On the cracking stress of RC elements subjected to pure shearing loads

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ABSTRACT: The purpose of the present study is to investigate the influence of re-bars on the fracture behavior of RC elements subjected to pure shearing stress in order to evaluate the shear strength on a member level or higher. In particular, in this paper, we discuss the influence of internal re-bars by comparing an RC element and a plain concrete element under cracking load (stress). Furthermore, in order to investigate the influence of shrinkage of concrete on the cracking load (stress), we report the results of pure shearing tests on concrete employing a shrinkage reducing admixture and expansive material.

1 INTRODUCTION

Shearing fracture of concrete structures is characterized by brittleness, and the quantification of shearing fracture behavior is an important factor in securing the safety of structures. Therefore, re-bars for shear reinforcement are more often than not placed in many concrete structures. However, the influence of such re-bars on the shear strength of concrete has not proven to be necessarily satisfactory.

In previous studies, not a few experimental and analytical researches have been conducted on reinforced concrete beam and slab members. In such researches targeted at a member level, it would be difficult to directly evaluate the influence of internal rebars on the shear strength of concrete. The present work aims to obtain the pure shearing property of reinforced concrete (RC) on an element level, facilitating the evaluation of the relative influence of the rebars.

In previous studies by the authors, a simplified apparatus for a pure shearing test was developed, and the mechanical properties of a plain concrete element subjected to pure shearing stress, of carbon fiber sheets reinforced concrete element, etc., were reported. However, we have so far carried out pure shearing tests of an RC element targeting the most common RC structures. Common concrete structures have an RC structure, and when shearing stress acts on it, the influence of re-bars on fracture behavior should not be negligible. Consequently, we attempted in the present study the experimental evaluation of a pure shearing fracture property of an RC element in comparison with a plain concrete element which had posed cleavage fracture (mode I) in the previous studies. In particular, in this paper, the influence of the presence or absence of re-bars on cracking load is reported regarding the concrete element subjected to pure shearing stress.

2 PURE SHEARING TEST PROCEDURE

2.1 *Loading apparatus and loading method*

The medium-sized apparatus for the pure shearing test (Figure 1) used in the present study can be installed in an Amsler type testing machine. As shown in Figure 2, a (vertical) uniaxial load is distributed in 45^{o} directions via the rotating loading jig so that pure shearing stress can be applied on a concrete test specimen. The reaction force in the horizontal direction is structurally received by the steel frames installed on the top and bottom. This method can be considered very economical because it uses a relatively simple jig and does not require multiple pressing devices.

Each loading plate used for this medium-sized pure shearing test is channel-shaped as shown in Figure 2, which shows that one rotating loading jig is pin-coupled structurally.

2.2 *Test specimens and experimental parameters*

As shown in Figure 3, test specimens for medium-sized pure shearing tests were prepared by attaching steel bolts (M12, embedded 25mm in length) to each of the steel loading plates on the four sides, with the role of spikes. Here, the spike-embedded areas in the concrete are considered to be parts conveying shearing stress to the interior concrete element.

