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STEEL FIBERS AS WEB REINFORCEMENT IN REINFORCED CONCRETE,(U)
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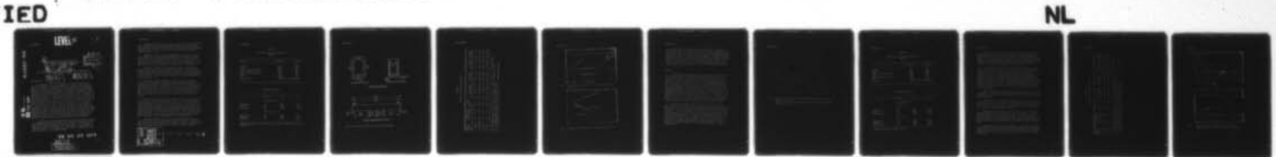

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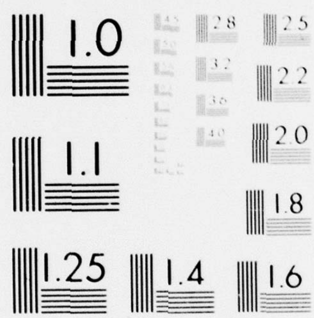

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(6) STEEL FIBERS AS WEB REINFORCEMENT IN REINFORCED CONCRETE. (U)

JUN 1978

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INTRODUCTION

Background: When steel fibers are randomly dispersed in a concrete or mortar mix, the properties of the basic material are altered. Flexural, compressive and shear strengths are increased, impact resistance and fatigue life are improved, and post cracking behavior is considerably modified. These improved properties have resulted in the widespread use of steel fiber concrete in pavements and pavement overlays, refractories and precast units. However, the use of the material in structural applications has been confined to small scale members. Insufficient research has been accomplished to provide reliable design criteria for large scale structural applications. Henager (1) has demonstrated that steel fibers in beams 8" x 12" x 144" (203 x 304 x 3658 mm) contribute to the ultimate strength of the beam, while Swamy and Al-Noori (2) have shown that steel fibers can be used in large members, 6" x 9" x 90" (152 x 228 x 2286 mm), to produce composite beams. Williamson and Knab (3) demonstrated that steel fibers substituted for shear reinforcing in full scale beams can increase the shear strength of the concrete sufficiently to allow the beam to exceed the ultimate design moment, however the beam did not achieve the desired flexural failure.

Although it has never been proposed that steel fibers replace conventional reinforcing in full-scale structural sections, it has been sufficiently demonstrated that steel fibers can contribute to the overall structural capacity of large members. This study is directed toward a better characterization of the contribution steel fibers can make in structural members.

Objective: the objective of this investigation was to determine the feasibility of replacing shear reinforcement (stirrups) with randomly distributed steel fibers for the prevention of diagonal tension (shear) failure in full-scale conventionally reinforced concrete beams. p. 14

Approach: This study was accomplished in two phases. Phase I (3) involved four full-scale conventionally reinforced concrete beams designed in accordance with ACI Code 318-71. Each beam was the same size and contained an equal amount of flexural steel. One beam had no shear reinforcement, one contained stirrups and two were made with straight steel fibers as a replacement for stirrups.

Phase II consisted of two additional fiber concrete beams similar to the first four except that a deformed fiber was used as shear reinforcement rather than the straight fiber. The mix design for Phase I is given in Table 1 together with the strength properties of the concretes. The beam cross-sections and loading arrangements are shown in Fig. 1.

Review of Results of Phase I: The results of the Phase I tests are given in Table 2, where the design moments and shear stresses are compared to the actual values. The beam with no shear reinforcement attained a moment only 72 percent of the design value. The beam with stirrups had reached a value 27 percent greater than the design value and still had not failed, though failure was imminent. The two beams with steel fibers as shear reinforcement attained moments 8 percent and 11 percent in excess of the design moments.

