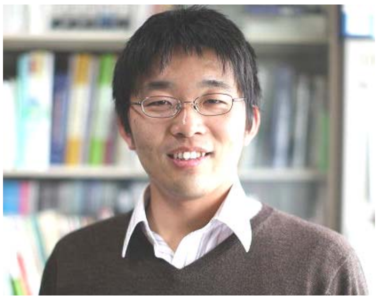
# SHEAR REINFORCEMENT FOR RC LINEAR MEMBERS BY A COMBINATION OF STEEL FIBERS AND SHEAR REINFORCING BARS



Ken Watanabe, Ph.D.
Assistant Senior Researcher
Structures Technology Division, Railway Technical Research Institute
2-8-38, Hikaricho, Kokubunji, Tokyo, 185-8540 JAPAN
E-mail：wataken@rtri.or.jp

Coauthors: Toshihide Kimura (Taisei Corporation)
Toru Kodama (Kajima Corporation)
Shunsuke Kita (Kajima Corporation)
Issei Odera (Recruit Co., Ltd.)
Junichiro Niwa (Tokyo Institute of Technology)

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## 1 Introduction

Reinforced concrete with steel fibers (RSF) can have a higher load-bearing capacity and greater ductility than conventional reinforced concrete (RC). The shear carried by the short steel fibers is usually expressed as a function of the shear carried by the concrete. The standard specifications of JSCE,[1] however, normally require shear-reinforcing bars in RC members. Since shear-reinforcing bars prevent diagonal cracks in the concrete from opening, the reduction in the shear force transferred by the steel fibers via the crack surfaces should be effective. Consequently, the combination of shear-reinforcing bars and fiber reinforcement should create synergetic shear-resistance in RSF linear members.

The goal of this study was to clarify the synergetic effect of shear-reinforcing bars and steel fibers on the shear-resistance mechanism of RSF linear members. A series of bending and lateral cyclic-loading tests were conducted to investigate the synergetic effect on the shear-resistance mechanism in RSF linear members. The tests revealed the best combination of steel fibers and shear-reinforcing bars for optimizing shear resistance in RSF linear members.

## 2 Experimental programs for RSF beams and columns

Figure 1 shows the outline of a tested RSF beam that was subjected to four-point bending. The beam width ($b_w$) was 150 mm, the shear span ($a$) 700 mm, the effective depth ($d$) 250-mm, and the longitudinal reinforcement ratio ($p_w$) 2.7%. The deformed-steel stirrups were 6 mm in diameter, arranged as transverse reinforcements, and spaced at stirrup ratios ($r_w$) of 0.12% to 0.30%. The yield strength of the rebar was 345 N/mm$^2$. The compressive strength ($f_c'$) at the time of the loading test was 51.5–85.5. Steel fibers were mixed with concrete at *SF* ratios of 0.3%, 0.5%, 0.75%, and 1.0% in order to examine the effect of the steel fiber content on the shear-reinforcement. The steel fibers had a wave shape, a length of 30 mm, and an aspect ratio of 50. The tensile strength was 1.0 kN/mm$^2$, the specific gravity 7.85, and the modulus of elasticity 210 kN/mm$^2$.

Figure 2 shows the test setup for the RSF column that was subjected to cyclic loading. The column had a loading height ($a$) of 800 mm and an effective depth ($d$) of 210 mm. Therefore, $a/d$=3.81. The column width ($b_w$) was 150 mm. The average value of the compressive strength $f_c'$ at 28 days for three samples was 37.9 N/mm$^2$. The steel fibers were mixed with *SF* ratios of 0.3% and 1.0%. The longitudinal tensile reinforcement ratio ($p_w$) was 2.46%. Tie bars consisting of 6-mm diameter deformed bars were arranged with spacing $s$ and shear reinforcing bar ratios ($r_w$) of 0.0, 0.21, and 0.42%. The yield strength of the tie bars ($f_{wy}$) was 345 N/mm$^2$. A total of six specimens with different *SF* and $r_w$ values were prepared.

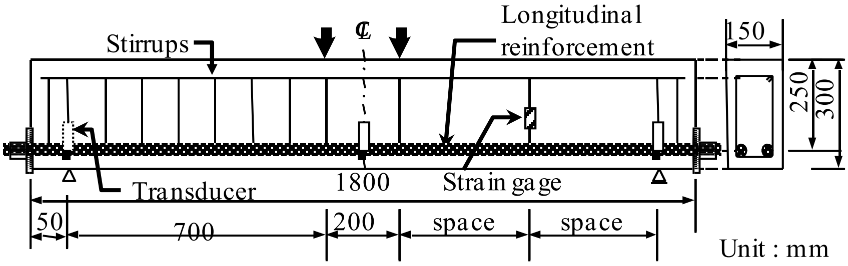



Figure 1 Sketch of a tested RSF beam.

