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A study on the cracks dispersible technique for R/C member

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ABSTRACT: The durability of a concrete structure is improved when cracks in the concrete are dispersed and their widths are reduced. The purpose of this research is to find an effective method for dispersing cracks. The relationships between the reinforcing ratio and the concrete cracks' widths are known. Also, glass fiber is used as a countermeasure for the cracks. Here, the cracks' dispersing performance was checked using a tension test on the reinforced concrete member. In this study, three types of specimens reinforced by a glass fiber sheet or by crack control rebar were tested. From the experimental results, the cracks' dispersing performance was observed in all specimens. However, it became clear that the quality of the cracks' dispersing performance depends on the reinforcing material.

1 INTRODUCTION

In recent years, the durability of a reinforced concrete structure is taken seriously. The cracks caused by the shrinkage of the concrete that cannot be avoided due to the character of the concrete, greatly influence the durability of a reinforced concrete structure. The research on a formulation that predicts the cracks caused by the shrinkage of concrete and on the related control technology has been studied for many years. However, a definitive theory has not been established due to the complexity of the mechanism. Also, there are cracks due to temperature change caused by the outside restriction of the structure. On the other hand, in recent years, control methods to limit crack width to a harmless size have been tried. For example, reinforcing steel bar and glass fiber sheets and chips disperse the cracks to small sizes. However, the crack distribution performance of such technology has not yet been evaluated clearly.

Considering this background, this study aims to experimentally clarify the crack dispersing performance of the reinforcing materials.

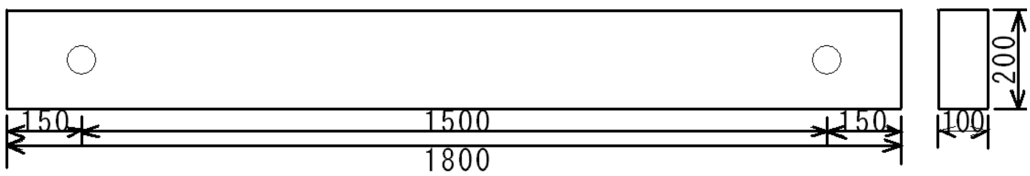

Figure 1. Detailed drawing that is common to all specimens.

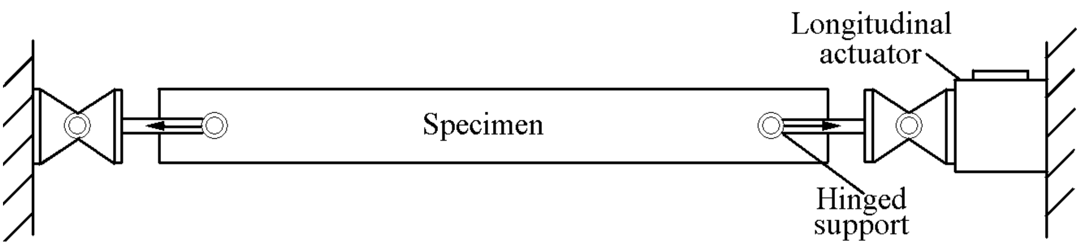

Figure 2. Testing apparatus.

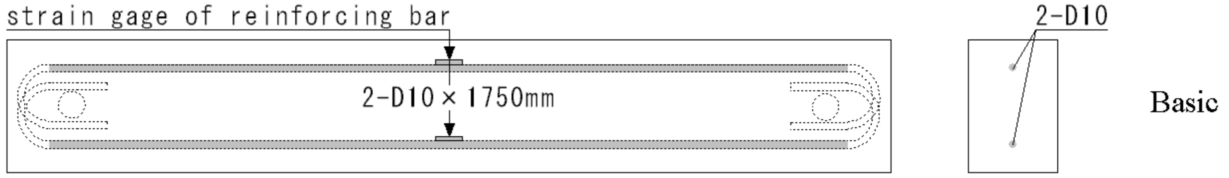

Figure 3(a). Arrangement of a basic specimen.

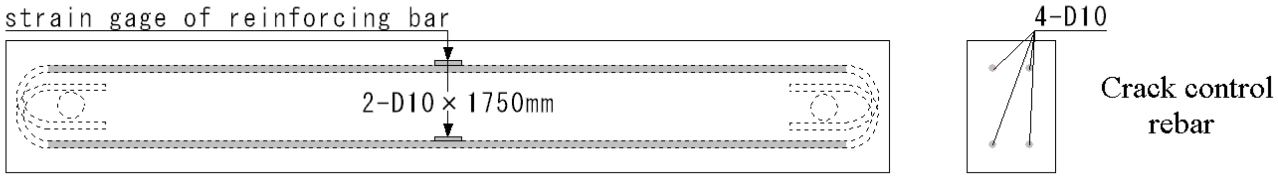

Figure 3(b). Arrangement of crack control rebar.

