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EFFECTS OF CONCRETE OVERLAY JOINT CONDITIONS AND STRAIN RATE ON SPLITTING TENSILE PROPERTIES

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In Japan, design ground motion has increased due to the frequent occurrence of large earthquakes. To improve seismic performance, dams and spillway gate piers (hereafter, piers) are being reinforced. The methods used to strengthen them include concrete overlay, jacketing, etc. On their boundaries, there are concrete joints. These joints are designed as integrated bodies. However, although no accidents have been reported, the joints may be a weak point. The purpose of this study is to understand the effects of concrete joint condition, assuming strengthening for dams and piers such as concrete overlay and jacketing. Dynamic splitting tensile tests of concrete specimens joining old and new bodies were conducted. In dynamic splitting tensile tests, the experimental parameters are the condition of joint surfaces in terms of strengthening and strain rate for earthquake ground motion. The conditions of joint surfaces are raw concrete surfaces, chipped surfaces, and surfaces with rebar insertion. Three cases of strain rate are considered, including a static case and two dynamic cases (about 1,000 μ/s and 10,000 μ/s). Test results showed all joint conditions caused a decrease in tensile strength. There was the effect of increasing tensile strength due to strain rate, regardless of joint condition. It was shown that concrete joints without adhesives might be weak points in reinforced structures.

Keywords: Splitting tensile test, Chipped joint, Rebar insertion, Dynamic, Dam, Spillway gate piers, Seismic retrofit.

1 INTRODUCTION

Japan has recently experienced several large earthquakes. Thus, there is a need to examine whether the seismic performance of dams and spillway gate piers (hereafter, piers) are in keeping with the guideline (River Bureau, Ministry of Land, Infrastructure and Transport 2005). According to the guideline, if dams and piers are found to be damaged, it is necessary to consider strengthening methods. However, there are few cases where the seismic performance of dams and piers has been improved, and thus no method to reinforce them has been established.

In Japan, a concrete overlay and jacketing are the methods often used to reinforce dams (Sato *et al.* 2000). In the strengthening design of dams, concrete joints are often considered as integrated bodies. This is because chipping and rebar insertion is performed to ensure the integration of old and new concrete. However, few data that chipping and rebar insertion maintain mechanical strength have been obtained when to reinforce dams. In addition, as concrete joints may be weak points, it is necessary to collect the mechanical properties of various processed concrete joints.

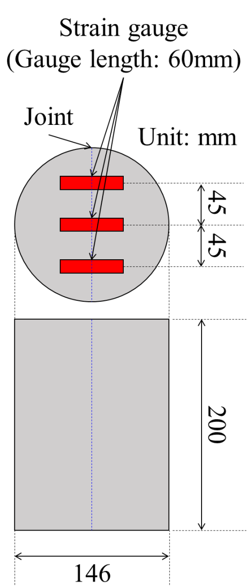
The purpose of this study is to understand the effects of tensile properties at various processed concrete joints, assuming strengthening approaches for dams and piers such as concrete overlay. Splitting tensile tests of concrete specimens that are joined old and new bodies were conducted. The conditions of joint surfaces were raw concrete, chipped and with rebar insertion. In addition, as earthquakes create a dynamic load, it is necessary to consider the effect of strain rate on monotonic loading speed to tensile properties. Therefore, a dynamic splitting tensile test of concrete specimens with various processed concrete joints was conducted.

2 EXPERIMENTAL PROGRAM

2.1 Specimen

The specimen shape for the splitting tensile test was a cylinder, φ146 × 200 mm in size, as shown in Figure 1. Specimens with joints were made by casting old concrete in half-cylinder frames and then casting new concrete beside the old in cylinder frame. There were two concrete mixtures (C1 and C2). Experimental parameters were the conditions of joint surfaces as strengthening and strain rate for earthquake ground motion. The series of joint conditions were no joint (integrated bodies), raw concrete, chipped, and connected with rebar insertion (hereafter. 0, N, C, S series). There were three cases of strain rate: one static and two dynamic cases (about 1,000 μ/s and 10,000 μ/s). Table 1 shows all the test cases. Variations of dynamic test results were larger. Therefore, two static samples were tested within whole specimens to increase dynamic samples.