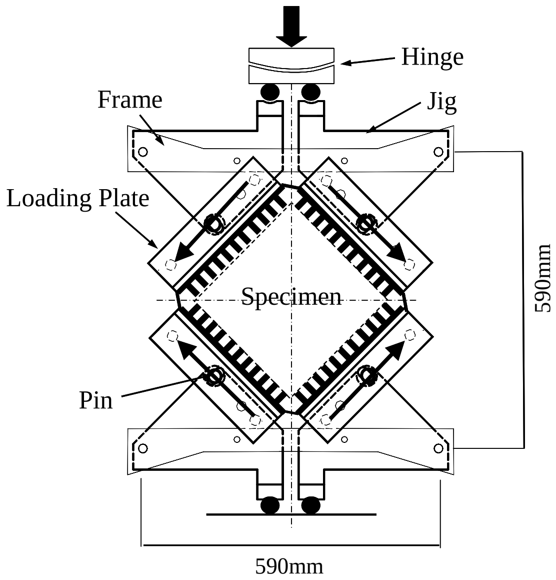


Figure 1. Pure shearing test

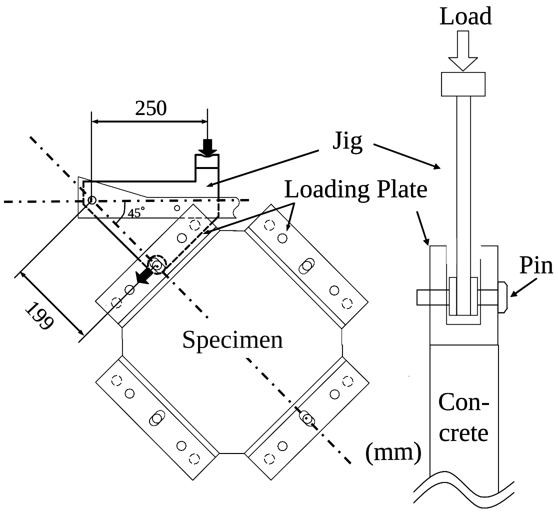


Figure 2. Providing method of pure shearing stress

Additionally, a long aperture (15x265mm) was provided at the center of each loading plate so that re-bars could be arranged at various angles. For pure shearing tests in the present study, a 1mm-thick rubber plate was installed between the loading plate and concrete so as to avoid excessive deformation to the concrete test specimen due to the rigid loading plate.

In the present study, re-bars having relatively small diameters (D13, D10) were worked into a channel shape and also provided with a hook on both ends in order to secure sufficient fixity of re-bars in the concrete element. The spacing between re-bars was 150 mm. The bar arrangement condition before casting is shown in Figure 4.

Generally, it is known that the (bending) cracking load of reinforced concrete is low in comparison with plain concrete because a tensile force is potentially generated in the concrete due to partial constraint of the free volume change (shrinkage) of the concrete excited by the re-bars (Niwa, Hidaka, Tanabe, 1996). Also, according to the previous study, it is reported that shear reinforcing bars influence the

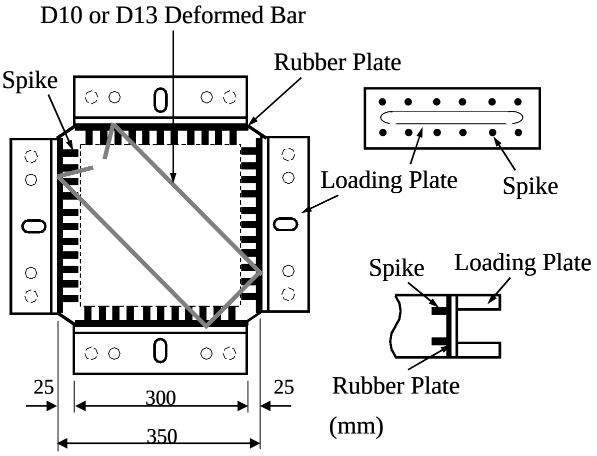


Figure 3. Detail of specimen

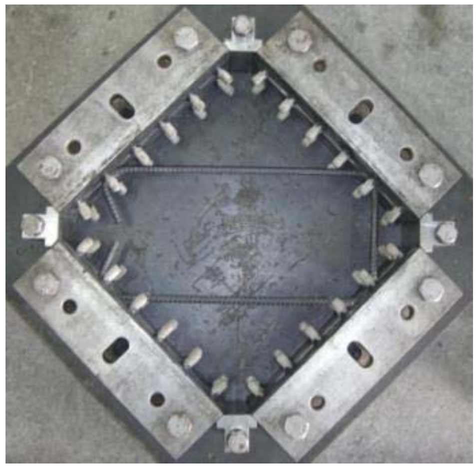


Figure 4. Re-bar set up

shear cracking load F_{ps} of RC beams employing high-strength concrete, but the fact is that there is not sufficient information about the influence of re-bars on the shear cracking of general-strength-level concrete.

With that, we investigated in the present study the influence of re-bars with respect to the pure shear cracking load F_{ps} by using normal-strength (W/C = 60%) concrete together with a shrinkage reducing admixture and expansive material. The experimental parameters employed in the present study are given in Table 1.

2.3 *Materials used and mixing conditions*

The mixing proportions of the prepared concrete are shown in Table 2. The experiments were conducted by setting the water-powder ratio (W/(C+Ex)) constant at 60% for the purpose of investigating the pure shearing property of normal strength concrete.