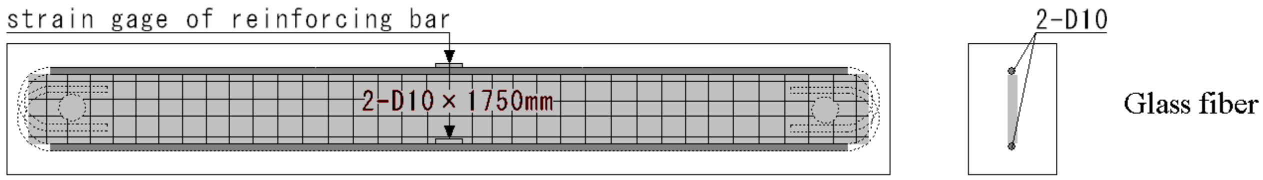

Figure 3(c). Arrangement drawing of glass fiber.

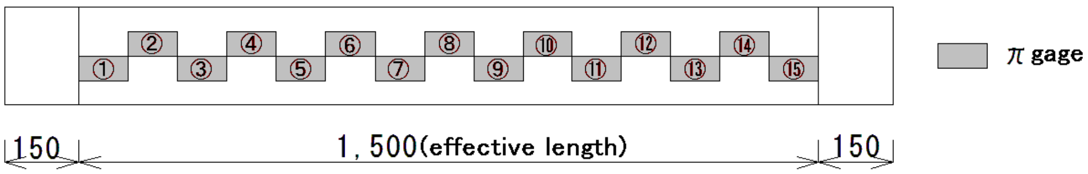

Figure 4. Arrangement of π gage(top surface of specimen).

Table 1. Material property of concrete and reinforcing bar.

Concrete		
compressive strength f'_c (N/mm^2)		18.9
Reinforcing bar		
diameter	D-10	
yield strength f_y (N/mm^2)	371	
tensile strength f_u (N/mm^2)	492	

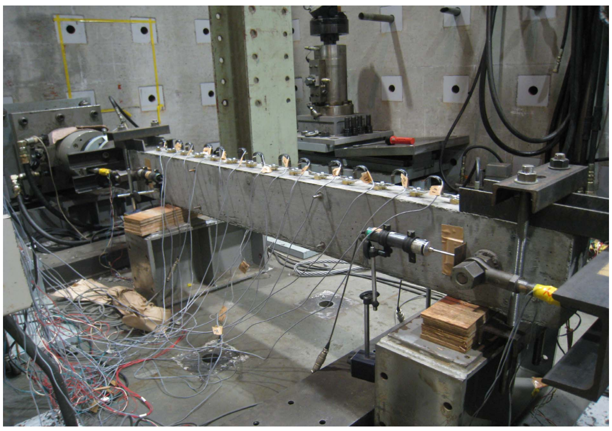

Figure 5. Tension test.

2 EXPERIMENT

2.1 *Purpose of experiment*

In the case of the restrained concrete member, the cracks occur by the restraining stress caused by the shrinkage of the concrete. This experiment aims to confirm the crack dispersing performance of two types of techniques and materials by conducting a tension test on a reinforced concrete beam.

2.2 *Material properties of specimen*

The material properties of the concrete and reinforcing bar are shown in Table 1.

2.3 *Summary of specimen*

The dimensions of the specimen are shown in Figure 1. Its length is 1,800mm. Its effective length, width, and height are 1,500mm, 100mm, and 200mm, respectively. The summary for each reinforcing material is described below.

a) Basic specimen

This specimen is the basic of this experiment. Only two deformed D-10 bars reinforce the specimen; in other words, in the basic specimen, additional material is not used (Fig. 3(a)).

b) Crack control rebar

Four deformed D-10 bars reinforce the specimen (Fig. 3(b)).

c) Glass fiber sheet

Two deformed D-10 bars and two glass fiber sheets reinforce the specimen (Fig. 3(c)).

2.4 *Experiment method*

Tension test of the specimen was carried out as shown in Figure .3. Elongation of the specimen is measured by π gage which are arranged at the top surface of the specimen (Figs. 4-5). Also, in an experiment, the crack property is confirmed.