The beam without shear reinforcement developed an average shear strength equal to the design value. At this point the beam failed catastrophically in shear as was expected (Fig. 2). The beam with stirrups reached an average shear stress 61 percent in excess of the design value, and although the beam contained numerous diagonal tension cracks, the beam did not fail; but there is no doubt that it would have failed in flexure, had the capacity of the loading machines not been exceeded. The two beams with fibers as shear reinforcement developed shear stresses 47 percent greater than the design value before the beams failed catastrophically in shear (Fig. 3).

The main conclusion that can be derived from these data is that steel fiber concrete can develop sufficient shear strength for the beam to exceed the ultimate design moment capacity. However, the shear strength was not sufficient to force a flexural failure.

Table 1

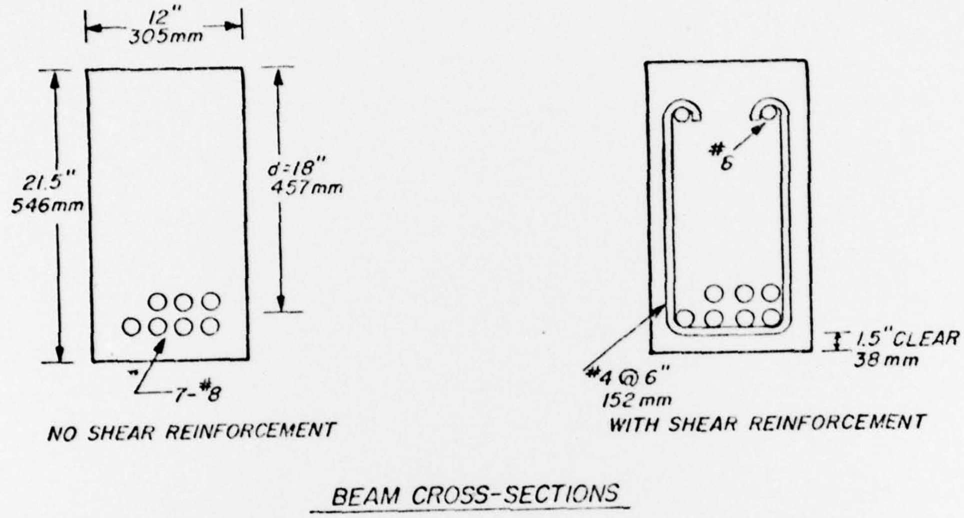
Design Mix and Strength Properties,
Phase I

Material	yd^3, lbs	m^3, kg
Cement	572	340
Sand	1485	882
3/8" (10 mm) aggregate	1485	882
Water, plain concrete	352	209
Water, fibrous concrete	393	233
Fibers	220	130
Air	4-6%	4-6%
Water reducer	per mfg. recommendations	

Strength Properties

	Age, days	psi	MPa
	Plain Concrete*		
Compression	29	4660	32.1
Flexural	34	530	3.65
Splitting	30	487	3.36
	Fiber Concrete		
Compression	34	4130	28.5
Flexural	35	694	4.78
Splitting	35	499	3.44

*Compression values are the average of 9 tests. All others are the average of 3.



