.0	0.02	-	3.32	3.51
c					0.26		19.0	0.03		3.83	
No.6-a					0.14	0.33	17.0	0.03	0.37	2.73	
b		92			0.38	0.17	18.0	0.06	0.23	2.75	2.76
c					0.11	0.17	17.0	0.02	0.18	2.80	
No.7-a										3.27	
b		72			-	-	-	-	-	3.20	3.14
c										2.96	
No.8-a					0.31		21.1	0.05		3.25	
b		73	316	29.0	0.29	-	20.1	0.07	-	3.77	3.49
c					0.04		21.0	0.04		3.45	
No.9-a					0.15	0.15	20.8	0.06	0.15	2.66	
b		74			0.13	0.10	19.9	0.08	0.11	2.98	2.92
c					0.15	0.18	21.0	0.06	0.11	3.13	
No.10-a										4.27	
b					-	-	-	-	-	4.42	4.32
c		76								4.28	
No.11-a					0.18					2.94	
b					0.49	-	-	-	-	2.68	2.51
c					0.55					1.91	
No.12-a					0.37		16.3	0.09		4.18	
c		84	428	38.0	0.57		16.2	0.07		3.83	
d					0.25		21.0	0.03		4.77	
e					0.38		18.1	0.08		4.29	
f		85			0.42	-	18.7	0.07	-	4.25	-
g					0.47		15.5	0.10		3.74	
h					0.47		5.9	0.14		3.33	
I		88			0.56		3.5	0.15		3.19	
j					0.48		7.2	0.10		3.49	

series No.3 , the situation (4) corresponds to the series No.5, No.8, and No12, the situation (5) corresponds to the series No.6 and No.9.

In order to prevent tension failure, a headed stud bolt as shown in Fig.1 was embedded at the center of all specimens with embedded depth of 50mm as shown in Fig.2 .

The dimensions and details of the specimens are illustrated in Fig.3. Specimens are all square concrete plates with a side length of 500mm considering the cone failed area , and with a depth of 150mm. Eight deformed bars with a diameter of 13mm and an yield strength of 3.54tf/cm^2, 3.83tf/cm^2, 4.71tf/cm^2 were arranged in the specimens so that they will not fail due to bending. All sides of the specimens are notched and aluminum plates are installed at the lower part of the specimens in order to induce cracks running through the stud.

Ordinary normal concrete with compressive strength of 270kgf/cm^2 was used. Six hours after casting of concrete, the specimen were covered with wet sand for 2 weeks to prevent the formation of drying shrinkage cracks on the specimens. Then the specimens were cured in the laboratory before testing. The age of the concrete at the test was 50 days, 70 days, 80 days, and about 90 days for specimen series No.1-3, specimen seriesNo.7-9, specimen series No.10-12, and specimen series No.4-6, respectively. The compressive and the splitting tensile strength of the concrete at the testing age were 388kgf/cm^2 and 41 kgf/cm^2 for the specimens (No.1-3), 346 kgf/cm^2 and 29 kgf/cm^2 for the specimens (No.4-6), 316 kgf/cm^2 and 29 kgf/cm^2 for the specimens (No.7-9), and 428 kgf/cm^2 and 38 kgf/cm^2 for the specimens (No.10-12).

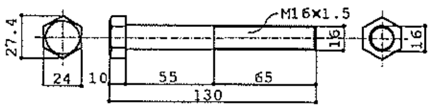

Fig.1 Detail of Anchor bolt

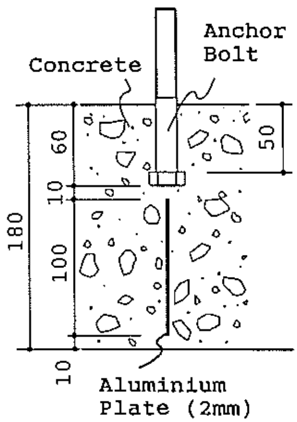

Fig.2 Detail of embeddment

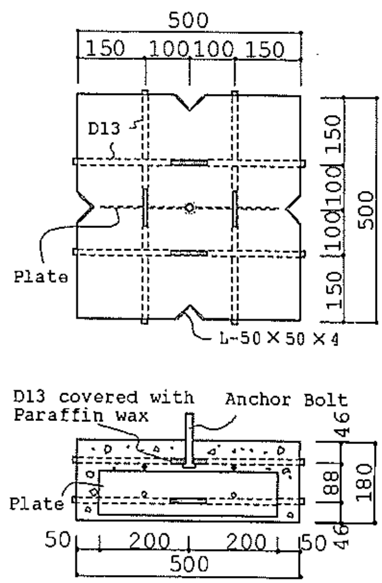

Fig.3 Detail of specimen

2.2 Method to crack the specimens and the crack width

As shown in Fig.4, the cracks on the specimen were introduced by splittng it under compressive load at both notched parts. The compressive load was about 30tf, by which the installed deformed bars seem to be yielded.

