Experimental Study on Tensile Strength of Concrete for Dams

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ABSTRACT

The tensile strength of concrete should be studied comprehensively in order to evaluate the seismic resistance of concrete dams. Direct tensile tests, splitting tensile tests and compressive tests were conducted in order to study the relationship between the compressive strength and the tensile strength of concrete, and the effect of loading rate on the tensile strength of concrete.

The following results were obtained:

1) Compressive strength, splitting tensile strength and direct tensile strength of concrete increase as the cement water ratio increases.
2) The direct tensile strength is smaller than the splitting tensile strength.
3) A higher rate of loading results in a larger tensile strength.

Keywords: *Concrete, Tensile Strength, Rate of Loading*

1. INTRODUCTION

The present Japanese design criteria specifies the middle-third condition in the design of concrete gravity dams and no tensile stress is induced in the dam under the design load combinations. However, large tensile stress is induced in the dams in the dynamic analysis of concrete gravity dams, and a detailed investigation of the tensile strength of concrete is therefore important to secure the seismic resistance of concrete gravity dams.

This paper discusses the results of direct tensile tests of concrete with three different mix proportions under various rates of loading.

2. OUTLINE OF TESTS

2.1. Test Methods

Splitting tensile tests are widely used for evaluating the tensile strength of concrete. However, direct tensile tests are necessary to accurately study the tensile strength of concrete. Direct tensile tests were therefore conducted in this study.

The test equipment is shown in Figure 1. Both ends of the concrete specimen were glued with epoxy resin adhesives to the attachment plates and they were fixed with bolts to the loading plates of universal dynamic test equipment. The bond strength

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of the hardened adhesives was approximately 9 N/mm^2 and was much larger than the tensile strength of concrete. The applied load on a concrete specimen was measured with loading cells and the loading rate was controlled at a specified value by the computer. The strain of the concrete specimen was measured using four strain gauges stuck on the specimen surface parallel to loading direction.

Splitting tensile tests and compressive tests were also conducted.

2.2. Mix Proportion of Concrete

The mix proportions of the concrete used in the tests are shown in Table 1. Three types of mix proportions were selected for the tests. They represent the mix proportion of RCD concrete, the conventional concrete used in gravity dams and the conventional concrete used in arch dams and are denoted as "RCD", "GRAVITY" and "ARCH", respectively. The water-cement ratio, which affects the strength of concrete, is 75%, 60% and 45%, respectively.

The concrete specimens were cylinders of 15 cm in diameter and 30 cm in height. To avoid failure at the ends, 3 cm was cut off from both ends of the specimens used for the direct tensile test were.

2.3. Test Conditions

1) Rate of Loading

Five different rates of loading were used in the direct tensile tests in order to investigate the effect of the rate of loading on strength. The rate of loading is as follows:

Compressive test:
0.2 $N/mm^2/s$

Splitting tensile test:
0.0067 $N/mm^2/s$
(tensile stress on expected failure plane)

Direct tensile test:
0.0067, 0.2, 2, 20, 60 $N/mm^2/s$

2) Tested Age of Concrete

All tests were conducted at the age of about 180 days which is selected to avoid the increase in strength by aging. Specimens were cured in water and were dried in a natural room environment for a week before the tests. Three cm was cut off from both ends of the specimens used for

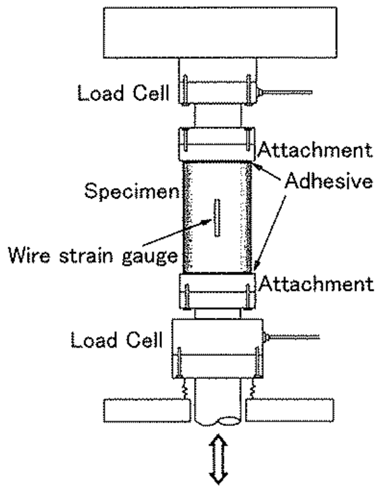

Fig. 1 Test Equipment

Table 1 Mix Proportion of Concrete

Mixture	Gmax (mm)	VC value (sec)	Slump (cm)	Air (%)	W/C (%)	s/a (%)	Unit Weight (kg/m³)					Admixture (kg)
							W	C	S	G 5-20 mm	G 20-40 mm	
RCD	40	20±10	—	—	75	42	119	159	891	652	612	0.398
GRAVITY	40	—	4±1	4±1	60	40	157	262	760	719	315	0.066
ARCH	40	—	4±1	4±1	45	37	156	347	675	738	433	0.156

the direct tensile tests on the 90th day of water cure.