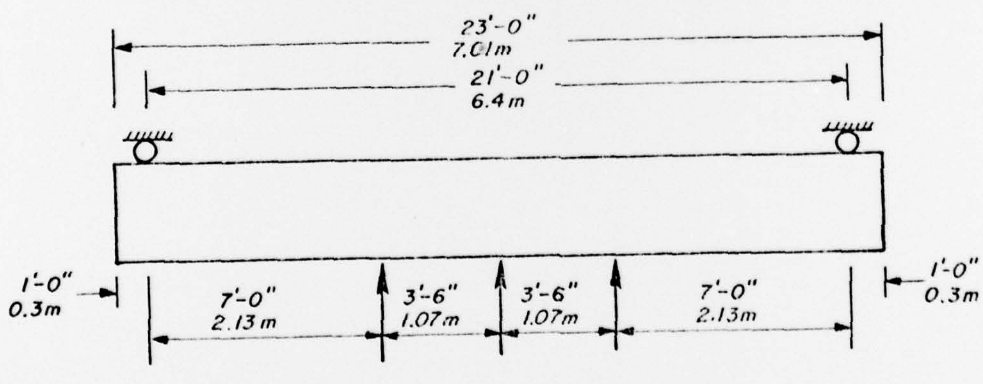


FIG. 1 Beam Cross-Sections and Loading Arrangement

Table 2

Results of Beam Tests, Phase I

Beam[1] No. and Type	Reinforcing Main	Reinforcing[2] Fiber lbs/yd[3]	Steel Ratio, ρ bal	Steel Ratio, ρ act	$\bar{M}u$ design k-ft (kN-m)	$\bar{M}u$ actual k-ft (kN-m)	v[3] design psi (MPa)	v actual psi (MPa)
1. Plain	7-#8[4]	None	.0291	.0256	420.8(570.6)	304.8(413.3)	194.(1.34)	192.(1.32)
2. Stirrups	7-#8	None	.0291	.0256	420.8(570.6)	534.0(724.1)	194.(1.34)	312.(2.15)
3. Fiber	7-#8	220	.0265	.0256	406.9(551.8)	439.5(596.0)	186.(1.28)	271.(1.87)
4. Fiber	7-#8	220	.0265	.0256	406.9(551.8)	450.0(610.2)	186.(1.28)	275.(1.89)

1. All beams were 12" x 21.5" x 23'-0" (.305 x .546 x 7.01 m). d = 18" (457 mm).
2. All fibers were 0.010 x 0.022 x 1.0 inches (0.254 x 0.559 x 25.4 mm).
3. v - average shear stress on cross-section = v/bd.
4. All reinforcing steel was ASTM A615 Grade 60. f_y = 64000 psi (441 MPa).

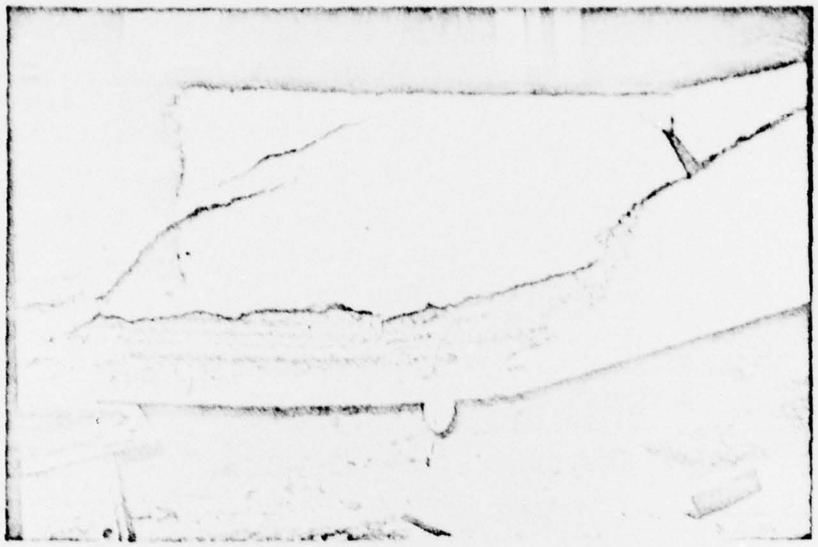


FIG. 2 Diagonal Tension Failure of Beam Without Stirrups or Fibers

FIG. 3 Diagonal Tension Failure of Fibrous Concrete Beam

All four of the beams developed visible diagonal tension cracks at very low loads, approximately 50 percent of ultimate. It was reasoned that if a greater post cracking strength could be developed by the fibers, then perhaps sufficient shear strength could be developed to force the beams to fail in flexure. Previous work had shown that concrete made with deformed fibers will develop a greater post cracking strength than that made with straight fibers. As a result of these observations, two additional tests were designed using a fiber with deformed ends. These tests constituted Phase II of the study.