3 EXPERIMENTAL RESULTS

3.1 *Summary of experimental results*

From the experimental results, it was confirmed that the reinforcing materials affected the crack dispersion. The details for each specimen are given below (a, b, and c sections). The list of the experiment results is shown in Table 2.

Table 2. List of the experiment results.

Specimen number	Kind of reinforcing material	Crack number	Maximum crack width at total displacement 1mm	Maximum load (kN)
1-1	Basic (2-D10)	4	Failure	42.54
1-2		5	0.401	51.70
1-3		4	0.576	51.40
2-1	Crack control rebar (4-D10)	7	0.190	71.74
2-2		5	0.208	63.50
2-3		7	0.157	68.06
3-1	Glass fiber sheet (2-D10)	5	0.301	55.12
3-2		6	0.289	58.06
3-3		6	0.276	62.20

a) Basic specimen

Four or five cracks occurred. The maximum load was about 50kN. After the test and unloading, those cracks' widths became about 1.4mm per crack.

b) Crack control rebar

The cracks dispersed into five to seven cracks. Crack widths narrowed to around 0.15mm to 0.2mm per crack. The maximum loading capacity of the member was increased to approximately 70kN. Furthermore, after the test and unloading, those cracks' widths became about 0.1mm per crack.

c) Glass fiber sheet

The cracks dispersed into five to six cracks. The maximum load was approximately 60kN. After the test and unloading, those cracks' widths became about 0.05mm per crack.

3.2 *Crack property*

The cracks on a typical specimen after the tension test are shown in Figure 6. In these figures, the circled numbers show the sequence of the occurrence of the cracks.

In the basic specimen, it is predicted that the first crack occurs in the center of the member. However, the first crack occurred 377mm from the left edge (Fig. 6(a)). In the other cases, this phenomenon was almost the same (Fig. 6(b) and Fig. 6(c)). However, after that, the cracks were dispersed and generated at suitable intervals. Then most the cracks spread through the cross-section of the member, but some cracks did not.

From these figures, it is clear that the member reinforced with the crack control rebar dispersed the cracks the most, following by the member reinforced with glass fiber sheet. Consequently, the maximum crack width of the member reinforced with the crack control rebar was the narrowest.

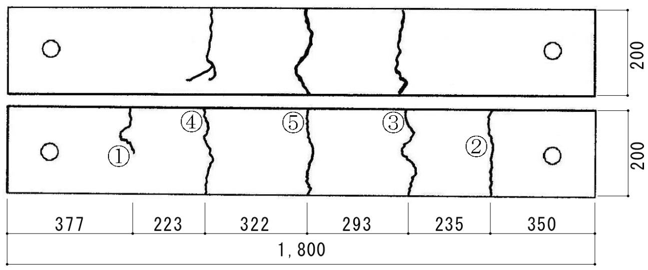

Figure 6(a). Crack property of the basic specimen. (1-2).

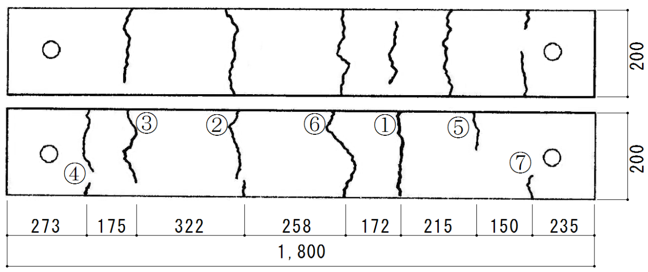

Figure 6(b). Crack property of crack control rebar(2-3).

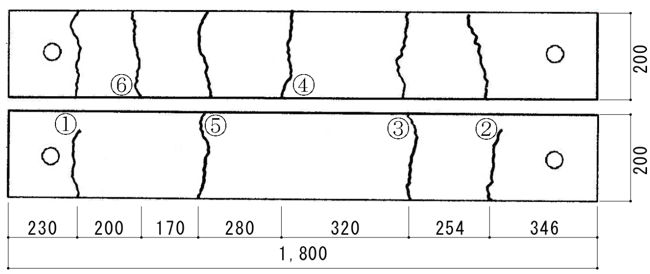

Figure 6(c). Crack property of glass fiber(3-2).

3.3 *Relationships of load - elongation of specimens*

The relationships between the load and the displacement of the effective span are shown in Figure 7. Here, the displacement is the total of the elongation of π gauges set to effective spans.