Table 1. Test cases.



No.	**Material**	**Joint surface**	**Number of Rebars**	**Strain rate**	**Number of specimens**
C1-N	Concrete 1	Raw	-	Static	4
C1-C		Chipped	-	Static	4
C1-S6		Rebar insertion	6	Static	4
C2-0	Concrete 2	Sound	-	Static	2
C2-0-1k			-	1000μ/s	4
C2-0-10k			-	10000μ/s	5
C2-N		Raw	-	Static	2
C2-N-1k			-	1000μ/s	4
C2-N-10k			-	10000μ/s	4
C2-C		Chipped	-	Static	2
C2-C-1k			-	1000μ/s	4
C2-C-10k			-	10000μ/s	4
C2-S1		Rebar insertion	1	Static	2
C2-S1-1k			1	1000μ/s	4
C2-S1-10k			1	10000μ/s	4
C2-S2		Rebar insertion	2	Static	2
C2-S2-1k			2	1000μ/s	4
C2-S2-10k			2	10000μ/s	4

Figure 1. Specimen.

2.2 Materials

The concrete mixtures used in this study are listed in Table 2. The concrete binder was prepared using a combination of ordinary Portland cement (C), water (W), fine aggregate (S), coarse aggregate (G), and Admixture (Ad). Two mixtures were tested: W/C 64.1% and 50.4%. Mix designs followed JIS A 5308 (2009) and aimed at compressive strengths at 28 ages are 26MPa and 37MPa. In one case of concrete mixture, both the old and new concrete mixture was the same. To produce specimens with joints, old concrete was cured in a curing room (room temperature about 20°C) for two weeks before casting new concrete. One day after new concrete was cast, specimens were demolded. They were subsequently placed underwater in a tank in the curing room (room temperature about 20°C) for one month.

The surface conditions of joints are shown in Figure 2. For the N series, the surface condition was raw surface after hardening concrete. For the C series, the surface condition was chipped to about 1-5 mm depth after hardening. The chipped depth of specimens of mixed C1 was about 1 mm, and that of C2 specimens was about 5 mm. Chipped surface conditions of C1 and C2 were different. For the S series, holes were provided on joint surfaces. Steel bars (D10) were inserted in the holes filled with epoxy adhesive. The concrete surface condition was the same as the N series. The number of inserted rebars was 1, 2, and 6. These series are designated S1, S2, and S6. The 0 series specimens without joints were made of new concrete. The material properties of the two concrete mixes are presented in Table 3; one of the D10 steel rebars are given in Table 4.

Table 2. Concrete mix proportion.

	W/C [%]	s/a [%]	Unit content [kg/m^3]				
			C	W	S	G	Ad
Concrete 1	64.1	48.8	273	175	875	951	2.73
Concrete 2	50.4	46.2	355	179	792	957	3.55

(a) (b)

Figure 2. Surface conditions of joints: (a) Joint surfaces of the specimens made for Concrete1 (C1); N, C, S6 series; (b) Joint surfaces of the specimens made for Concrete2 (C2); N, C, S1, S2 series.

Table 3. Material properties of concrete.

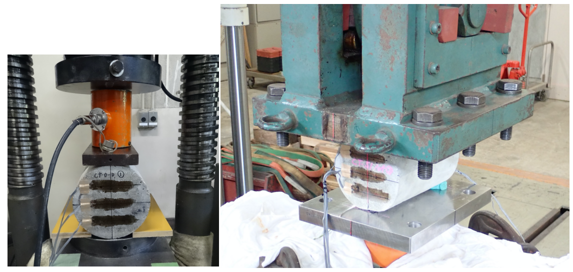
Concrete	Body	Compressive strength [MPa]	Tensile strength [MPa]	Elastic modulus [GPa]	Age [days]
Concrete1	Old	31.6	3.11	27.4	99
Concrete1	New	34.1	2.84	27.9	42
Concrete2	Old	35.1	2.97	29.7	42
Concrete2	New	37.6	2.83	28.5	28

