A STUDY OF R/C BEAMS ADDITIONALLY
REINFORCED WITH STEEL FIBERS

by

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CHAPTER 1 - INTRODUCTION

Concrete is a universal building material that has been used for thousands of years, probably beginning in ancient Egypt (20). The facility with which, when plastic, concrete can be poured to fill forms of practically any shape is a primary factor in its wide use as a building material. Concrete also has a high fire resistance and is usually available locally at a comparatively low cost.

However, because of its natural composition concrete is a relatively brittle construction material. Its tensile strength is small compared to its compressive strength. The tensile strength of concrete is an order of magnitude lower than the compressive strength (i.e., compressive strength $f_c' = 5000$ psi, tensile strength; $f_t' = 500$ psi) (25). This prevents the economical use of concrete alone in structural members subjected entirely or partially to tension.

In the second half of the nineteenth century it was discovered that the addition of steel in the tension zone of a concrete section would provide a method to utilize the compressive strength of concrete. The addition of steel, generally high tensile strength deformed bars, provides a high tensile strength at low cost, greater ductility and smaller section while better utilizing the compressive strength of the concrete (24). The resulting combination of the two materials is known as reinforced concrete.

Fiber reinforced concrete is concrete containing, in addition to the normal aggregate, randomly distributed, short,

discontinuous discrete fibers (20). This report will deal only with the addition of steel fibers. The fiber size ranges from 10-30 mils (.25 to .76 mm) in diameter and 1-2 1/4 inches (2.54 to 5.92 cm) in length. Their physical characteristics vary from straight round fibers to deformed rectangular fibers (18).

There has been a great deal of research into the mechanics of concrete reinforced with steel fibers. There is, however, a need to provide a collective summary describing steel fiber reinforced concrete, its history, mix procedures, analysis and design in conjunction with normal reinforcement. It is the object of this report to provide such information.

CHAPTER 2 - FIBER REINFORCED CONCRETE

Historical Information

The use of fibers for reinforcement is not a new concept.
The use of fiber reinforcement dates back to ancient times
when straw and grass were used to reinforce sun-baked bricks
(17). This type of reinforcement was done throughout the
world including the Great Plains of the United States by the
Indians and pioneers of the West. In more recent times,
horse hair was used to reinforce plaster and until just recent-
ly, asbestos fibers were being used to reinforce Portland
cement (21). Patents for various methods of incorporating
wire segments or metal chips into concrete have been granted
since the turn of the century.

The use of closely spaced wires and random fibers was
researched in the late 1950's and early 1960's by Romualdi
and Batson (21), and Romualdi and Mandel (21). Their research
lead to a patent based on fiber spacing. Another patent was
granted in 1972 on fiber aspect ratio. The PCA (Portland
Cement Association) investigated fiber reinforced concrete in
the late 1950's. With the surge in fiber reinforcing new
materials were investigated other than steel. Organic fibers
such as nylon, polyprophylene, and polyesthylene have been
used. Non-organic glass and deformed steel, and asbestos
fibers have been used elsewhere in the world (4,8,12,14,20).
Although a relatively old concept, the use of fiber reinforced
concrete has just recently been accepted in the United States
(21).

Modern Fiber Reinforced Concrete

The fiber reinforcement considered in this report consists of short 1-2 1/4 inches (2.54 to 5.72 cm) steel strands. The fibers may be round, rectangular in cross section and may be straight or deformed in some way (See Fig. 1). The round, straight fibers are produced by chopping or cutting cold drawn wire between 10 and 30 mils (.25 to .76 mm). The flat fibers can be produced by either flattening round wire or shearing flat steel sheets to a typical cross section range of 6 to 16 mils (.15 to .44 mm) in thickness and 10 to 35 mils (.25 to .90 mm) in width. Deformed fibers are fibers, flat or round, that have been flattened or bent at the extreme ends to increase the strength of the fiber bond to the concrete (3,7,11).

In dealing with fiber reinforced concrete it is essential to consider the fiber aspect ratio and fiber volume. The fiber aspect ratio is defined as the ratio of length of fiber to equivalent diameter (for a rectangular cross section; the area transformed into a circle with equal cross sectional area. The equivalent diameter would then be the diameter of the circle). For example, a fiber 1.18 in. (30 mm) in length with a diameter of .016 in. (.40 mm) has an aspect ratio of about 74. The aspect ratio is a dimensionless number, used principally in the mix design to avoid fiber segregation or balling. The aspect ratio also affects the post cracking resistance. To avoid fiber balling in mixing and to provide a near uniform distribution, a maximum aspect ratio of 100 is