3. TEST RESULTS

3.1. Comparison of Strengths of Concrete with Different Mix Proportions

The relationship between the cement water ratio and compressive strength is shown in Figure 2, the relationship between the cement water ratio and splitting tensile strength is shown in Figure 3, and the relationship between the cement water ratio and direct tensile strength (loading rate of 0.0067 N/mm^2/s) is shown in Figure 4. All strengths show the larger values for higher cement water ratio. However, the increase is less notable in the splitting tensile strength and the direct tensile strength than in the compressive strength. In addition, the direct tensile strength of RCD is especially low.

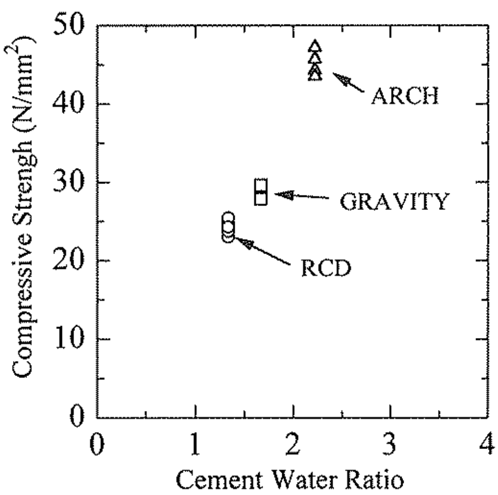

Fig. 2 Relationship between Cement Water Ratio and Compressive Strength

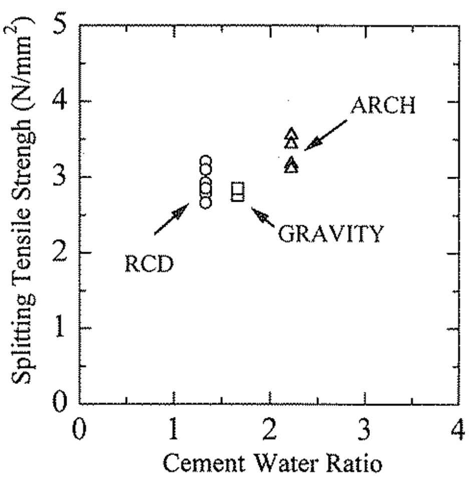

Fig. 3 Relationship between Cement Water Ratio and Splitting Tensile Strength

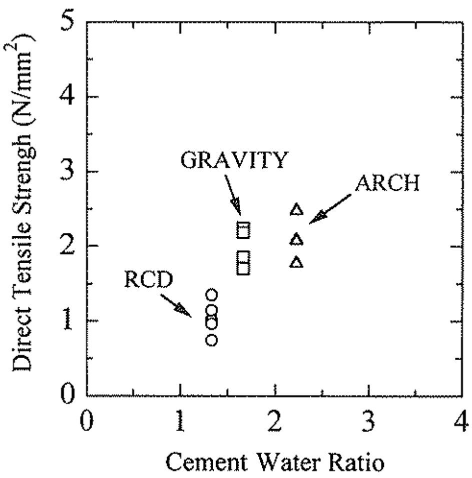

Fig. 4 Relationship between Cement Water Ratio and Direct Tensile Strength

3.2. Relationships between Compressive Strength, Splitting Tensile Strength and Direct Tensile Strength

The relationship between compressive strength and splitting tensile strength is shown in Figure 5 for three mix proportions. The splitting tensile strength increases as compressive strength increases. The ratio of splitting tensile strength to compressive strength is 1/9 to 1/7 for RCD, 1/11 to 1/12 for GRAVITY and 1/9 to 1/10 for ARCH.

The relationship between compressive strength and direct tensile strength (loading rate of 0.0067 N/mm²/s) is shown in Figure 6 for three mix proportions. The ratio of direct tensile strength to compressive strength is 1/22 to 1/32 for RCD, 1/13 to 1/17 for GRAVITY and 1/18 to 1/25 for ARCH.

