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Pull-out test of stud bolts embedded in concrete under an in-plane force

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1. INTRODUCTION

There are many steel plates with stud bolts embedded in the RC walls of a nuclear reactor building to support equipment and piping. When an earthquake occurs, the steel plates are subjected to an out-of-plane force due to the inertia force acting upon equipment and piping. Furthermore, the walls are subjected to an in-plane force, and cracks may occur in the walls (see Fig. 1).

A large number of experimental studies (Matsuzaki et al. 1982, ACI 1985) have been carried out on the pull-out strength of stud bolts embedded in concrete. Few studies have been performed to understand the strength of stud bolts embedded in concrete under an in-plane force and, further, no studies have been carried out on the strength under simultaneous in-plane force for concrete and out-of-plane force for stud bolts.

This paper describes a test performed to understand the pull-out strength determined by the interaction of in-plane and out-of-plane forces.

2. TEST PROGRAM

2.1 *Pull-out test under an in-plane force*

An evaluation method on the pull-out strength under an in-plane force has been already proposed. (Nagano et al. 1989) However, the method is based on the past test data, and those tests are the out-of-plane loading under a constant in-plane force and the in-plane loading under a constant out-of-plane force.

For this reason, the pull-out tests under simultaneous in-plane and out-of-plane forces were carried out. In the tests, the embedded plate was subjected to an out-of-plane force in conjunction with an in-plane shear deformation of the shear wall.

The tests are three kinds; (1) pull-out strength under various loading conditions "P1", (2) pull-out strength under various in-plane stress conditions "P2", (3) pull-out strength in cases embedded plates closely located "P3".

2.2 *Simple pull-out strength test*

The results of past research (AIJ 1985) indicate that, where the embedded length of stud bolt is short, the strength is dominated by the pull-out cone failure of the concrete, and the results are scattered. Accordingly, in evaluation of the results for the pull-out tests under an in-plane force, it is important to confirm the strength under no an in-plane force. Therefore, the simple pull-out strength test was also carried out.

3. PULL-OUT TEST UNDER AN IN-PLANE FORCE

3.1 *Test specimen*

RC I-shaped shear wall type specimens with steel plates installed were prepared for the pull-out tests under an in-plane force.

The specimens are listed in Table 1, and the configuration of the specimens is shown in Fig.2. Material properties of the concrete and steel are shown in Table 2 and Table 3.

The test variations included: (1) loading ratios between in-plane and out-of-plane forces, (2) locations of steel plates in the web wall, (3) number of embedded steel plates, and (4) size of web wall. Tests for 15 specimens were carried out.

3.2 *Test method*

The in-plane load was given by fixing each specimen to a loading frame, then applying static horizontal force to both ends of the loading slab at the top of the specimen. The cyclic horizontal force is applied incrementally with a prescribed in-plane shear deformation angle which is an in-plane shear deformation divided by clear height of the web. The in-plane shear deformation is calculated by subtracting the bending deformation from the overall horizontal deformation.

The out-of-plane load was given by cyclically applying tensile force to the embedded plates. The level of the out-of-plane load corresponded to the in-plane shear deformation angle based on the prescribed loading conditions for each specimen. The loading conditions for each specimen and the loading set-up are shown in Fig.3 and Fig.4. A normalized value of the out-of-plane force, P/Puc, shown in Fig.3 is defined by Eq.1

$$P / Puc = P / Ac \sqrt{Fc} \quad \text{------------------------------------} \quad \text{Eq.1}$$

where P (kgf) pull-out force applied to embedded plate, Puc (kgf) calculated value of the pull-out strength, Ac (cm^2) the effective projected area, the effective stress area, and Fc (kgf/cm^2) compressive strength of concrete.

3.3 *Test results*

Test results are summarized in Table 4. The normalized values of the pull-out strength, Pu/Puc, vary depending on the test conditions, and the values are between 0.50 and 0.88. The specimens P1-1 and P3-1, which were only subjected to the in-plane load, show shear failure mode at the web. All the other specimens, which were subjected to in-plane and out-of-plane loads, show pull-out cone failure of the concrete around the embedded plate. The load-deformation angle relationship of the specimens is almost the same as that of the specimens that are only subjected to an in-plane load, in spite of variations in the loading conditions.