2.3 Test Method

In this study, the static splitting tensile test followed JIS A 1113 (2018), as shown in Figure 3(a). Stress rate was 0.06 ± 0.04 MPa/s. In the test, the load and strain were recorded every second, while strain was recorded by three strain gauges at the side, as shown in Figure 1. The dynamic splitting tensile test was carried out using a loading device with a hydraulic actuator capable of high-speed loading at 1000 mm/s (Figure 3(b)). This test method referred to a previous study, which aimed high-speed loading at 100N/mm^2/s (Kongo et al. 2014). This test is controlled by the actuator's displacement. Displacement increments were decided from the strain rate of split direction aims 1000 μ/s and 10000 μ/s. The measurements were the same as for the static test.

Table 4. Material properties of D10 steel rebar

Steel rebar	Yield stress [MPa]	Tensile strength [MPa]	Elastic modulus [GPa]
D10	365.0	507.2	181.9



(a) Static splitting tensile test (b) Dynamic splitting tensile test

Figure 3. Test setups of splitting tensile test.

3 EXPERIMENTAL RESULTS

3.1 Static Splitting Tensile Test

In some cases, the fracture load might not be discriminated despite the occurrence of splitting tensile fracture because the specimen is continuously sandwiched in the vertical direction. Therefore, if fracture load could not be discriminated, it was determined when the concrete strain exceeded 500 μ. The fracture strain at the 0 series was 120-470 μ. In this test, it was confirmed that the load increment was small enough with strain growth after strain exceeded 500 μ. Table 5 shows the results of static splitting tensile tests, such as tensile strength, fracture strain and tensile strength ratio. Fracture strain was recorded at the center gauge of the three strain gauges, and tensile strength ratio was based on tensile strength of the test shown in Table 3. In N and S series, fracture strain was 500 μ, because the fracture load of most specimens could not be discriminated. None of the S series specimens were separated after joint failure. Separated cylinders were sandwiched in the vertical direction. Subsequently, separated cylinders experienced compressive failure. Tensile stress calculated from the compressive fracture load was 2.62-3.07 MPa, almost the same as sound tensile strength. When the specimen was removed from device, the joint was broken. However, inserted rebars were not pulled out, and old and new concrete did not separate.

Table 5. The result of Static splitting tensile test.

No.	Material	Joint	Tensile strength [MPa]	Fracture strain [μ]	$f_{t,st}/f_{t,st,0}$
C1-N	Concrete1	Raw	0.28	500	0.10
C1-C		Chipped	0.73	614	0.26
C1-S6		Rebar insertion	0.54	500	0.19
C2-0	Concrete 2	Sound	2.96	132	1.00
C2-N		Raw	0.42	255	0.14
C2-C		Chipped	1.43	260	0.48
C2-S1		Rebar insertion	0.64	500	0.22
C2-S2		Rebar insertion	0.71	500	0.24

3.2 Dynamic Splitting Tensile Test

Table 6 shows the result of the dynamic splitting tensile test. Strain rate was calculated by dividing the strain increment by the time when strain at the center of the three strain gauges was from 100–200 µ. In the case of not obtaining a continuous strain-time relationship from 100 to 200µ, the continuous section is searched from the previous strain-time relationship, and the strain rate is calculated. In almost all N and S series specimens, fracture strain was 500 µ. In the S series, inserted rebars were not pulled out, and old and new concrete did not separate as well as static splitting tensile test.

Table 6. The result of Dynamic splitting tensile test.

