研 究 速 報

UDC 624.012.454 : 677.53 : 669.14

Study On Reinforced Concrete Members Using Fiber Reinforced Concrete (7)
——Shear Strength Of Singly Reinforced Concrete Beams——
繊維補強鉄筋コンクリート構造部材に関する研究(7)

Ranjan Kumarasiri WEERARATNE*, Taketo UOMOTO* and Tsugio NISHIMURA*
ランジャン K. ウィーララタナ・魚 本 健 人・西 村 次 男

1. Introduction

Studies (1, 2) conducted so far on shear strength of fiber reinforced concrete (FRC) have emphasized mainly the strength gained by use of a certain type of fiber only. Effects of parameters associated with the composition of FRC and testing conditions on the shear behavior have yet to be clarified. Therefore the purpose of this paper is to clarify shear mechanism of FRC beams.

Parameters studied are the type of fiber, fiber content by volume (Vf), shear span to depth ratio (a/d), main steel reinforcement ratio (p), effective depth of the beam (d) and the compressive strength of concrete (fc'). The most effective parameters are sought and discussed. From the observations made, a failure mechanism is hypothesized and the shear strength improvement due to fibers is explained.

2. Test programme

Shear behavior of FRC beams was examined by performing 4-point loading tests. Tests were carried on simply supported singly reinforced concrete beams without any shear reinforcements cast with either plain or FRC. Details of the beams cast and loading method are shown in Fig. 1. Test specimens remained in the forms for 24 hours and were then moist cured for a period of 2 to 3 weeks and were stored in normal laboratory atmosphere until tested. Static 4-point loading tests were performed at the age of 4 to 5 weeks.

Ordinary portland cement was used in all specimens and the aggregates were well graded river sand and gravel which meet requirements of J. S. C. E. The coarse aggregates had a maximum normal size of 15mm. Fibers used were steel fibers of indented cut wire (d=0.5 mm, 1=30 mm), sheared fiber (0.5 x 0.5 mm x 30 mm) and deformed polyethylene fiber (d=0.9 m, 1=40 mm). The tensile and compressive strengths of concretes used are listed in Table 1.

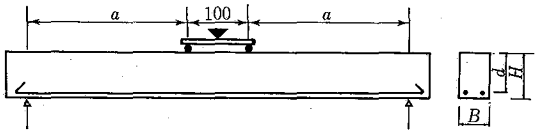

Fig. 1 Details of beams cast and loading arrangement

Table 1. Properties of concretes cast with different fibers

Type of Fiber	Vf	fc'	ft	σ
Plain	0	530	28	—
Indented	0.75	540	30	14
	1.5	510	35	25
Sheared	0.75	490	18	5.5
	1.5	555	28	14
Polyethylene	3	470	26	2

Note: fc' -Compressive strength(kgf/cm2)
ft --Tensile strength (kgf/cm2)
σ - Tensile post cracking strength (kgf/cm2)
Vf - Fiber content by volume (%)

3. Results and discussion

3.1 Failure modes and strength of beams

For beams of plain concrete with a/d ratio from 1 to 5. all the beams failed in shear. Diagonal cracks started opening and widening with the increase of load and final failure occured with a sudden drop in load. In the case of steel fiber reinforced concrete (SFRC), most of the beams failed by flexure. Shear failure of SFRC beams is thought to begin from small cracks at the shear span widening and propagating diagonally towards the compression region. Fibers within the cracks act as reinforcements transferring

* Dept. of Building and Civil Engineering, Institute of Industrial Science, University of Tokyo.

stresses and when final failure occurs, crushing of concrete of the compression side and also fiber pullout from the matrix occur.

On presenting the data in a manner maximum moment M vs a/d as shown in Fig. 2, the differences in behavior of plain concretes and FRC are quite clear. Indented cut wire type of fibers exhibit farely constant moment capacity, irrespective of a/d ratio, specially when a/d is greater than 2.5. In fact, these fibers showed the highest strength for all the beams tested. Even beams with 0.75% of this fiber showed greater strength than the specimens with 1.5% of sheared fiber. Polyethylene fibers with 3%, despite having a high fiber content showed the lowest strength among FRC beams. This shows that, indented cut wire type of fibers are very effective in increasing the shear capacity of reinforced concrete beams.

3.2 Effect of parameters on critical shear stress

Critical shear stress defined by the parameters P max, breadth b, and effective depth d is as follows:

$$\tau cr = P\ \mathrm{max}/2bd$$

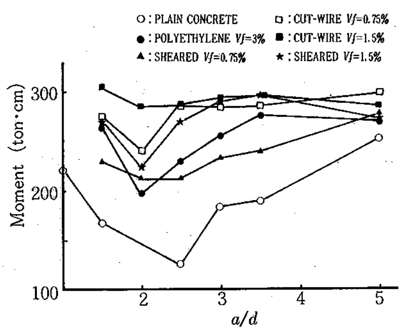

Fig. 2　Maximum moment vs a/d ratio

Table 2.　Correlation analysis results for beams which failed in shear.

