Transactions of the **13th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, August 13-18, 1995

Pull-out strength of a headed stud in cracked concrete

Takiguchi, K., Hotta, H.
Tokyo Institute of Technology, Tokyo, Japan

ABSTRACT: Pull-out strength of a headed stud due to cone failure of concrete with/without cracks was examined. The purpose of this paper is to present basic empirical data to decide the criteria for designing a headed stud embedded in a shear wall under earthquake. As a result, it is known that cracks running through the stud reduce the pull-out strength, but it almost recovers when the cracks are closed again by a external compressive load.

1 INTRODUCTION

Many headed studs are embedded in RC shear walls in nuclear-related facilities in order to fast some equipments and pipings. The walls are forcibly deformed due to shear force, and come to be in biaxial states of stress during an earthquake. The cyclic external force due to the earthquake often induces cracks in the wall, and moreover closes them again. The purpose of this paper is to indicate basic empirical data on pull-out strength of cast-in-situ headed studs due to cone failure of concrete to decide the criteria for designing the headed studs embedded in the shear walls under the above complicated situations. On the pull-out strength of the fasteners, the extensive research works have been performed by R. Eligenhausen, however, the informations from his researches are partly not enough when the object installing the fasteners is limited to the shear wall during an earthquake. Hence, during an earthquake, the walls are in biaxial states of stress, and the cracks are opened and closed again and again.

In this paper, the pull-out strength of a stud embedded in a concrete plate under the following five situations is discussed from a fundamental experimental work.
(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 crack closed due to compression
(5) with a closed crack and a open crack orthogonal with each other

2 EXPERIMENT

2.1 Specimen

Eighteen specimens listed in Table 1 were made and tested. The situation (1) mentioned

Table 1 List of specimens

Name of specimen	Symbol	σ_B (kg/cm^2)	Splitting tensile strength (kg/cm^2)	Crack width (mm)		Compressing force (t)	Pull-out strength (t)
No.1 -1		388	41	-	-	-	3.40
-2				-	-	-	3.32
-3				-	-	-	2.97
No.2 -1				-	0.26	-	2.42
-2				-	0.33	-	2.03
-3				-	0.17	-	2.36
No.3 -1				0.17	0.19	-	1.73
-2				0.19	0.34	-	1.47
-3				0.24	0.35	-	1.78
No.4 -1		346	29	-	-	-	3.21
-2				-	-	-	2.86
-3				-	-	-	3.09
NO.5 -1				-	0.01	17	3.39
-2				-	0.02	17	3.32
-3				-	0.03	19	3.83
No.6 -1				0.37	0.03	17	2.73
-2				0.23	0.06	18	2.75
-3				0.18	0.02	17	2.80

in the above section corresponds to the specimens (No.1 and No.4 series). The situations (2), (3), (4) and (5) corresponds to the No.2, No.3, No.5 and No.6 series, respectively. A headed stud bolt as shown in Fig.1 is embedded at the center of all specimens with embedment depth of 50mm as shown in Fig.2 so that the bolt itself will not be failed due to tension.

The dimensions and detail of the specimens are illustrated in Fig.3. The 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 3.76tf/cm^2 are arranged in the specimens so that they will not be failed due to bending. All sides of the specimens are notched and aluminium plates are installed at the lower part of the specimens in order to induce cracks running through the stud.

The concrete placed was the ordinary concrete of which nominal strength was 270kgf/cm^2. After casting the concrete, the specimens were covered with a vinyl sheet for 2 weeks, and the form was removed after for 2 week moist curing. After removing the form, they were covered again with wet sand until the testing age so as not to be cracked due to

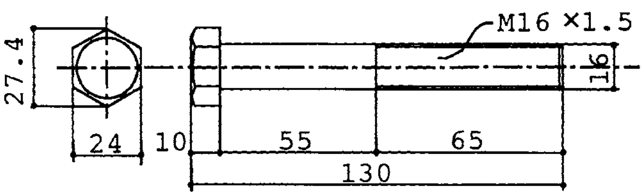

Fig.1 Detail of embedded headed stud (unit : mm)