In the basic specimen, the first crack occurred at approximately 35kN of tensile load, after which the load was increase up to 50kN. Then, when the load reached 53kN, the elongation of the member reached 0.5mm. At this point, it was observed that the reinforcing bar had reached its yield strength (Fig. 7(a)).

In the specimen reinforced by the crack control rebar, the first crack occurred at approximately 35kN of tensile load, after which the load was increased to 65kN. However, in this case, the member did not reach the yield strength, although the elongation of the member reached 1.0mm. After the test and unloading, the elongation of the member returned to approximately 0.4mm (Fig. 7(b)).

In the specimen reinforced by grass fiber sheet, the first crack occurred at approximately 25kN in tensile load, after which the load was increased to 58kN. In this case, the member did not reach the yield strength, although the elongation of the member reached 1.0mm (Fig. 7(c)). After the test and unloading, the elongation of the member returned to approximately 0.2mm. These results mean that the glass fiber sheet has the same effect as the steel bar.

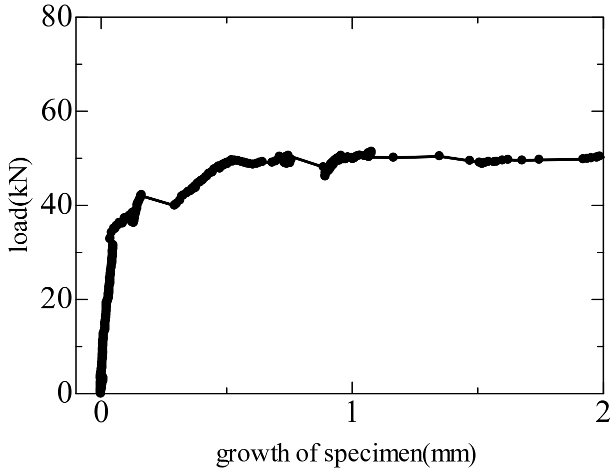

Figure 7(a). Load - elongation of specimen (non measures).

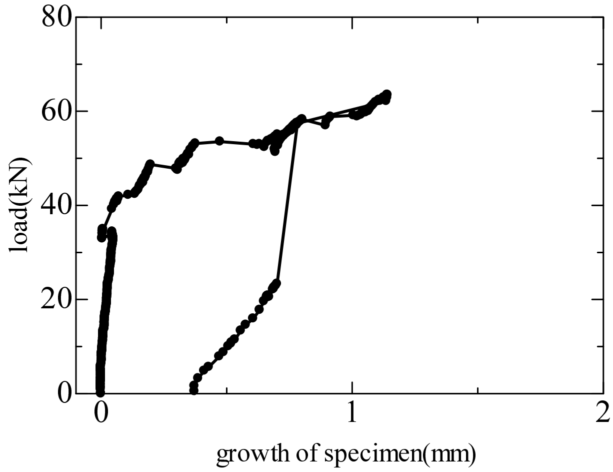

Figure 7(b). Load - elongation of specimen (crack control rebar).

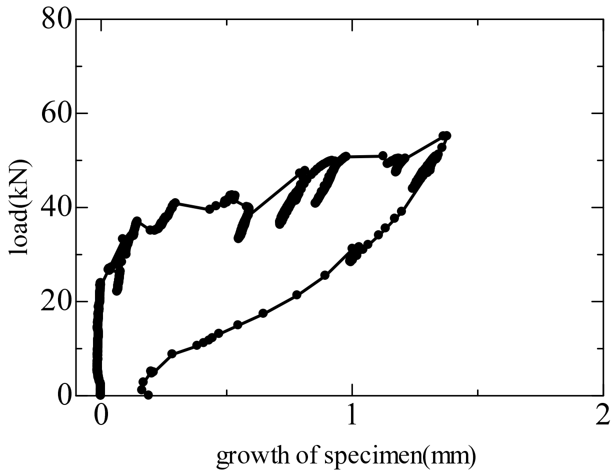

Figure 7(c). Load - elongation of specimen (glass fiber).

3.4 *Relationships of load – displacement by π gage*

Figures 8(a), (b), and (c) show the elongation of π gauges set up at effective spans. In these figures, only the data when the gauge observed the cracks is shown.

In the basic specimen, it is clear that the reinforcing bar of the member began to yield as shown in Figure 7(a). Also, as can be checked from gauge No. 7, the member is yielding in Figure 8(a).