Example of final cracking is shown in Fig.5. The number of cracks in each specimen varies depending on difference in the in-plane shear deformation angle at the time of out-of-plane failure. Fig.6 shows example of web surface failure when the embedded plate is completely spalled out after the test. The shape of sections, where the concrete is destroyed, varies among the specimens, and no consistent tendency was observed.

4. SIMPLE PULL-OUT STRENGTH TEST

4.1 *Test specimen*

RC flat panel type specimens with steel plates installed were prepared for the simple pull-out tests under no an in-plane force. Three specimens were tested corresponding to each specimen of the pull-out tests under an in-plane force. The shape and size of the embedded plate are identical to those of the specimens of the pull-out tests under an in-plane force. Tests for 39 specimens called, S-types, were carried out.

Furthermore, 18 specimens using larger embedded plates to confirm a scale effect, F-Type, and 12 specimens with two sets of the embedded plates to investigate an effect by that the sets of embedded plates are close together, W-Type, were also tested.

The specimens are summarized in Table 5. Material properties are shown in Table 2 and Table 3.

4.2 *Loading method*

The loading is a monotonous and self-balancing, namely. The out-of-plane tensile force (i.e., the pull-out force) is applied to the embedded plates on both sides of each specimen by jacks. The bottom surface of the specimen is set on a sliding expansion bearing.

4.3 *Test results*

The normalized values of the pull-out strength are between 1.05 and 1.43 for S-types, between 1.06 and 1.25 for F-types, and between 1.05 and 1.21 for W-types.

5. DISCUSSION

The relationship between the normalized values of the pull-out strength, Pu/Puc, and the shear deformation angle, γ, is illustrated in Fig.7. In spite of the loading conditions, the stress conditions in the wall and the number of the embedded plates in the wall, the test results generally satisfy the allowable limit zone that was proposed by the past study. (Nagano et al. 1989) Therefore, the adequacy of the proposed zone was confirmed, and the conventional evaluation method of the pull-out strength was validated.

Fig.8 illustrates the relationship between the compressive strength of concrete, Fc, and the maximum pull-out strength, Pmax/Ac, where Pmax is the maximum out-of-plane load and Ac is the effective projected area of each specimen. The figure also presents the results of the past tests. (AIJ 1985) It shows that there is little scattering in the results of the tests, and that the results distribute above the curve $\sqrt{Fc}$ in the diagram.

It is reported that crack in concrete cause 60～70% decreasing in the pull-out strength. (Eligehausen et al. 1993) Fig. 9 illustrates the relationship between the re-normalized value of the pull-out strength, Pu/P', and the shear deformation angle for the pull-out tests under an in-plane force, where P' is the average out-of-plane load obtained from the simple pull-out strength. The figure indicates that the re-normalized pull-out strength decreases to about 60 %. Therefore, it is confirmed in the tests that cracks cause decreasing in the pull-out strength.

6. CONCLUSION

As test results, the pull-out strengths under various loading and stress conditions, and in cases the embedded plates closely located, were verified. Furthermore, the proposed allowable limit zone based on the different loading conditions was confirmed, and the conventional evaluation method of the pull-out strength was validated. Consequently, much valuable data for evaluating the pull-out strength was obtained.

7. ACKNOWLEDGMENT

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REFERENCES

(1) Matsuzaki, I et al. 1982, "Study on the Bearing Capacity of Embedded Steel Plates used for Supporting Machines and Pipes (Part 10)", Annual Meeting of Architectural Institute of Japan (AIJ)

(2) Code Requirements for Nuclear Safety Related Concrete Structures (ACI 349-85) 1985, ACI Committee 349, American Concrete Institute (ACI)

(3) Nagano, T et al. 1989, "Experimental Study on Supporting Ability of Machinery Anchorage in Reinforced Concrete Walls", Trans. of 10th SMiRT, Vol. H, pp19-24

(4) Design Recommendations for Composite Constructions 1985, AIJ

(5) Eligehausen, R et al. 1993, "Behavior of Fasteners Loaded in Tension in Cracked Concrete", submitted to ACI Structural Journal for possible publication

Table 1 List of specimens for pull-out test under an in-plane force

Specimens	Web Wall Haight	Web Wall Length	Shear Span Ratio	Number of Embedded Plates	Number of Specimens
P 1 - 1 ~ 7	100 cm	150 cm	0.71	2 (One Pair)	7
P 2 - 1 ~ 3	150 cm	150 cm	1.01	2 (One Pair)	3
P 3 - 1 ~ 5	100 cm	150 cm	0.71	4 (Two Pairs)	3
	120 cm	180 cm	0.71	4 (Two Pairs)	2