Fig. 1 - Dramix [R]
Deformed Steel Fibers

Source: Dramix [R] Bekaert Steel
Wire Corporation
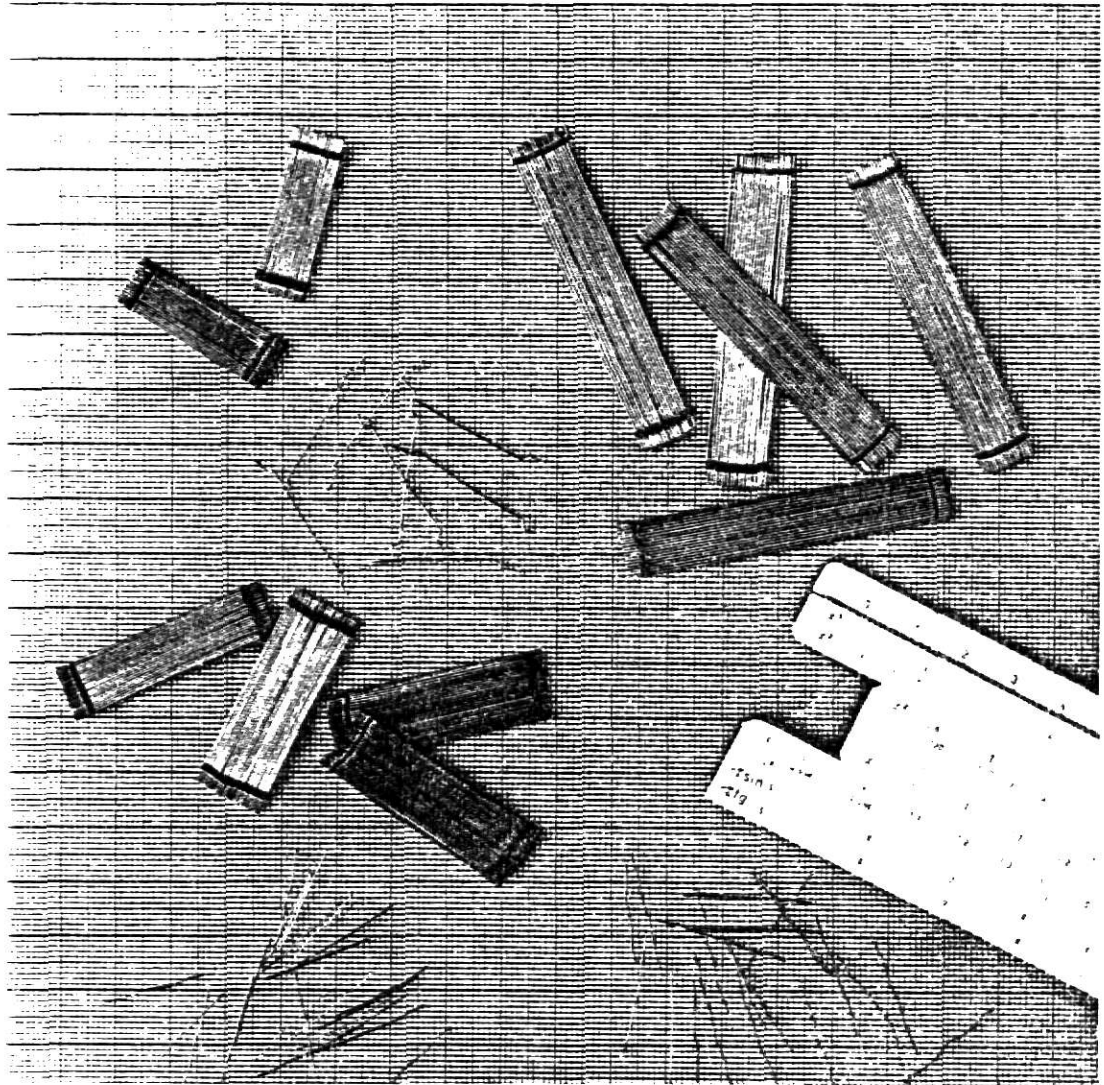
recommended. A ratio of around 75 is generally the most effective for post crack resistance and uniform fiber dispersement within the mix (18,19,20,22). This is illustrated in Table 1 taken from Reference 19.

The volume of fibers to the total mix volume is also an important consideration. The volume of fibers is described as the percent of fiber volume to the volume of the mix. In general, fiber volume ranges from 0.5 to 2.5 percent. It should be noted that the larger the fiber volume the more difficult it is to mix and the workability is decreased (10, 18,19).

Applications

Steel fiber reinforced concrete is not a cure-all material for concrete construction. It does, however, have a broad range of uses in both cast-in-place and precast concrete products.

Fibrous concrete has a tremendous potential where durability and crack control are major considerations. It has been used for airport and highway surfaces and withstood the impact loads very well (9,10,21). Steel fiber concrete has also been used for industrial floors, bridge decks, and various hydraulic structures (3,9).

The U. S. Corps of Engineers has used steel fiber reinforced concrete for several hydraulic structures (4,6). A sluiceway for the Libby Dam on the Kostenai River was repaired with fibrous concrete. Fibrous concrete was used as a top layer 18 inches for a spillway on the lower monumental lock and dam located on the lower Snake River (4). The Corps also

TABLE 1 - SUMMARY OF RESULTS - MORTAR (1:3.5, 0.65)
SPECIMENS WITH 0.5 PERCENT BY VOLUME OF
FIBERS IN TENSION

Direction of fibers with respect to that of the applied load	Length of fibers, in.	Aspect ratio (L/d)	Tensile strength*, lb	Post cracking load*, lb	Relative toughness
Effect of aspect ratio					
Random	1	100	760	320	1.5
	3/4	75	790	430	1.7
	1/2	50	770	0	1.4
	1/4	25	790	0	1.0

*Multiply by 0.453 to express in kgf.