PHASE II

Materials and Fabrication: The steel fibers used were Dramix ZC 50/50 manufactured by Bekaert SA. The fibers are 0.02 x 2.0 inches (0.5 x 50 mm) and are deformed at the ends (Fig. 4). The ultimate strength of the fibers is in excess of 200,000 psi (1379 MPa). The main reinforcing steel was ASTM A615 Grade 60 with f_y = 64 ksi (441 MPa) for Beam No. 5 and f_y = 72 ksi (496 MPa) for Beam No. 6. The concrete was specified to be 5000 psi (34.5 MPa) at 28 days, however, poor control at the batch plant caused the concrete strengths to vary for the different beams. The concrete design mix and strength parameters are given in Table 3. The beams were fabricated in oiled plywood forms using primarily external vibration. They were cured at room temperature by coating with a curing compound. Cylinder and beam specimens were cured in the same manner alongside the beams. The concrete strength values shown in Table 3 are those obtained on the same days that the beams were tested.

Testing: The beams of Phase II were tested on a 21'-0" (6.4 m) span with the main loading actuators at the third points as shown in Fig. 1. For these tests, the loading was upward, while for the Phase I tests, the loading was downward; otherwise, there was no difference. A third actuator was placed at the center of the beams for use when the capacity of the main actuators was exceeded. Loading was accomplished with a CGS system. Deflections were obtained by Physitech and dial gages. Readings were taken at 10 kip (44.5 kN) intervals; closer when required. Except for the dial gages, all values were recorded through digital readout equipment. Shear strains at various locations were obtained for Beam No. 6 with SR-4 strain gages.

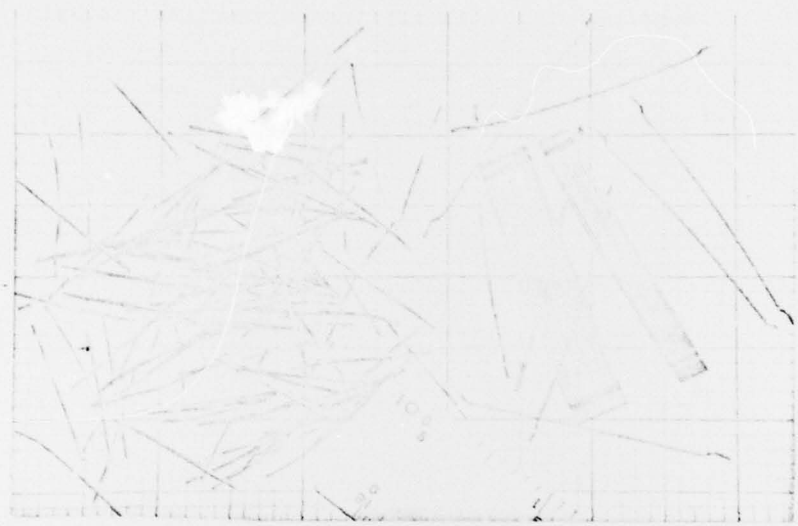


FIG. 4 Left - U.S. Steel "Fibercon" Straight Steel Fibers Used in Beams No. 3 and 4.
Right - NV Bekaert SA "Dramix" Crimped End Steel Fibers Used in Beams No. 5 and 6.

Table 3

Design Mix and Strength Properties,
Phase II

	yd^3, lbs	m^3, kg
Cement	572	340
Sand	1485	882
3/8" (10 mm) aggregate	1485	882
Water	286	154
Fibers-Bekaert ZC 50/50	145	91
Air	4-6%	4-6%
Pozzolith	per mfg. recommendations	

Strength Properties*

	Age, days	psi	MPa
	Fiber Concrete		
	Beam No. 5		
Compression	30	6060	41.80
Flexure	30	1275	8.79
Split tensile	30	1000	6.89
	Beam No. 6		
Compression	43	5860	40.40
Flexure	43	1080	7.45
Split tension	43	700	4.83

*All values average of three tests.

Results: Table 4 compares the design values of the moments and shear stresses with the values obtained from the tests of the two beams. Beam No. 5 achieved 97 percent of the design moment, while Beam No. 6 reached a moment one percent greater than the design moment. Both beams failed in flexure by first yielding of the reinforcing steel followed by crushing of the concrete. Failure was gradual in both cases, extending over several minutes.