Note : Web Thickness 25 cm, Web Reinforcement Ratio 1.06 % (D16 @150 mm Double), Concrete Covering Depth 50 mm, Embedded Plate 225 mm x 225 mm, Stud Bolts 4- ϕ 13, Length of Bolt below the Head 79 mm, Space between Bolts 150 mm

Table 2 Material properties of concrete (unit : kgf/cm^2)

Specimens	Compressive Strength	Split Cylinder Tensile Strength	Young's Modulus	Specimens (Simple Pull-out Strength Test)	Compressive Strength
P 1 - 1	249	23.4	2.62×10^5	–	–
P 1 - 2	269	22.2	2.75×10^5	P 1 - 2 - S 1 ~ 3 P 1 - 2 - F 1 ~ 3	269
P 1 - 3	242	23.1	2.82×10^5	P 1 - 3 - S 1 ~ 3 P 1 - 3 - F 1 ~ 3	242
P 1 - 4	263	26.6	2.86×10^5	P 1 - 4 - S 1 ~ 3 P 1 - 4 - F 1 ~ 3	263
P 1 - 5	281	23.4	2.99×10^5	P 1 - 5 - S 1 ~ 3 P 1 - 5 - F 1 ~ 3	281
P 1 - 6	278	27.7	3.23×10^5	P 1 - 5 - S 1 ~ 3 P 1 - 5 - F 1 ~ 3	278
P 1 - 7	306	26.0	3.12×10^5	P 1 - 6 - S 1 ~ 3 P 1 - 6 - F 1 ~ 3	306
P 2 - 1	293	26.1	2.96×10^5	P 2 - 1 - S 1 ~ 3	293
P 2 - 2	311	25.7	3.03×10^5	P 2 - 2 - S 1 ~ 3	311
P 2 - 3	322	26.6	2.96×10^5	P 2 - 3 - S 1 ~ 3	322
P 3 - 1	265	19.6	2.72×10^5	–	–
P 3 - 2	293	23.3	2.84×10^5	P 3 - 2 - S 1 ~ 3 P 3 - 2 -W 1 ~ 3	293
P 3 - 3	291	21.8	2.84×10^5	P 3 - 3 - S 1 ~ 3 P 3 - 3 -W 1 ~ 3	291
P 3 - 4	300	23.6	2.88×10^5	P 3 - 4 - S 1 ~ 3 P 3 - 4 -W 1 ~ 3	300
P 3 - 5	315	26.2	2.94×10^5	P 3 - 5 - S 1 ~ 3 P 3 - 5 -W 1 ~ 3	315

Table 3 Material properties of re-bars and stud bolts (unit : kgf/cm^2)

Specimens	Re-bar (D16)			Stud Bolt(ϕ 13)	
	Yield Stress	Tensile Stress	Young's Modulus	Tensile Stress	Young's Modulus
P 1 - 1 ~ 7	3846	5479	1.95×10^6	5044	2.14×10^6
P 2 - 1 ~ 3	3718	5505	1.92×10^6	4870	2.16×10^6
P 3 - 1, 3	3953	–	1.92×10^6	4663	1.94×10^6
P 3 - 2	3825	–	1.87×10^6	–	2.07×10^6
P 3 - 4, 5	3936	–	1.93×10^6	–	2.21×10^6

Table 4 Test reults of pull-out test under an in-plane force

Specimens	Measured Values at Maximum Out-of-plane Load				Puc (tonf)	Pu / Puc
	Pu (tonf)	Q (tonf)	R (x10^{-3})	γ (x10^{-3})		
P 1 - 1	-	(252)*	(10.0)*	(6.1)*	-	-
P 1 - 2	11.2	210	4.7	3.3	15.1	0.74
P 1 - 3	10.8	183	3.3	2.2	14.3	0.76
P 1 - 4	11.2	135	1.9	1.3	15.0	0.75
P 1 - 5	10.1	252	6.6	4.5	15.5	0.65
P 1 - 6	12.1	227	4.5	3.4	15.4	0.79
P 1 - 7	12.6	166	2.4	1.7	16.1	0.78
P 2 - 1	13.9	183	4.0	4.5	15.8	0.88
P 2 - 2	14.1	187	4.3	2.4	16.3	0.86
P 2 - 3	14.3	174	3.8	2.5	16.5	0.87
P 3 - 1	-	(264)*	(9.9)*	(6.7)*	-	-
P 3 - 2	7.7	164	3.0	2.4	15.4	0.50
P 3 - 3	8.9	116	1.4	1.0	15.4	0.58
P 3 - 4	8.6	246	3.2	2.4	15.6	0.55
P 3 - 5	9.7	-154	-1.5	-1.0	16.0	0.61