Several examples of the crack width measured using a microscope (x100) after removing the load is described in Fig.5. The crack width was measured at eight spots with an interval of 5cm per a one crack, and their averages are indicated in Table 1.

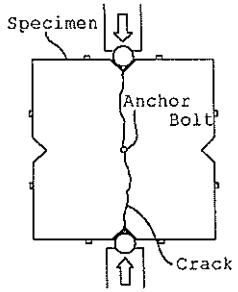

Fig.4 Method to produce the carck

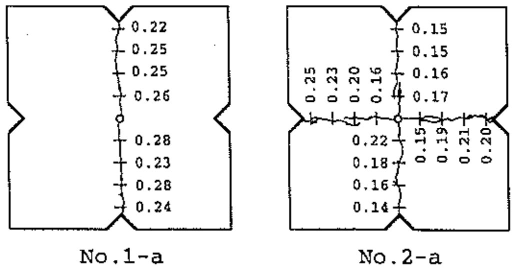

Fig.5 Width of the cracks

2.3 Method to close the crack

The open crack was closed again by fastening the specimen using loading beams and four PC bars as shown in Fig.6. For specimen of series No.5 and No.6, the center line of the fastening force is identic to the position of vertically arranged upper deformed bars, and the upper part of the concrete where the stud is just embedded is stressed. Meanwhile the specimens of series No.8, No.9, and No.12, the center line of the fastening force is identic to the center of the specimen section.

2.4 Pull-out testing method

The apparatus for the pull-out test is illustrated in fig. 7. The reaction frame with four legs was put on the specimen, then using a coupler, the head of the bolt connected with the embedded stud was pulled up vertically stud by a hydraulic jack set at the center of the specimen through four steel bars. Since the span of the legs of the reaction frame was about 400mm, the observe object of the specimen was not confined at all. The tensile load and the bond-slip displacement of the bolt were measured using four calibrated load cells and a set of LVDTs, respectively. The compressive strain induce by compressive force on specimen series No.8, No.9, and No.12 were measured by strain gauges which were placed on the D-13mm steel bar.

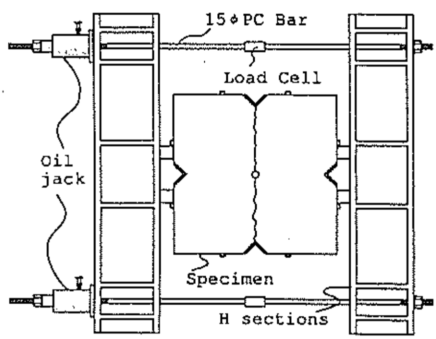

Fig.6 Method to close the crack

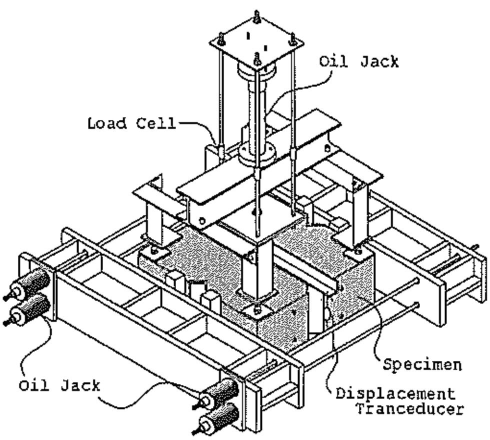

Fig.7 Apparatus for the pull out test

3.EXPERIMENTAL RESULT

The ratio of maximum pull-out strength of specimens series No.2, No.3, and No.11 to average pull-out strength of No.1 and No.10 specimens is indicated in Fig.8, while the load vs. displacement is shown in Fig.9. From Fig.9 it can be seen that the pull-out strength was 30% and 50% lower than the non-cracked specimens. Fig.10 and Fig.11 shows the load vs.displacement curves of the specimen of the series No.4~6, No.7~9. It can be observed from these figures that strength and stiffness are almost completely recovered as the crack was closed by fasting the specimen before compressive load was applied. The effect of difference fasting point was not seen. The test results of specimens series No.1~9 are compared in Fig. 12. In this figure, the vertical axis stands for the pull-out strength normalized by a formula recommended in AIJ code.