No.	Material	joint	Tensile strength [MPa]	Fracture strain [µ]	Strain rate [µ/s]	$f_{t,dy}/f_{t,st}$
C2-0	Concrete 2	Sound	2.96	132	1.13	1.00
C2-0-1k			3.73	241	985	1.26
C2-0-10k			4.70	496	11248	1.59
C2-N		Raw	0.42	255	0.63	1.00
C2-N-1k			0.37	559	3015	0.89
C2-N-10k			0.66	290	11565	1.56
C2-C		Chipped	1.43	260	0.94	1.00
C2-C-1k			1.96	358	2038	1.37
C2-C-10k			1.83	113	15644	1.28
C2-S1		Rebar insertion	0.64	500	22.44	1.00
C2-S1-1k			0.77	500	3563	1.20
C2-S1-10k			1.14	1010	51739	1.78
C2-S2		Rebar insertion	0.71	500	14.90	1.00
C2-S2-1k			1.06	500	2399	1.48
C2-S2-10k			0.87	500	47647	1.22

4 DISCUSSION

4.1 Tensile Strength Compared at Each Joint

Table 5 shows tensile strength and fracture strain compared by joint conditions in a static splitting tensile test. The fracture strain of the 0 series was the lowest in all series. It is difficult to evaluate the effects of fracture strain in other series because they had larger variations in fracture strain than 0 series. In 0 series, the secant modulus calculated from dividing tensile strength by fracture strain was 22.4 GPa. This was almost equal to the elastic modulus in Table 3. On the other hand, in the C series, the secant modulus was lower than that of the 0 series due to higher fracture strain.

The tensile strength ratio of the N series was 10-15%, and that of the S series was 15-25% in both C1 and C2. Therefore, the inserted rebars process increased tensile strength very little. The results of C1-S6, C2-S1, and C2-S2 show the tensile strength of the joint also does not depend on the number of inserted rebars. On the other hand, the result of the C series shows tensile strength stays relatively higher than in the N and S series. The results differed greatly, however, between C1 and C2. This was because of differences in the depth of the chipping process between the C1-C and C2-C series, as shown in 2.2. So, the tensile strength of joints depends on chipping properties. In this study, the maximum tensile strength of a chipped joint was 50% that of a sound specimen. In future work, it will be necessary to quantitatively evaluate the relationship between chipping properties and tensile strength.

4.2 Tensile Strength Compared with Strain Rate

Figure 4 shows the relationship between tensile strength and tensile-strength ratio by strain rate. In Figure 4(b), the tensile strength ratio is based on the static tensile strength of each series.

Figure 4(b) also shows the equation from a previous study about the effect of strain rate on specimens without a joint (Ross *et al.* 1996, Federation Internationale de Beton 2013). The result of the 0 series shows the effects of strain rate, which are 26% at 1000 μ/s and 59% at 10000 μ/s. This is consistent with the calculated results using the equation from a previous study; thus, the dynamic tests were properly performed in the 0 series. In the C series, dynamic tests showed the effect of strain rate. However, the tensile strength ratio at 1000 μ/s was almost the same as that at 10000 μ/s. It is considered that the effect of the difference between each chipped property, which was performed by hand, was larger than the effect of strain rate. In the N, S1, and S2 series, the tensile strength ratio for the dynamic test was about 90–180%. Thus, they showed larger variations than the 0 series. This is because the absolute value of tensile strength in the static test was small. It was confirmed that increasing strain rate tends to make tensile strength higher than static testing in all joints.

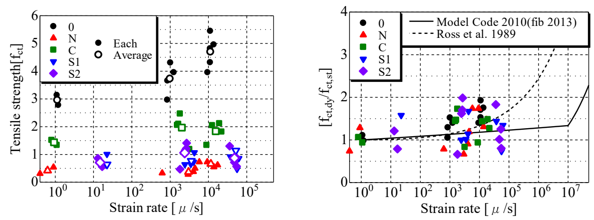


Figure 4. The relationship of tensile strength and strain rate: (a) tensile strength; (b) tensile-strength ratio based on static tensile strength.

5 CONCLUSIONS

The following are the main conclusions obtained from the test results in this study:

1. Compared to the tensile strength of the no joint case, joint properties maintained 10-25% at raw joint and joints with inserted rebars, and 25-50% at the chipped joint. Inserted rebars were barely affected by the tensile failure of joint but may help prevent joint separation.
2. Tensile strength of chipped joints depends on the degree of chipping condition, but this has not been quantitatively evaluated. Chipped joints maintained just 50% of the tensile strength in the no joint case.
3. Increasing strain rate tended to increase tensile strength more than static testing in all joints.

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