Note : ( )*: Values at maximum in-plane load

Pu : Pull-out force applied to embedded plate

Q : In-plane load

R : Overall horizontal deflection

γ : In-plane shear deformation angle

Puc : Calculated values of the pull-out strength without an in-plane force

$Puc = Ac\sqrt{Fc}$ where Ac : Effective projected area, Fc : Compressive strength of concrete

Pu / Puc : Normalized values of the pull-out strength

Table 5 List of specimens for simple pull-out strength test

Specimens	Size of Specimen	Size and Number of Embedded Plates	Stud Bolts in Embedded Plate	Reinforcement	Number of Specimens
P 1 - 2 - S 1, S 2, S 3 ~ 7 - S 1, S 2, S 3	100 x 100 x 25 cm	225 x 225 cm 2 (One Pair)	4 - φ16	D16@150 mm Double	18
P 1 - 2 - F 1, F 2, F 3 ~ 7 - F 1, F 2, F 3	140 x 140 x 35 cm	300 x 300 cm 2 (One Pair)	4 - φ22	D22@200 mm Double	18
P 2 - 1 - S 1, S 2, S 3 ~ 3 - S 1, S 2, S 3	100 x 100 x 25 cm	225 x 225 cm 2 (One Pair)	4 - φ16	D16@150 mm Double	9
P 3 - 2 - S 1, S 2, S 3 ~ 5 - S 1, S 2, S 3	100 x 100 x 25 cm	225 x 225 cm 2 (One Pair)	4 - φ16	D16@150 mm Double	12
P 3 - 2 - W1, W2, W3 ~ 5 - W1, W2, W3	100 x 130 x 25 cm	225 x 225 cm 4 (Two Pairs)	4 - φ16	D16@150 mm Double	12