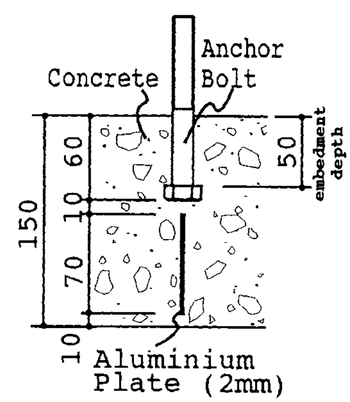

Fig.2 Detail of the section of the specimen (unit : mm)

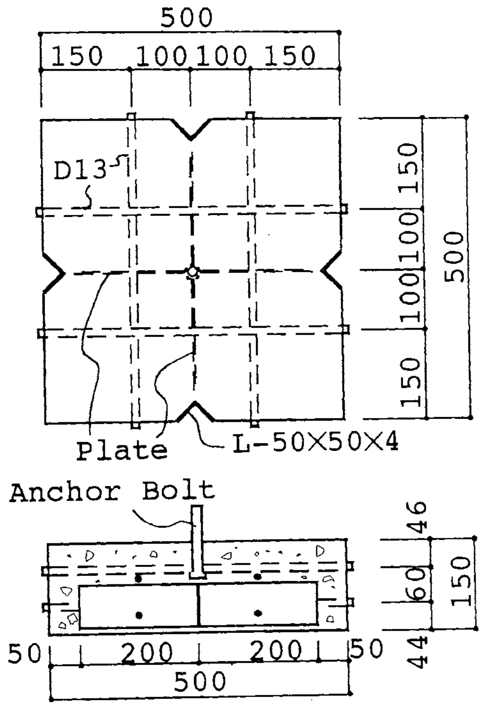

Fig.3 Dimension of the specimen (unit : mm)

drying shrinkage before the test. The age of the concrete at the test was about 50 days for the specimens (No.1-3), and about 90 days for (No.4-6). The compressive and the splitting tensile strengths of the concrete is 388kgf/cm^2 and 41kgf/cm^2 for the specimens (No.1 -3), and, 346kgf/cm^2 and 29kgf/cm^2 for the specimens (No.4 -6) at the testing age.

2.2 Method to crack the specimens and the crack width

Figure 4 shows the method to crack the specimen. The specimens were split due to the compression loaded from the both notched parts. The compressive load was about 30tf, by which the installed deformed bars seem to be yielded.
The several examples of the crack width measured using a microscope(x100) after

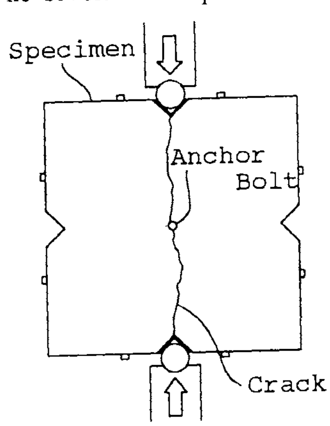

Fig.4 Method to crack the concrete

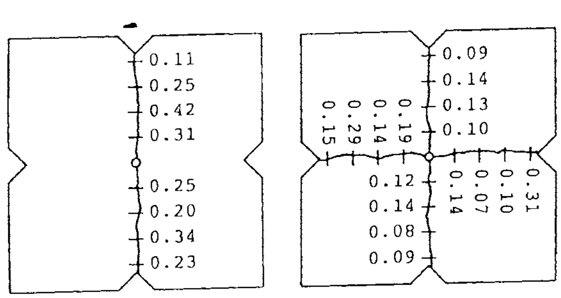

Fig.5 Crack width observed by microscopic examination (unit : mm)

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 described in Table 1. They are about 0.2mm.

2.3 Method to close the crack

The apparatus to close the crack is shown in Fig.6. The once opened crack was closed again by fastening the specimen using loading beams and four PC bars as shown in the figure. The line of action of the fastening force is equivalent to the position of the arranged upper deformed bars vertically. The fastening force ranged from 17tonf to 19tonf.