The relationship between splitting tensile strength and direct tensile strength (loading rate of 0.0067 N/mm²/s) is shown in Figure 7 for three mix proportions. The ratio of direct tensile strength to splitting tensile strength is approximately 2/3 for GRAVITY and ARCH, and only 1/3 for RCD, which is significantly smaller than the others.

A smaller direct tensile strength compared to the splitting tensile strength may be attributed to the difference in the failure condition. Failure occurs at the weakest plane in a specimen in the direct tensile test while failure occurs in the prescribed plane in a specimen in the splitting tensile test.

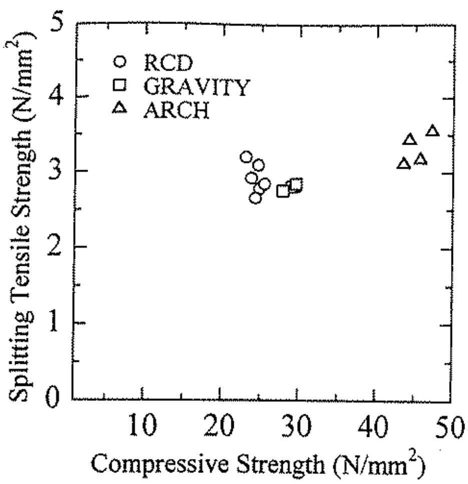

Fig. 5 Relationship between Compressive Strength and Splitting Tensile Strength

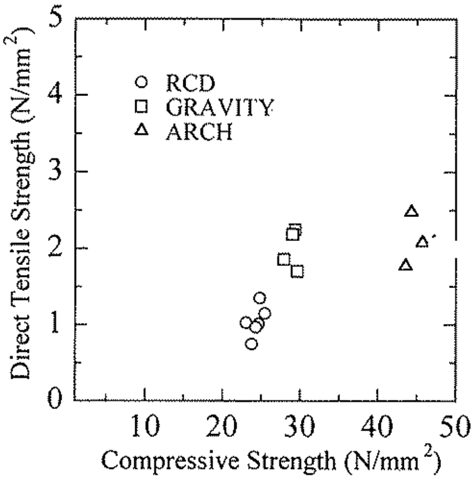

Fig. 6 Relationship between Compressive Strength and Direct Tensile Strength

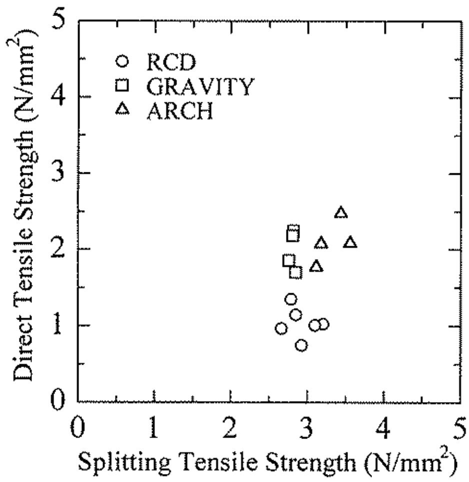

Fig. 7 Relationship between Splitting Tensile Strength and Direct Tensile Strength

3.3. Effects of Rate of Loading on Direct Tensile Strength

The relationship between the rate of loading and direct tensile strength is shown in Figure 8 for RCD, Figure 9 for GRAVITY and Figure 10 for ARCH. These figures are summarized in Figure 11 where the mean values of the test results are plotted. Figure

11 shows that tensile strength of all mix proportions increases, as the rate of loading becomes larger, although the dispersion of test results is large.

Figure 12 shows the normalized direct tensile strength where the tensile strength at a rate of loading of 0.0067 $N/mm^2/s$ is assumed to be unity. The direct tensile strength is about 20% larger at 2 $N/mm^2/s$ than at 0.0067 $N/mm^2/s$ and about 50% larger at 20 $N/mm^2/s$.