The average shearing stresses in Beam No. 5 were 45 percent greater than the design value. This is consistent with the values of Beams No. 3 and 4 of Phase I, except for the fact that they failed as a result of diagonal tension cracks, while Beam No. 5 had only one visible diagonal tension crack even at the point of failure. Beam No. 6 developed an average shear stress 67 percent greater than the design value, with only one hairline diagonal tension crack in the beam. This crack developed at a stress of approximately 245 psi (1.69 MPa) but remained closed through the point of failure. Again, the failure of Beam No. 6 was gradual, with yielding of the tension steel first, followed by gradual crushing of the concrete (Fig. 5).

Fig. 6 shows the load-centerline deflection curve for four of the beams. It can be seen that neither the fibers nor the stirrups influenced the stiffness of the members. The remaining two beams had similar curves.

Strain gages were placed at opposite sides of the beam at mid-depth and at 45° to the long axis, in the theoretical direction of the diagonal tension. The gages were 38" (965 mm) from the support, in the region of constant shear. Measured values for the two gages were .000098 and .000095, respectively.

Discussion: The results shown in Tables 2 and 4 show good agreement with the fiber concrete beam moments theoretically determined by standard ACI Code design procedures and those obtained experimentally. The actual values ranged from 3 percent below to 10 percent above the calculated values. This indicates that no special design procedures are required when using fibers as shear reinforcement.

The average shear stresses developed by the beams with fibers ranged from 40 to 67 percent greater than the shear stress developed by the plain concrete. These stresses were sufficient to force the beams to fail in flexure for those that were made with the crimped end fibers.

Table 4

Results of Beam Tests, Phase II

Beam[1] No. and Type	Reinforcing Main	Fiber[2] lbs/yd^3	Steel Ratio, ρ bal	act	$\bar{M}u$ design k-ft(kN-m)	$\bar{M}u$ actual k-ft(kN-m)	v^3 design psi (MPa)	v actual psi (MPa)
5. Fiber	7-#8[4]	145	.0293	.0256	445.9(604.6)	431.5(585.1)	194.(1.34)	282(1.94)
6. Fiber	7-#8	145	.0284	.0256	486.1(659.1)	493.0(668.5)	194.(1.34)	324(2.23)

1. All beams were 12" x 21.5" x 23'-0" (.305 x .546 x 7.01 m). d = 18" (457 mm).
2. Fibers were Bekaert ZC-50/50 0.02 x 2.0 inches (0.5 x 50 mm).
3. v = average shear strength on cross-section = v/bd.
4. All reinforcing steel was ASTM A615 Grade 60. For Beam No. 5 f_y = 64000 psi (441 MPa), and for Beam No. 6, f_y = 72000 psi (496 MPa).

FIG. 5 Top - Overal View of Beam No. 5 at Failure
Bottom - Close-up of the Failure Zone of Beam No. 5