Type of beam	Correlation coefficients for			
	p	fc'	a/d	Vf
Indented cut wire	0.321	0.266	−.796	0.723
Sheared fiber	—	—	−.767	0.643
Polyethylene Fiber	—	—	−.762	0.15

To examine the effects of parameters on the critical shear in a more rigorous manner, multiple regression analysis was carried out on the data obtained for FRC beams which failed in shear. Correlation coefficients of the analysis are presented in Table 2.

3.2.1 Effect of fiber content Vf

The effect of steel fiber content upon the shear strength of beams is shown in Fig. 3, a plot of shear strength vs Vf for both type of steel fibers varying with different a/d values. It should be noted that although shear increment is apparent for all the fibers, it is not uniform, and seems to depend on both type of failure and fiber content Vf. τcr increment with Vf seems to be smaller for flexural failure data. This shows that the effect of fibers is larger in shear strengthening than in flexure.

Regression analysis data (Ref. Table2) regarding critical shear stress shows the most effective parameter which describes the material properties is the fiber content. Among the fibers, indented cut wire type of fiber gives the highest correlation (0.723) and polyethylene the lowest (0.15), which means indented cut wire type of steel fiber is very effective in shear strengthening.

3.2.2 Effect of a/d ratio

Among the parameters studied, this parameter which describes the loading condition of the beams seems to be one which influences most the critical shear. Correlation coefficients also show a value around −0.75 for all the types of beams under shear failure. Plots of τcr vs a/d for steel, polyethylene and

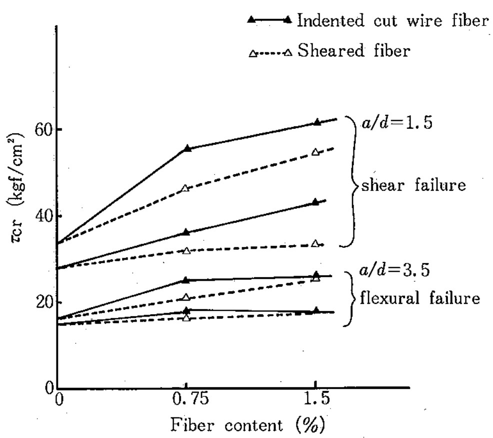

Fig. 3　Effect of fiber content on critical shear

plain concrete beams show a similar behaviour of increasing τcr as a/d decreases. In order to seek for a linear behavior, τcr was plotted with d/a. Fig. 4 shows the different lines obtained for different FRC beams. Straight lines obtained show that there is a better linearity for fiber concretes than plain concrete. It also can be observed from this figure that SFRC beams show a higher gradient than plain or polyethylene FRC.

3.2.3 Effect of main reinforcement ratio *p*

Tests have shown that the diagonal cracking load increases with p. A high steel content in the shear span will mean narrower flexural cracks at a given load, and this will enable aggregate interlock and dowel action to carry a larger load. Increased strength of beams resulting from larger main reinforcement ratio is demonstrated by Fig. 5. This figure shows that the increment of τcr due to p is more for fiber concretes than plain concrete.

3.2.4 Effect of effective depth *d*

In this series of tests, flexural loading tests were carried on relatively small beams, such as beam height 10 cm and 20 cm. It has been found that for plain concrete, results of such laboratory tests cannot be directly applied to full size beams, because there is some evidence suggesting shear strength decrease with the increase in depth of the member. Fig. 6a for plain concrete shows τcr drops as much as 30-40% with increase of effective depth, when the beams fail in shear. Similar figure drawn for indented cut wires (Ref Fig.6b) shows almost a constant τcr value. A slightely higher value shown when height is 20 cm may be due to the fact that p is larger than the beams of 10 cm. Reports are also available indicating that relative loss of shear strength of large beams was not significant when beams with web reinforcements were compared. Since the effect of fibers is similar to having web reinforcements, same kind of behavior may be expected.

3.2.5 Effect of *fc′* of concrete

There was no correlation between shear strength of beams and compressive strength of FRC. For plain concrete the tensile strength can be directly related to to its compressive strength. However this is not true for FRC. Table 1 shows almost equal fc', but increase in both maximum tensile and post cracking tensile strength as fiber content increases. The same table also shows although concretes of dilferent fibers have the same fc', their tensile strength can differ depend-