On the other hand, in the case of the member with the crack control rebar, the widths of all the cracks measured with the π gauges are less than 0.2mm, as shown in Figure 8(b). After the test and unloading, the widths of all the cracks measured with the gauges are less than 0.05mm.

In the case of the member using the glass fiber sheet, the width of the maximum crack measured with the gauge was 0.35mm, as shown in Figure 8(c). After the test and unloading, the widths of all the cracks measured with the gauge were less than 0.05mm.

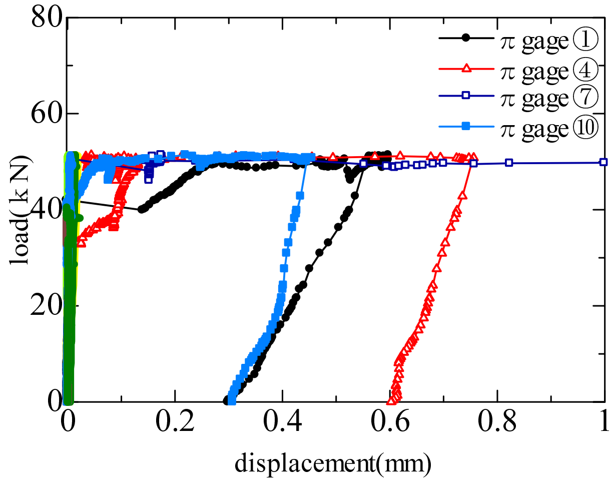

Figure 8(a). Load - displacement by π gage (non measures).

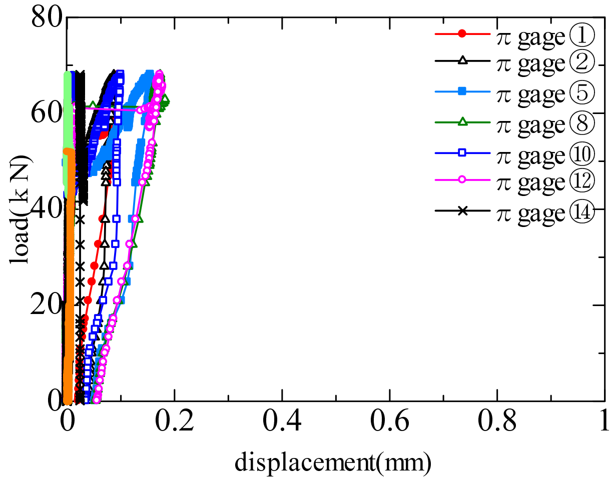

Figure 8(b). Load - displacement by π gage (crack control rebar).

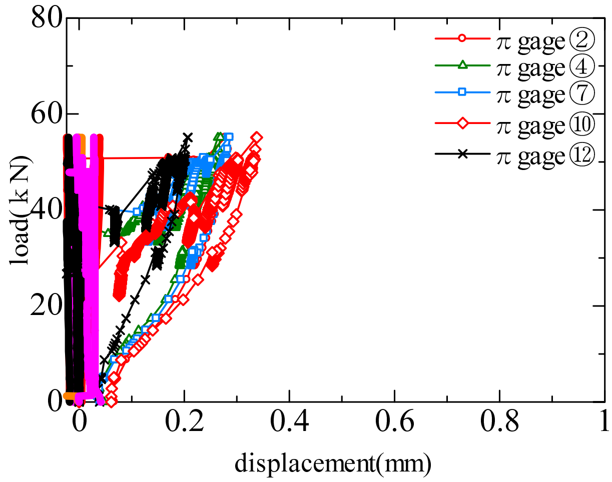

Figure 8(c). Load - displacement by π gage (glass fiber).

4 CRACK SPACING AND CRACK WIDTH

Nominal maximum crack spacing and the maximum crack width in the tensile member are derived by following equations (1) and (2).

$$l_{max} = \frac{C_1 \times \phi \times f_t}{p \times \tau_{max}} \quad (1)$$

$$w_{max} = \frac{l_{max}}{E_s}\left(\sigma_{s\,max} - \frac{C_2 \times f_t}{p}\right) \quad (2)$$

l_{max} : maximum crack spacing (mm)
w_{max} : maximum crack width (mm)
p : reinforcement ratio
τ_{max} : maximum bond stress (N/mm^2)
E_s : modulus of elasticity (E_s=200GPa)
ϕ : diameter of reinforcing bar
f_t : tensile strength of concrete (N/mm^2)
$\sigma_{s\,max}$: tensile stress of reinforcing bar (N/mm^2)
C_1, C_2 : bond stress distribution coefficient by the theory of Brice
4 C_1=0.500, C_2=0.500

Equations (1) and (2) depend on the quantity of the reinforcing bar of the member. That is, the bonding characteristic and the tensile strength of the fiber sheet are not considered. Therefore, it is not confirmed whether they can apply to fiber reinforcement sheet.