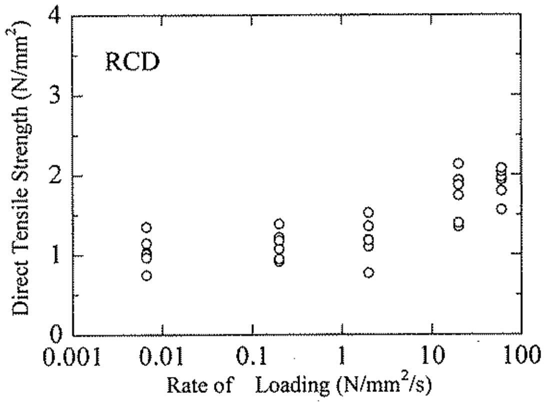

Fig. 8 Rate of Loading and Direct Tensile Strength (RCD Mixture)

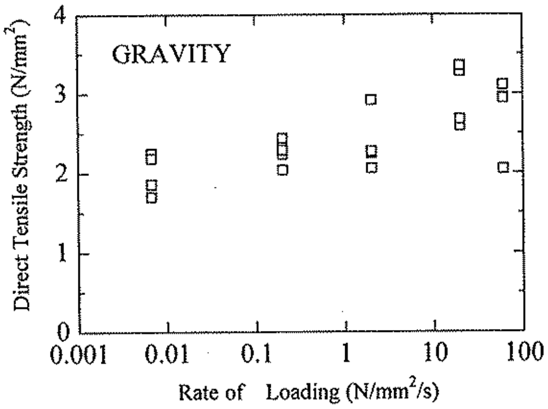

Fig. 9 Rate of Loading and Direct Tensile Strength (GRAVITY Mixture)

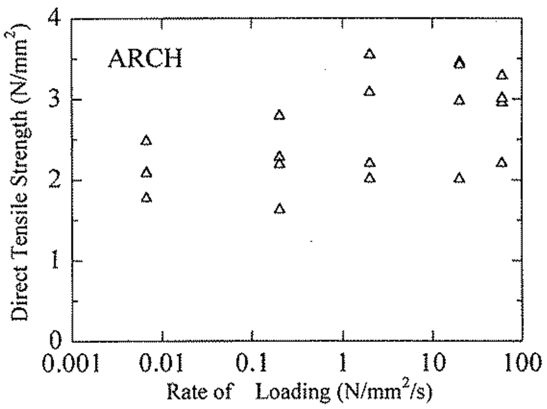

Fig. 10 Rate of Loading and Direct Tensile Strength (ARCH Mixture)

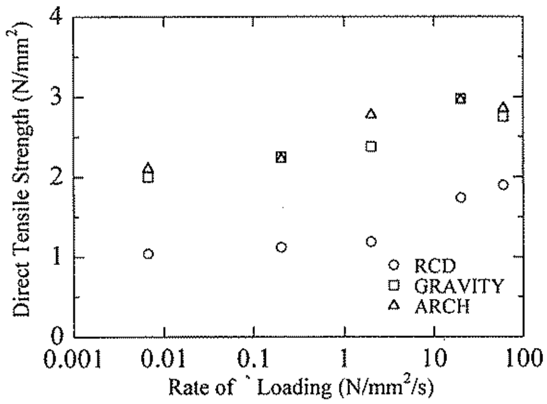

Fig. 11 Rate of Loading and Direct Tensile Strength (All Mixtures)

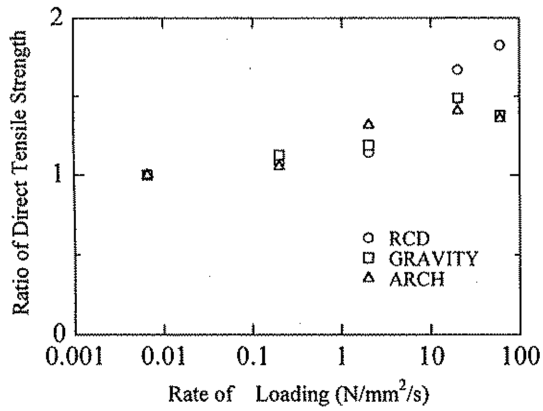

Fig. 12 Rate of Loading and Normalized Direct Tensile Strength

3.4. Effects of Rate of Loading on Elastic Modulus

Elastic modulus is defined here as the secant modulus between 0 μ and 50 μ of strain. The relationship between the rate of loading and the elastic modulus is shown in Figure 13 for RCD, Figure 14 for GRAVITY and Figure 15 for ARCH.