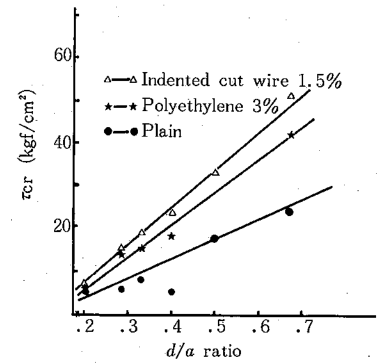

Fig. 4　τcr vs d/a ratio

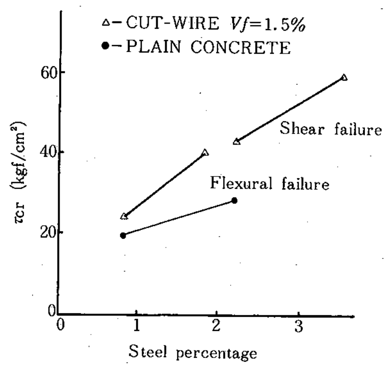

Fig. 5　Effect of main reinforcement ratio p% on critical shear

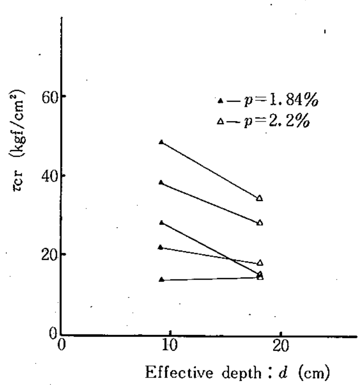

Fig. 6(a)　Effect of effective depth on critical shear for plain concrete beams

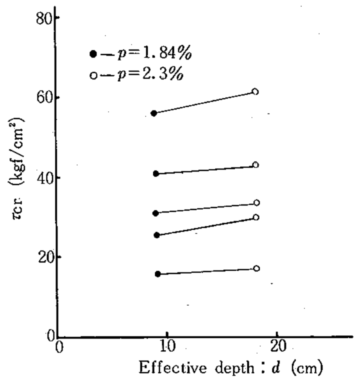

Fig. 6(b)　Effect of effective depth on critical shear for SFRC beams

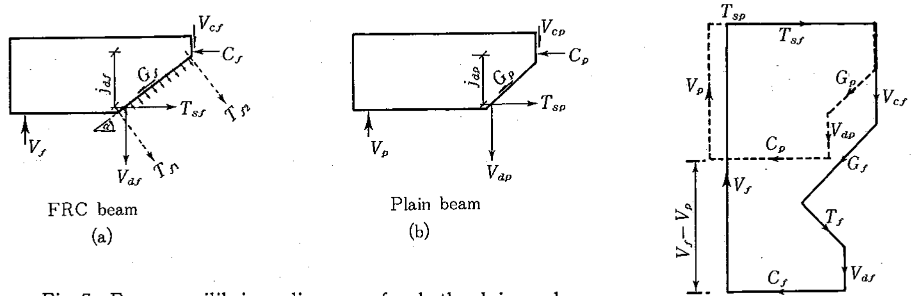

Fig. 7 Force equilibrium diagrams for both plain and fiber concrete beam portions

ing on the types of fiber. From these observations it can be deduced that cracking loads and maximum loads of fiber concrete beams, which depend mostly on tensile strengths, are not related to compressive strength of concrete.

4. Some reasons for steel fiber reinforced concrete beams to have a higher shear failure loads

Fig. 7 illustrates the forces that maintain the equilibrium of a free body of part of a simply supported beam, due to a biaxial state of stress created by shear. Although quantitative differences in the force components are not considered, some reasons are discussed for the FRC beams to maintain a higher shear force across the beam section.

As can be observed, the main difference with the plain concrete beam body in the forces that maintain the equilibrium being the tensile forces that prevail across the diagonal crack. The direct shear tests indicate the SFRC specimens to have a much higher direct shear strength. Since cracks are minimized and arrested in FRC and also dowel forces created by fiber itself may be higher. Hence interlock forces may also be higher. R. N Swamy (3) indicates there is an increase in the stiffness of the dowel zone due to the presence of fibers. Qualitative force diagrams are drawn for both plain and FRC and a higher value of support reactions are thus quite evident. The additional resisting moment component due to tensile forces across the crack is shown in the same figure. Thus although compressive strength of FRC is not improved it can be shown that a higher shear force (support reaction) can exist in a FRC beam as compared to plain concrete beams.

5. Conclusions

1) Indented cut wire type of fibers are very effective in increasing the shear capacity of reinforced concrete beams.

2) Polyethylene fibers, though they are effective in improving flexural properties, can not be recommended as a means of improving the shear capacity of reinforced concrete members, even with a high fiber content.

3) The range of a/d ratio of reinforced concrete beams which fail in shear is less when steel fibers are used.

4) Critical shear depends mostly on a/d ratio, fiber content and the main reinforcements ratio. The height of the specimen does not seem to effect much when the height of FRC beams is less than 20 cm

5) Shear failure of singly reinforced SFRC beams starts from small cracks at the shear span. Cracks widen and propagate diagonally towards the compression zone as the load increases. Fibers within the cracks act as reinforcements transfering stresses, and final failure occurs by crushing of concrete at the compression zone and pulling out of fibers across the diagonal cracks. (Manuscript received, June 5, 1985)

References

1) Taketo UOMOTO, Tsugio NISHIMURA and R. K WEERARATNE: Study on Reinforced Concrete Members Using Fiber Reinforced Concrete (4), SEISAN-PENKYU, Vol. 36, no. 4
2) Roop L. Jinadal: Shear and Moment Capacity of Steel FiberReinforced Concrete Beams, ACI publication, SP 81-1
3) R. N Swamy and H. M bahia: Influence of Fiber Reinforcement on the Dowel Resistence to Shear, ACI Journal Symposium Paper, Title No 76-17