The compressive force on the concrete of the series No.8, No.9, No.12 was caluculated by considering the bausinger effect and the results were ploted in Fig.13. A linear The relationship between recovery rate and magnitude of compressive stress is empirically formulated.

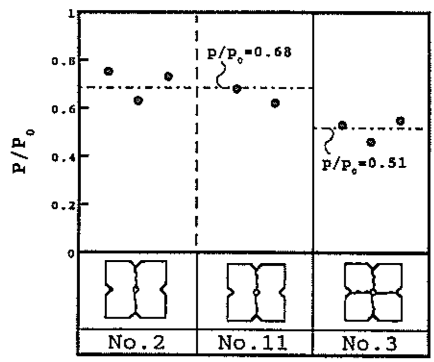

Fig.8 Effect of cracks

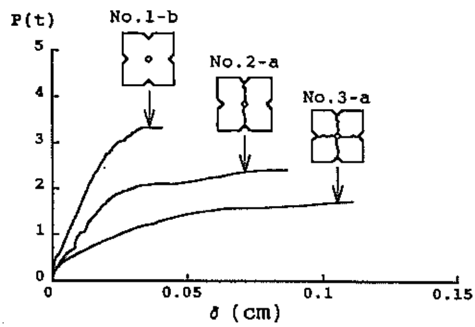

Fig.9 Load vs.Displacement (No.1 ~ 3)

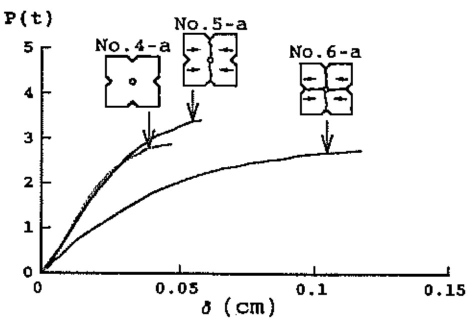

Fig.10 Load vs.Displacement (No.4 ~ 6)

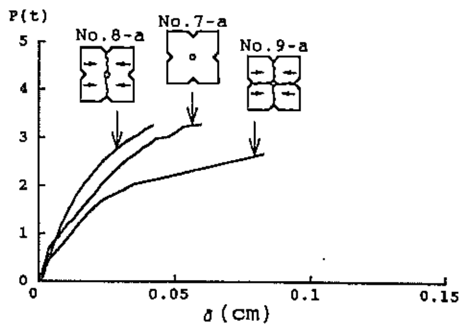

Fig.11 Load vs.Displacement (No.7 ~ 9)

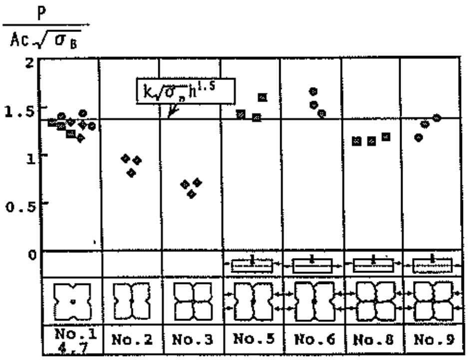

Fig.12 Effect of the compressive force

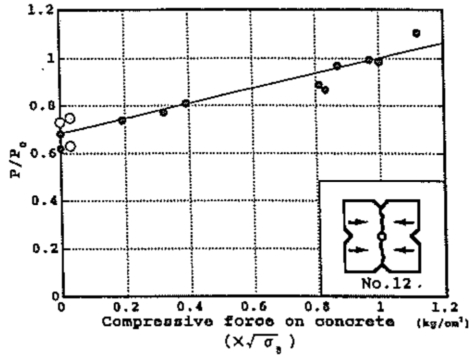

Fig.13 Compressive force vs.recovery of the pull out strength

4.CONCLUSIONS

(1) Cracks running through a stud reduce both the pull-out strength and the stiffness of headed studs due to cone failure of concrete.

(2) A single open crack running through a stud reduces the pull-out strength to 70%, and two orthogonal open crack to 50%.

(3) If the compressive force is loaded again to cracked concrete and the crack is completely closed near the surface of the concrete, where a stud is embedded, the pull-out strength is almost recovered to the strength of concrete without cracks.

(4)The relationship between the compressive force on the concrete and the recovery of the pull out strngth is nearly linear. And by the compressive force is about $\sqrt{\sigma_B}$, the pull out strength with one crack is almost equal to the pull out strength without crack.

REFERENCES

1. Architectual Institute of Japan , *Design Recommendation for Composite Construction,* 1985
2. Rehm, G. , Eligenhausen, R. and Mallee, R., *Befestingungstechnik* : Betonkalender , Vol. Ⅱ , 1992