Figure 16 shows the normalized elastic modulus where the elastic modulus at a rate of loading of 0.0067 N/mm^2/s is assumed to be unity. The elastic modulus does not seem to be affected by the rate of loading.

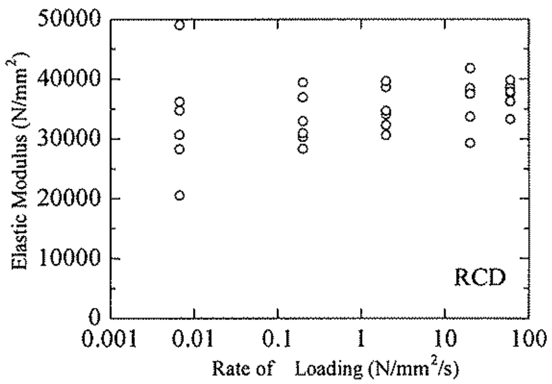

Fig. 13 Rate of Loading and Elastic Modulus (RCD Mixture)

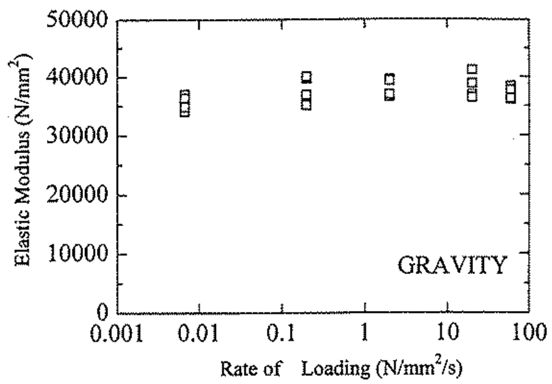

Fig. 14 Rate of Loading and Elastic Modulus (GRAVITY Mixture)

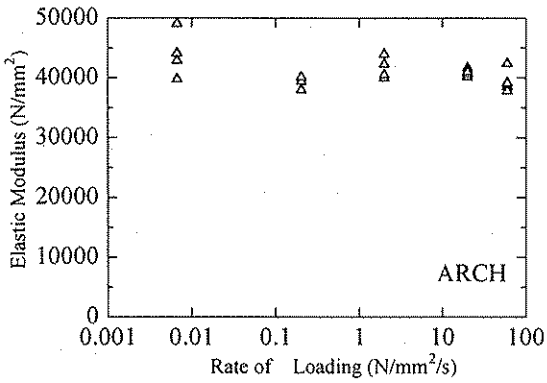

Fig. 15 Rate of Loading and Elastic Modulus (ARCH Mixture)

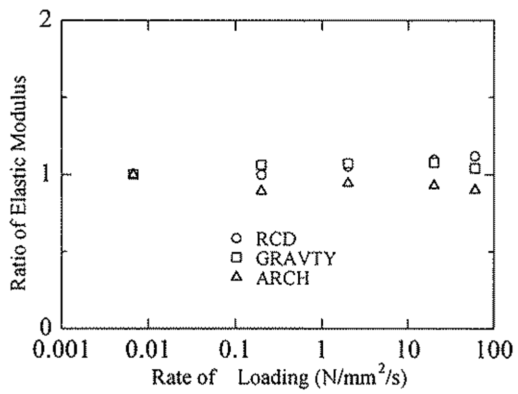

Fig. 16 Rate of Loading and Normalized Elastic Modulus

4. CONCLUSION

The following conclusions are derived from the results of the strength tests.

1) The compressive strength, splitting tensile strength and direct tensile strength of concrete increase as the cement water ratio increases. The increase in the splitting tensile strength and the direct tensile strength, however, is smaller than the increase in the compressive strength.
2) The direct tensile strength of concrete is smaller than the splitting tensile strength of concrete. This tendency is

notable in RCD concrete.

3) The direct tensile strength of concrete increases as the rate of loading increases.

4) The elastic modulus is not affected by the rate of loading.

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