Also, due to the use of early-strength Portland cement, we conducted experiments at the age of 7 - 8 days in Tests No.1, No.2, and No.4 to No.8 (15 days in Test No.3 only). In these tests, drying effects were minimized by sufficient compress curing until the tests performed.

Table 1. Experimental parameters

No.	Specimen	Re-bar diameter	Expansive material (Ex) kg/m^3	Shrinkage reducing admixture (SRA) kg/m^3	Curing method
1	NS-M0	---	---	---	Wet
1’	D13(0^o)-M0	D13	---	---	Wet
2	NS-M20	---	20	---	Wet
2’	D13(0^o)-M20	D13	20	---	Wet
3	NS-M0	---	---	---	Wet
3’	D10(0^o)-M0	D10	---	---	Wet
4	NS-M0	---	---	---	Dry
4’	D10(0^o)-M0	D10	---	---	Dry
5	NS-M0+	---	---	10	Wet
5’	D10(0^o)-M0+	D10	---	10	Wet
6	NS-M20	---	20	---	Wet
6’	D10(0^o)-M20	D10	20	---	Wet
7	NS-M30	---	30	---	Wet
7’	D10(0^o)-M30	D10	30	---	Wet
8	NS-M40	---	40	---	Wet
8’	D10(0^o)-M30	D10	30	---	Wet

Table 2. Mix proportions of concrete

Mix No.	W/(C+Ex)	W/C	W	C	S	G	Ad	Ex	SRA
	%	%	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
M0	60	60	160	267	790	1092	C x1.0%	---	---
M0+	60	60	160	267	790	1092	C x1.0%	---	10
M20	60	65	160	247	790	1092	C x1.0%	20	---
M30	60	68	160	237	790	1092	C x1.0%	30	---
M40	60	71	160	227	790	1092	C x1.0%	40	---

3 PURE SHEAR CRACKING AND CRACKING LOAD (PURE SHEARING STRENGTH) OF RC ELEMENT

3.1 *Pure shear cracking pattern*

Cracking pattern caused by the pure shearing tests and cracking loads (pure shearing strengths f_{ps}) are collectively shown in Figure 5. In every experiment using the medium-sized apparatus for the pure shearing test, the plain concrete element posed cleavage fracture (mode I) in which one vertical crack (pure shear cracking) occurred and developed as the principal tensile stress component was prominent, as show in the previous studies using the small-sized apparatus.

On the other hand, the cracking patterns differed with experimental parameters in the pure shearing tests of the RC element. Pure shear cracking patterns are discussed below for the various experimental parameters (re-bar diameter and mix proportion).

3.1.1 *Diameter of re-bar*

On the D13(0^o)-M0 test specimen and D13(0^o)-M20 test specimen employing D13 re-bars, cracking occurred along the re-bar axis and along the interface between the loading plate and concrete (tips of spikes) after the occurrence of pure shear cracking. On the other hand, on the D10(0^o)-M0 test specimen employing D10 re-bars, pure shear cracking occurred, and no cracking was found in other directions.

The reason for this can be explained as follows: since the (shearing) reinforcing effects of the D13 re-bars were sufficiently high with respect to the dimensions of this test specimen, cracking occurred at the interface between the loading plate and concrete and near the re-bar axis, which presented relatively low strength since the force was applied against the principal tensile stress component of the pure shearing stress state. In the present study, which concerns experiments on the shearing properties of an element of the RC structure, the fracture behavior obtained by using the D13 re-bars may not be a representative. Therefore, in the following experiments, we discussed the pure shear cracking property by using the D10 re-bars.

3.1.2 *Amount of expansive material and shrinkage reducing admixture*

On the D10(0^o)-M20 test specimen employing expansive concrete with the amount of expansive additive 20 kg/m^3 (standard amount added), pure shear cracking developed in the vertical direction developed. At the same time, on the test specimens (D10(0^o)-M30 and D10(0^o)-M40) with the amounts of expansive material 30 kg/m^3 and 40 kg/m^3, respectively, cracking occurred along the interface between the loading plate and concrete (tips of spikes) after the occurrence of pure shear cracking. It is presumed that the chemical pre-stressing (strain) effects of expansive concrete limited the principal tensile stress component that acted on the cross sections at