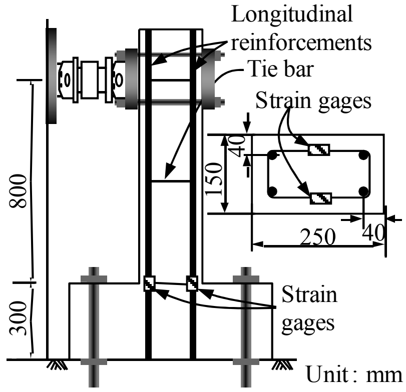



Figure 2 Test Set-up and a tested RSF column.

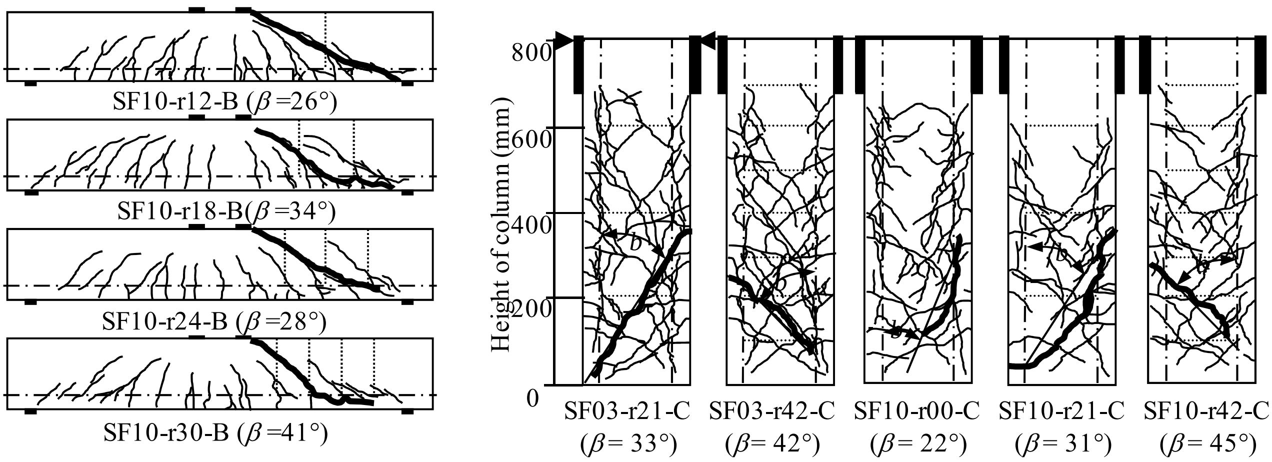



Figure 3 Crack patterns of failed RSF beams and columns.
(Bold lines indicate the diagonal crack with a remarkable crack width.)

The shear-load capacities of the tested RSF members were calculated according to the design guidelines of the Japan Society of Civil Engineers (JSCE). The capacity was expressed using as the sum of the shear resistance of the RSF member without stirrups ($(1+\kappa)V_c$) and the shear resistance carried by the stirrups ($V_s$). (Eq. (1)) With reference to Eqs. (1) and (2), index, $\kappa_{exp}$ was introduced for evaluating the reinforcing effect of the steel fibers.[1, 2]

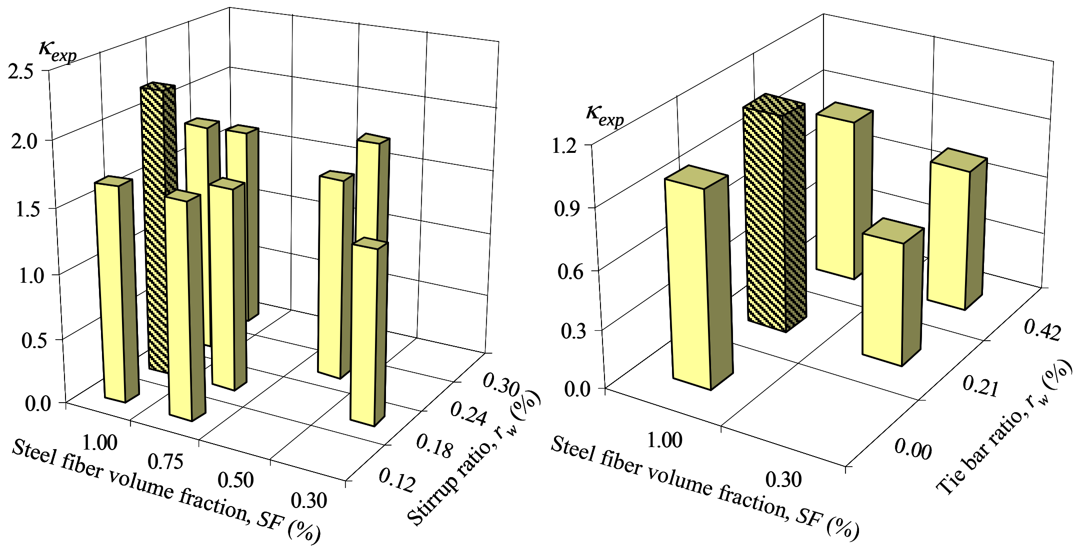
$$V_{\max} = (1+\kappa)V_c + V_s \quad (1)$$