Table 3 shows the results of the comparison with the theoretical values calculated by the equations above and the actual values.

In comparisons of the theoretical maximum crack spacing (l_{max}) and measured maximum crack spacing (l'_{max}), on average the theoretical values agree approximately with the actual values for the basic specimen and in the member reinforced with crack control rebar. In the member reinforced with glass fiber, the theoretical values are overestimated.

In this experiment, the maximum crack width was the assumed value, which is the elongation divided by the number of cracks when the specimen yielded. In the comparisons of the theoretical maximum crack width (w_{max}) and measured maximum crack width (w'_{max}), the theoretical value is overestimated compared with actual value in the basic specimen and in the member reinforced with crack control rebar. In the member reinforced with glass fiber, the theoretical values are overestimated even more.

From the above-mentioned results, it was confirmed that equations (1) and (2) cannot be applied to fiber reinforcement. Therefore, equations (3) and (4) were proposed for the maximum crack spacing and maximum crack width, respectively.

In equations (3) and (4), the multiplier for the underestimate was derived using Table 5.

Table 3. Maximum crack spacing.

Specimen number	l'_{max} (mm)	l_{max} (mm)	ml_{max} (mm)	$\frac{l_{max}}{l'_{max}}$	$\frac{ml_{max}}{l'_{max}}$
1-2	250	248	248	0.99	0.99
1-3	300	250	250	0.83	0.83
2-1	187	179	179	0.96	0.96
2-2	250	233	233	0.93	0.93
2-3	187	189	189	1.01	1.01
3-1	250	255	232	1.20	0.93
3-2	214	246	223	1.15	1.04
3-3	214	242	220	1.13	1.03

Table 4. Maximum crack width.

Specimen number	w'_{max} (mm)	w_{max} (mm)	mw_{max} (mm)	$\frac{w_{max}}{l'_{max}}$	$\frac{mw_{max}}{l'_{max}}$
1-2	0.25	0.31	0.26	1.23	1.02
1-3	0.27	0.31	0.25	1.14	0.95
2-1	0.13	0.17	0.14	1.34	1.11
2-2	0.14	0.16	0.13	1.13	0.94
2-3	0.09	0.17	0.14	1.90	1.58
3-1	0.22	0.30	0.17	1.36	0.77
3-2	0.13	0.31	0.17	2.30	1.30
3-3	0.19	0.31	0.18	1.66	0.94

Table 5. Coefficient by reinforcing materials.

Materials	k1	k2
Reinforcing bar	1.00	1.00
Glass fiber	0.91	0.68

$$_{ml}\max = \frac{C_1 \times \phi \times f_t}{p \times \tau_{\max}} \times k_1 \tag{3}$$

$$_{mw}\max = 0.51 \times \frac{_{ml}\max}{E_s}\left(\sigma_{s\,\max} - \frac{C_2 \times f_t}{p}\right) \times k_2 \tag{4}$$

As shown in Table 4, the accuracy of the equation for crack spacing (3) has improved, as has the accuracy of the equation for crack width (4).

5 CONCLUSION

To clarify the crack dispersing performance of reinforcing materials, a tension test on a reinforced concrete beam was done. Based on test results, the following conclusions can be drawn:

1. In the case of the member using the crack control rebar, the crack dispersion effect was 1.5 times more than for the basic specimen. Also, in the case of the member using the glass fiber sheet, the effect was observed 1.3 times more than for the basic specimen.
2. On the maximum crack width, in the case of the member using the crack control rebar, it was on-fourth that of the basic specimen at 1mm elongation of the member. In the case of the member using the glass fiber sheet, it was one-half.
3. From these results, it was clear that the cracks are dispersed by the crack control rebar and the glass fiber sheet. Also, it indicates that the glass fiber sheet has almost the same effect as a steel bar.
4. However, in this experiment, since there were few tests, we could not quantify the effect. To quantify the crack distribution effects, it is necessary to conduct more experiments.
5. Using the proposed equation for crack spacing and crack width, the accuracy of the theoretical values improve somewhat. To get an exact equation, more experimentation is required.

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