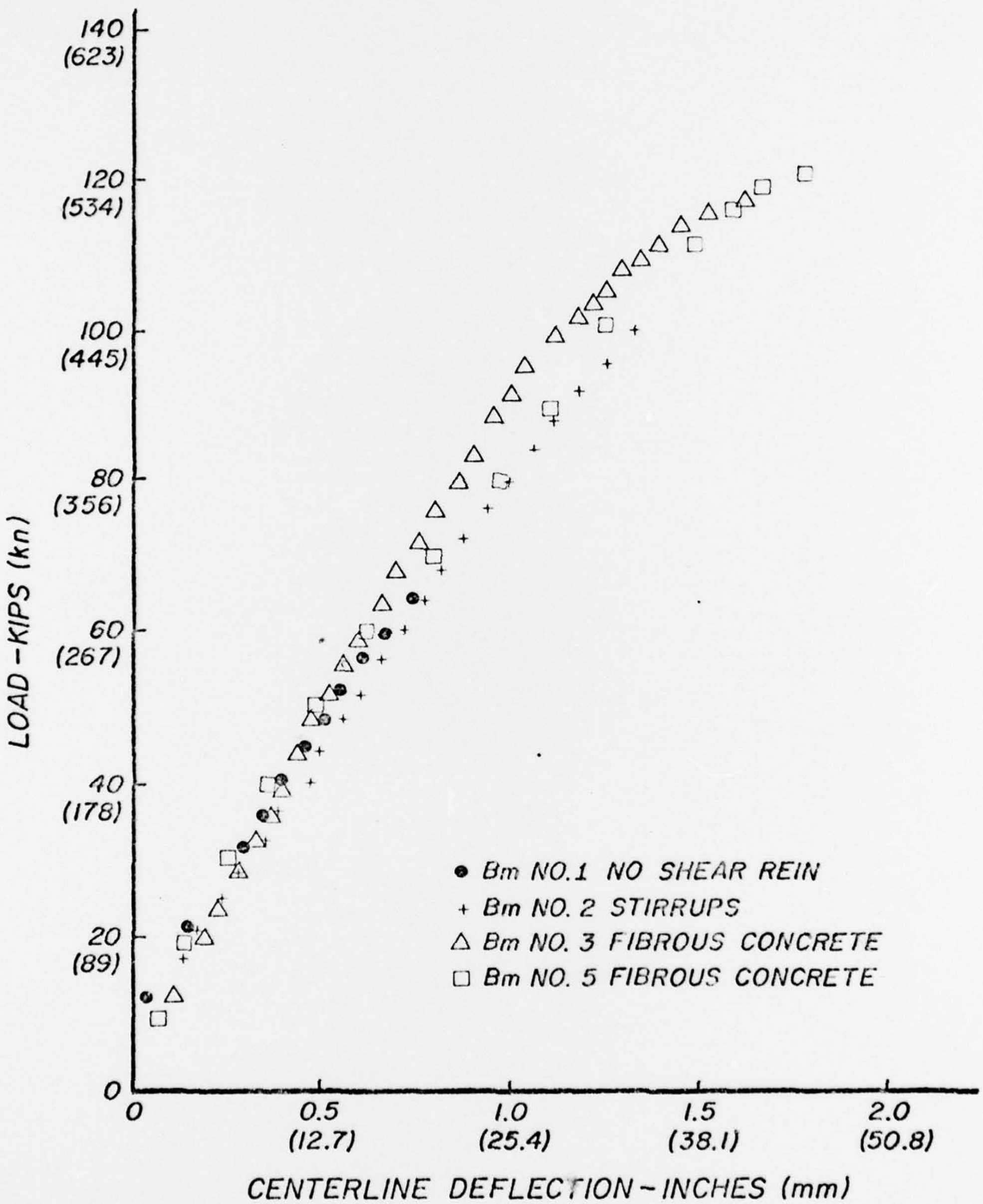


FIG. 6 LOAD - DEFLECTION CURVES

The load-deflection curves of Fig. 6 indicate that the fibers have no effect upon the stiffness of the beams. This is in contrast to what can be expected when steel fibers are used in small members. Both the stiffness and ductility can be considerably affected by the presence of fibers, especially for small beams.

The strains measured by the gages indicate a maximum shear stress 25 percent greater than the average shear stress. This is based upon a Young's modulus derived from the procedure given in the ACI Code, where $E = 57000\ (f'_c)^{\frac{1}{2}}$. Although the interaction of stresses due to shear and flexure are not clearly defined in a reinforced concrete beam, it would be expected that the maximum stress would occur at mid-depth as found here.

Conclusions: The following conclusions are based upon the use of steel fibers with deformed ends (Dramix) to replace stirrups; in full-scale reinforced concrete beams loaded with concentrated forces.

(1) Steel fibers can be used to replace stirrups in beams with no reduction in the ultimate design moment capacity,

(2) Steel fibers increase the shear strength of concrete beams sufficiently to prevent catastrophic diagonal tension failure, while forcing the beam to fail in flexure,

(3) ACI Code procedures can be used without modification to design reinforced concrete beams that contain steel fibers as shear reinforcement;

(4) Low volume percentages of steel fibers have no effect upon the stiffness of full-scale beams; and

(5) ~~This study indicates that~~ steel fibers present a potentially more economic alternative to the use of stirrups in reinforced concrete design.

References

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