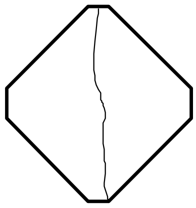
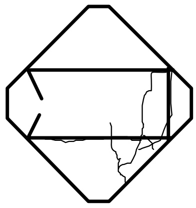
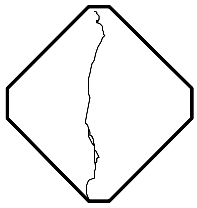
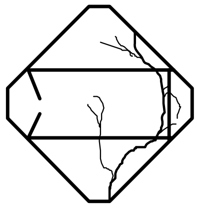
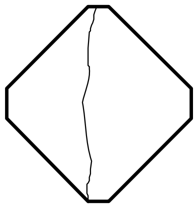
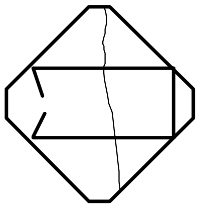
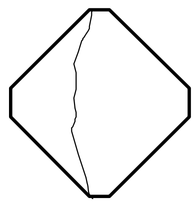
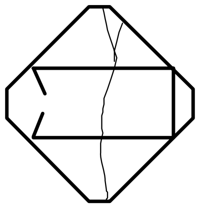
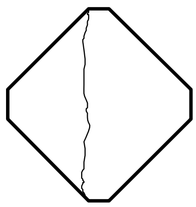
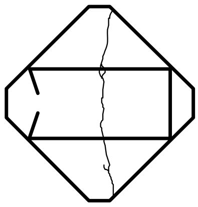
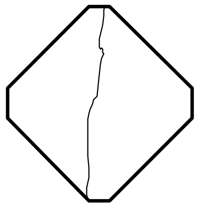
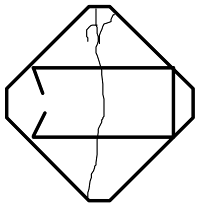
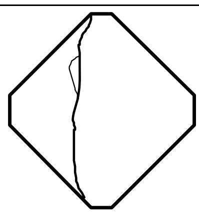
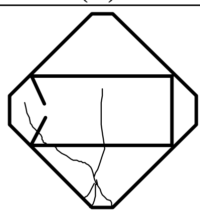
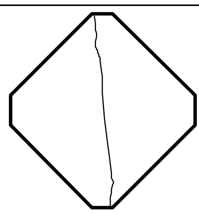
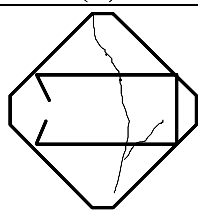
No.	1		2	
	NS-M0	D13(0^{o})-M0	NS-M20	D13(0^{o})-M20
Crack sketch				
F_{ps}	97.8kN	79.7kN	79.5kN	78.7kN
f_{ps}	2.04N/mm^2	1.66N/mm^2	1.66N/mm^2	1.64N/mm^2
RC/NS	0.81		0.99	
No.	3		4	
	NS-M0	D10(0^{o})-M0	NS-M0	D10(0^{o})-M0
Crack sketch				
F_{ps}	92.4kN	83.3kN	121.1kN	104.0kN
f_{ps}	1.93N/mm^2	1.74N/mm^2	2.53N/mm^2	2.17N/mm^2
RC/NS	0.90		0.86	
No.	5		6	
	NS-M0+	D10(0^{o})-M0+	NS-M20	D10(0^{o})-M20
Crack sketch				
F_{ps}	108.6kN	108.8kN	74.5kN	83.3kN
f_{ps}	2.27N/mm^2	2.27N/mm^2	1.56N/mm^2	1.74N/mm^2
RC/NS	1.00		1.12	
No.	7		8	
	NS-M30	D10(0^{o})-M30	NS-M40	D10(0^{o})-M40
Crack sketch				
F_{ps}	44.4kN	51.7kN	40.5kN	39.2kN
f_{ps}	0.93N/mm^2	1.08N/mm^2	0.85N/mm^2	0.82N/mm^2
RC/NS	1.17		0.97	

Figure 5. Crack sketch and cracking load (f_{ps}, F_{ps})

the center of the test specimens, and cracking developed in the areas in which they had little influence.