$$\kappa_{\exp} = (V_{\exp} - V_c - V_s)/V_c \quad (2)$$

## 3 Optimized combination for $\kappa_{exp}$

Figure 3 illustrates the crack patterns in the failed beams that had an *SF* of 1.0% and in the RSF columns after the loading tests. In each figure, broken lines indicate the locations of the shear reinforcements and bold solid lines denote the diagonal cracks with notable widths. Solid lines indicate other cracks. Figure 4(a) shows that the $\kappa_{exp}$ values for the RSF beams vary with the *SF* and $r_w$ values. The values of $\kappa_{exp}$ monotonically increase as the ratios of *SF* increase under identical $r_w$ values, while they do not increase monotonically as $r_w$ increases under identical *SF* values. This implies the existence of an optimized combination of *SF* and $r_w$ that produces the largest $\kappa_{exp}$ in the range of this study. The $\kappa_{exp}$ values of the RSF beams in this study reach the maximum $\kappa_{exp}$ (2.22) when $SF$ = 1.0% and $r_w$ = 0.18%. Figure 4(b) indicates that the values of $\kappa_{exp}$, which are the ratios of $V_{\kappa exp}$ to $V_c$, for the RSF columns with an *SF* value of 0.3%, are smaller than 1.0. However, the values of $\kappa_{exp}$ increase as $r_w$ increases. A similar tendency was also observed in RSF columns when $SF$=1.0% and 0% ≤ $r_w$ ≤ 0.21%.

Figure 3 suggests that the value of $\beta$ increases and the length of the diagonal crack decreases as $r_w$ increases. In addition, the shear-reinforcing bars effectively prevented a rapid opening of the diagonal crack. Because the shear force could be transferred via the bridging effect of the steel fibers, the force




(a) $\kappa_{exp}$ in RSF beams. (b) $\kappa_{exp}$ in RSF columns.

Figure 4. $\kappa_{exp}$ of RSF beams and columns as functions of *SF* and $r_w$.
(Shadowed column corresponds to the maximum $\kappa_{exp}$.)

transferred along the diagonal crack increases as the length of the diagonal crack increases, and decreases as its width increases. The results for the four RSF beams with an *SF* of 1.0% and the RSF columns show that, as $r_w$ increased, the crack width, as well as the length of the diagonal crack, tended to decrease. The combination of both positive and negative contributions to shear transfer along the diagonal crack should result in variations in the value of $\kappa_{exp}$ as well as in the shear carried by the steel fibers ($V_{\kappa exp}$). This suggests that the value of $\kappa_{exp}$ associated with the length and width of the diagonal crack could be a key to obtaining the optimized combination of *SF* and $r_w$ for shear reinforcement of RSF beams.

Figure 4 also shows that all of the $\kappa_{exp}$ values for the RSF beams are greater than 1.34. The values of $\kappa_{exp}$ for the RSF columns, however, range from 0.63 to 1.05. Hence, the $\kappa_{exp}$ values for the RSF columns are lower than the $\kappa_{exp}$ values for the RSF beams when the *SF* ratios are identical. These results are due to differences in the crack patterns. According to Fig. 3, the cracks occurred in the flexure tension zone of the RSF beams and only one diagonal crack was critical. In addition, the critical diagonal crack developed across the shear span. The critical diagonal crack was longer in the RSF beams than in the RSF columns. The longer the diagonal crack, the more important the bridging effect of the steel fibers. The variations in the value of $\kappa_{exp}$ under different loading conditions were due to the shapes of diagonal cracks.

## 4 Conclusions

(1) The value of $\kappa_{exp}$ varies with the volume ratio of steel fibers to concrete (*SF*) and the shear reinforcement ratio ($r_w$) in the RSF beams and columns.

(2) There is an optimized combination of *SF* and $r_w$ that increases the value of $\kappa_{exp}$. In particular, the $\kappa_{exp}$ values of the RSF beams reach the maximum ($\kappa_{exp}$ = 2.22) when the beam has an *SF* value of 1.0% and an $r_w$ value of 0.18%.

(3) Since the $\kappa_{exp}$ value is associated with the length and width of the diagonal crack, this would be a key to understanding the optimized combination of *SF* and $r_w$ for the shear-reinforcing bars in the RSF beams and columns.

(4) The critical diagonal crack is longer in the RSF beams than in the RSF columns. This produces a higher shear transfer force due to the bridging effect of the steel fibers along the diagonal crack, leading to larger $\kappa_{exp}$ values.

## References


[1] JSCE, Standard Specifications for Concrete Structures-2002, Structural Performance Verification, 2005

[2] Japan Society of Civil Engineers (JSCE), Guidelines of Design for RSF Piers, Concrete Library 97, 1999.