As the line of action of the fastening load is equivalent to the position of the upper reinforcing bars, the distribution of the stress of the concrete and the internal reaction force of the bars seem to be in Fig.7. Hence the upper deformed bars are yielded, the lowers are not be yielded, and the upper part of the concrete, where the stud is just embedded, is stressed.

Actual compressive stress at the surface was unknown, because the depth of the neutral axis could not be specified. If the depth to the neutral axis of 30mm is assumed for the compressive stress distribution of the concrete, the compressive stress of about 60kg/cm^2 at the surface is obtained from the equilibrium of the forces. Considering that the crack width before fastening was about 0.2mm, the assumption of the depth of the neutral axis would not be too far different from the actual value. Therefore the fastening load does not ensure the crack completely closing from the surface to the embedment depth, and the crack might be still opened at the position of the bolt head.

Though a certain opening about 0.01mm was observed from the microscopic examination after fastening the specimen as shown in Table1, that is because the both crack surfaces contacted again with a minute horizontal or vertical gap by fastening the specimen.

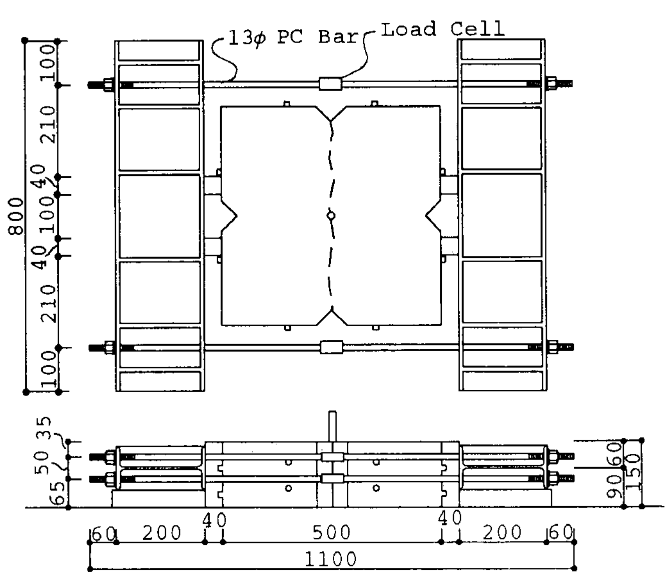

Fig.6 Apparatus to close the crack (unit : mm)

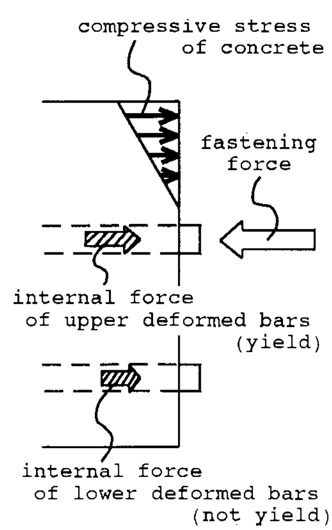

Fig.7 Stress distribution in the section

2.4 Pull-out testing method

The apparatus for the pull-out test is detailed in Fig.8. The reaction frame with four legs was put on the specimen, the head of the bolt connected with the embedded stud using a coupler was pulled up vertically by a hydraulic jack set at the center through four steel bars. The span of the legs of the reaction frame was about 400mm, and the frame does not confine the cone failing of the specimen at all. The tensile load and the slipping-out displacement of the bolt were measured.

3 EXPERIMENTAL RESULT

Figure 9 shows the load vs. displacement curves of the specimens. It is known that the crack reduces the strength and the stiffness, but increases the displacement at the failure. The pull-out strength becomes 70% of the non-cracked specimen due to an influence of a crack. As for the specimen with two orthogonal open cracks, the strength becomes a half of the non-cracked specimen. However, fastening the specimen and closing the crack again, the strength and the stiffness are almost completely recovered to the non-cracked specimen's.