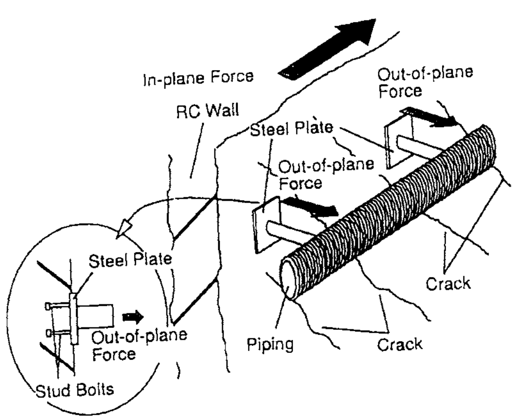

Fig.1 Steel plates in an RC wall

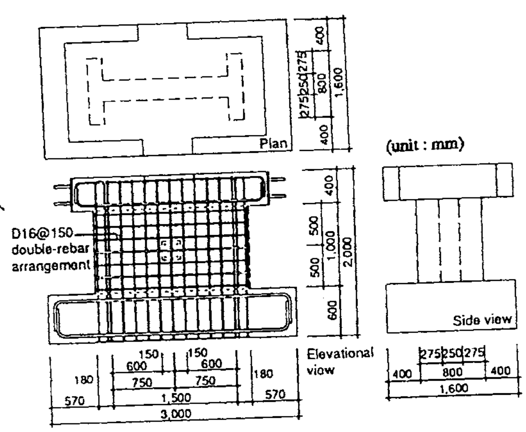

Fig.2 Configuration of "P1" specimens for pull-out test under an in-plane force

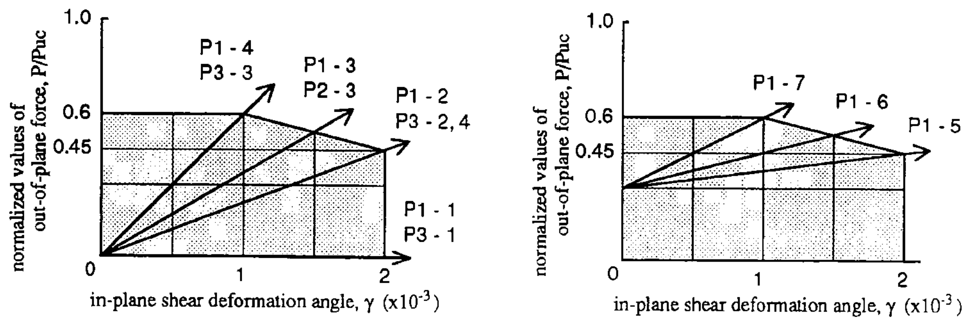

Fig.3 Loading conditions for pull-out test under an in-plane force

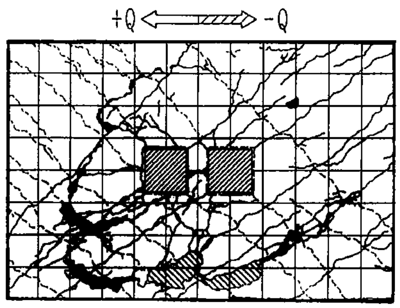

Fig.5 Example of final cracking pattern at the web wall (P3-4)

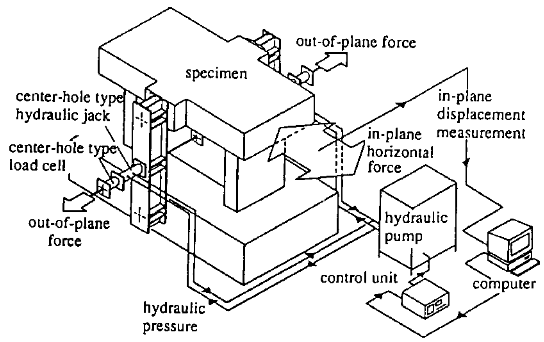

Fig.4 Loading set-up

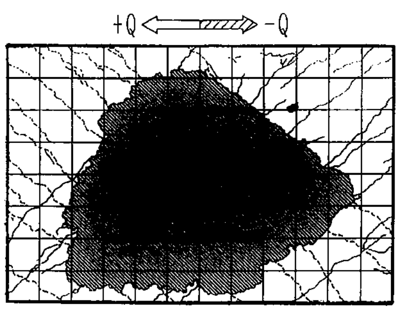

Fig.6 Example of web surface failure (P3-4)

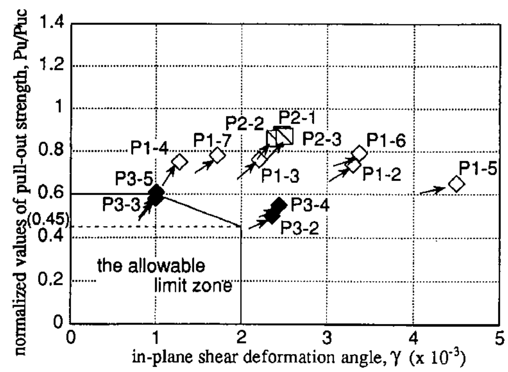

Fig.7 Relationships between normalized pull-out strength and shear deformation angle

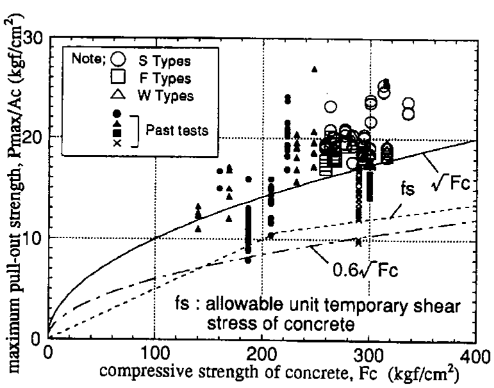

Fig.8 Relationships between the concrete strength and maximum pull-out strength

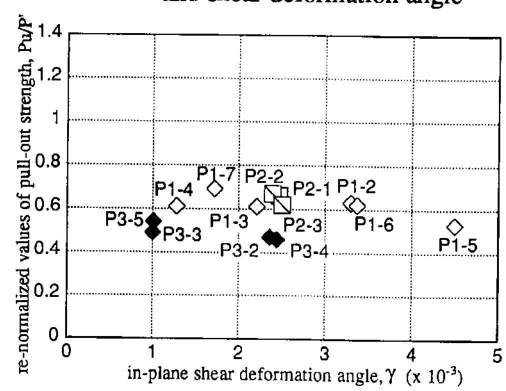

Fig.9 Relationships between re-normalized pull-out strength and shear deformation angle