The D10(0^{o})-M0+ test specimen employing the shrinkage reducing admixture showed cleavage fracture (mode I) in which one pure shear cracking occurred as in the D10(0^{o})-M0 and D10(0^{o})-M20 test specimens.

3.2 *Cracking load (pure shearing strength)*

The purpose of the present study is to investigate the influence of internal re-bars in the concrete element on the first cracking (shear cracking) load. Therefore, we decided to perform comparative evaluation of cracking loads F_{ps} by preparing test specimens with and without re-bars in No.1 to No.8 concurrently. The cracking loads, pure shearing strengths f_{ps}, and strength ratios (RC/NS) associated with the existence and non-existence of the re-bars of the respective test specimens are shown in Figure 5 as mentioned above. In the present study using the RC element, pure shearing strengths fps were obtained from the cracking load Fps, because the purpose of the present study is to evaluate the strength characteristics of concrete element. As in the previous section, pure shear cracking loads F_{ps} (pure shearing strengths f_{ps}) are shown below as systematically arranged by experimental parameters.

3.2.1 *Re-bar diameter*

Focusing on the results of Tests No.1 (D13) and No.3 (D10), we note that the strength ratios associated with the existence and non-existence of the re-bars are 0.81 and 0.90, respectively, and the cracking load F_{ps} of the RC element is smaller than that of the plain concrete element in either Test No. In Test No.4 on condition of 15 days of air curing after casting (conditions other than curing were the same as in Test No.3), the strength ratio was the smallest among Tests No.3 ~ No.8 using D10 re-bars.

Also, when the results of No.2 (D13) and No.6 (D10) using expansive concrete with the amount of expansive material 20 kg/m^3 are compared, the strength ratios associated with the existence and non-existence of the re-bars were 0.99 and 1.12, respectively. With the use of expansive concrete, the cracking load F_{ps} of the RC element is comparatively improved, but the cracking load F_{ps} of the D13(0^o)-M20 test specimen employing the D13 re-bars remains almost equal to that of the NS-M20 test specimen of the plain concrete element.

3.2.2 *Shrinkage reducing admixture*

From the above experiment, since the action of potential initial stress associated with the shrinkage of concrete was theorized, similar experiments were conducted on concrete employing a shrinkage reducing admixture (Test No.5). The result was that the cracking loads F_{ps} of the NS-M0+ test specimen and D10(0^o)-M0+ test specimen were almost the same, approximately 109 kN (RC/NS = 1.00). By comparing this result with the results of Tests No.3 and No.4, it can be seen that the initial stress acting on the concrete could also greatly influence the shear cracking load F_{ps} in the element-level experiments used in the present study.

3.2.3 *Amount of expansive material*

Based on the above results, we conducted similar comparative experiments on concrete having different amounts of expansive material. In Test No.6 (M20), the strength ratio associated with the existence and non-existence of the re-bars was 1.12 as mentioned above, while the same ratio in Test No.7 (M30) was 1.17, and furthermore the strength ratio associated with the existence and non-existence of the re-bars in Test No.8 (M40) was 0.97, which indicates that there was not much improvement of the strength as a result of the expansion. The experimental results indicate that reinforcing effects against the occurrence of shear cracking may be obtained by adding appropriate amounts of expansive additive even with re-bars having relatively small diameters, such as stirrups.

4 CONCLUSIONS

In the present study, we discussed the influence of internal re-bars by comparing the cracking loads (stresses) of an RC element and plain concrete element subjected to pure shearing stress. Conclusions obtained in the present study are listed below.

1) Even with the use of normal-strength concrete, the cracking load of the RC element under the influence of potential initial stresses caused by re-bars was reduced to approximately 80-90% compared with the plain concrete element. From this, emerges the possibility that the influence of internal re-bars may not always be negligible in the evaluation of a proof strength of concrete members on which shearing stress acts on the element level.
2) If the reinforcing effects of re-bars are large and if the chemical pre-stressing (strain) effects of expansive concrete are large, only the (pure) shear cracking of the RC element is prominent, and does not lead to fracture, and cracking therefore develops at other brittle zones.
3) With the concrete employing a shrinkage reducing admixture, the cracking load was approximately equal irrespective of the presence or absence of re-bars. Also, with the concrete employing appropriate amounts of expansive material, the cracking load of the RC element can be improved compared to that of the plain concrete element.

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