The all testing results are compared with each other in Fig.10. The vertical axis stands for the pull-out strength normalized by the one recommended for a design in "Design Recommendation for Composite Construction "published in Architectural Institute of Japan. The formula is as follows;

$$P = Ac\sqrt{\sigma_B}, \tag{1}$$

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,

$$Ac = \pi h(h+D), \tag{2}$$

where, h: embedment depth and D: diameter of a stud. The dashed line described in the figure stands for the pull-out strength presented by R.Eligenhausen, which is given by

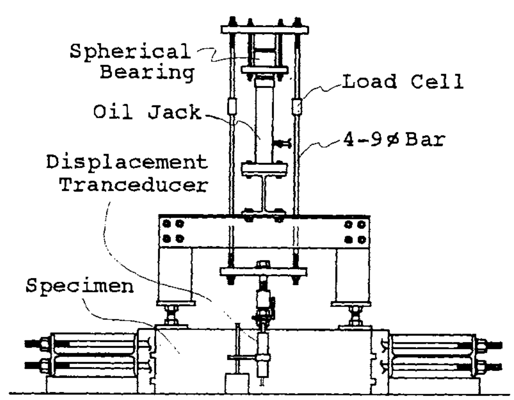

Fig.8 Pull-out testing apparatus

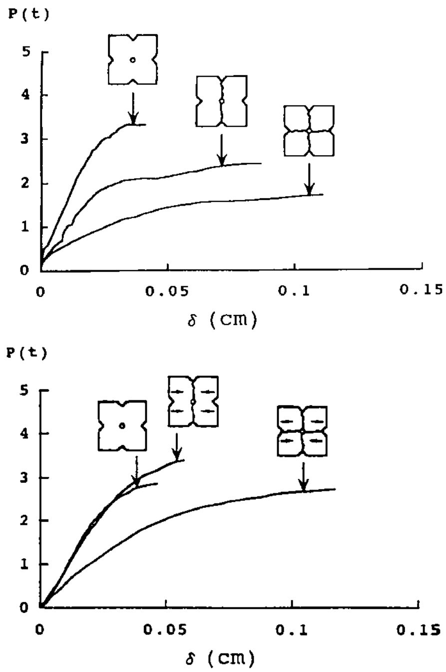

Fig.9 Load versus displacement curves

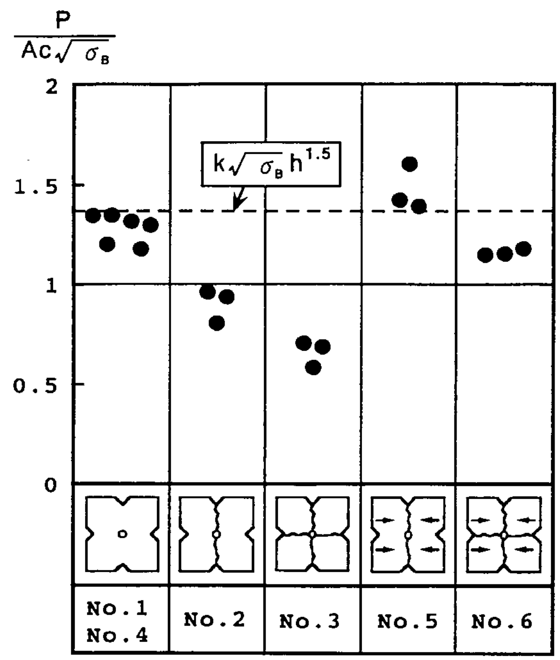

Fig.10 List of all testing results

the following equation.

$$P = k\sqrt{\sigma_B}\ h^{1.5}, \tag{3}$$

where, k is the empirical coefficient (=$15.7\sqrt{kg/cm}$).

4 CONCLUSIONS

(1) Cracks running through a stud reduce both the pull-out strengthand 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 cracks 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.

REFERENCES

Rehm, G., Eligenhausen, R. and Mallee, R. 1992. Be festigungstechnik : *Betonkalender, Vol.II*

Design Recommendation for Composite Construction : 1985 Architectural Institute of Japan