Source: Shah, Surendra P. and Rangan, B. V., "Fiber
Reinforced Concrete Properties," ACI Journal,
Proceedings, Vol. 68, No. 2, Feb. 1971, pp.
126-135.

used fiberous concrete for Basarwater Armor Units off the coast of Eureka, California, along with other hydraulic projects (6).

In precast members the use of fiberous concrete is not as wide spread as it is with cast-in-place concrete. The major uses at this time consist of precast garages where the fibers reduce crack and spalling damage during transportation and precast concrete pipe where the fibers reduce cracking and increase the strength characteristics of the pipe (3,10, 20,25).

CHAPTER 3 - MIX DESIGN, METHODS, AND PLACEMENT

Mix Design

There are several factors involved in the design of
fiber reinforced concrete mixes. The most important aspect
of mix design is to insure a uniform dispersion of the fibers
within the mix. The factors to consider in the mix design are:

1) The fiber aspect ratio

2) The fiber volume

3) The mix materials

4) The mix proportions

The fiber aspect ratio is the most critical element in
the uniform dispersement of fibers. To avoid segregation or
balling of fibers, or combination of fibers and other mix
materials, the fiber aspect ratio for round or flat straight
fibers should be a maximum of 100 (15). The aspect ratio for
deformed or hooked fibers should be somewhat less (around 70
to 85) depending on the amount and shape of the deformation,
hooked fibers having a greater tendency to ball (15,18,19).

The fiber volume is important for a uniform distribution.
For best results the fiber volume should be kept between 0.5
to 4 percent. It should be noted that fiber volumes above
2 percent result in a decrease in mix workability (10,18,19).

The material used for fiber reinforced concrete mixes
is essentially the same as standard concrete; cement, water,
sand, coarse aggregates, and conventional admixtures. The only
change being the maximum size of coarse aggregate recommended
is 3/8 inch. According to Snyder and Lankard (20) the addition
of coarse aggregate to a steel fiber containing mortar results

in a decrease in first crack and ultimate tensile strength of
the material. The information presented in this report is
based on research using the maximum size aggregate of 3/8 in.

The procedure for proportioning fiberous concrete mixes
parallels that used for conventional concrete mixes. A trial
mix is usually tested and adjustments in fiber and water con-
tents made. It is important to realize the requirement for
water will increase with an increase in fiber content. Exper-
ience suggests water cement ratios from 0.4 to 0.6 and cement
contents of 550 to 950 lbs. to provide adequate coating of
fibers with cement paste (21). An example of a typical
fiberous concrete mix is shown in Table 2.

Mix Methods

The method of actually adding and mixing the steel fiber
is dependent on the type of mixing equipment available (15).
The increase in first crack and ultimate flexural strengths
can only be attained if the fibers are displaced uniformly.
The most widely used method of providing adequate dispersion
is to add the fibers to the dry aggregate and mix before the
water is added. The actual procedure for mixing the concrete
may vary due to available equipment, however, for batch or
ready-mix concrete operation the following mixing sequences
are presented in order of preference (21):

1) blend fiber and aggregate prior to charging the mixer,
such as combining fibers on a conveyor belt. Then proceed
with standard mixing procedure.

TABLE 2 - TYPICAL PROPORTIONS FOR NORMAL
WEIGHT FIBER REINFORCED CONCRETE

Cement	550-950 lb/cu yd
W/C ratio	0.4 to 0.6
Percentage of sand to aggregate	50 to 100 percent
Maximum aggregate	3/8 in.
Air content	6 to 9 percent
Fiber content	0.5 to 2.5 percent by volume of mix (steel - 1 percent = 132 lb/cu yd glass - 1 percent = 42 lb/cu yd nylon - 1 percent = 19 lb/cu yd

1 lb per cu yd = 0.5933 kg/m^3
1 in.   = 2.54 cm

Source: "State of the Art Report on Fiber Reinforced Concrete,"
         ACI Journal, Committee 544, Proceedings, Vol. 70, No.
         11, Nov. 1973, pp. 729-744.

2) Blend fibers with previously mixed fine and coarse
aggregate at standard mixing speed. Add cement followed by
water and admixtures or add cement and water simultaneously.

3) Add fiber to previously mixed water and aggregates.
Then add remaining water and cement.

4) Add all blended dry ingredients to mixer containing
the correct amount of water.

At the present time most steel fibers are supplied in-
dividually in 40-60 lb. boxes (21). However, fibers shipped
in this manner must be loosened prior to mixing. Just recently,
Bekaert Steel Wire Corporation developed a procedure of gluing
the fibers in collated bundles thereby providing a larger
apparent diameter, improving the initial mixing and eliminat-
ing the necessity to manually loosen shipped fibers. After
the initial mixing the fibers separate due to the mechanical
action and solubility of the glue. This new development would
appear to decrease the cost of mixing and increase the uniform
dispersion of fibers throughout the mix (3).

Placement

The addition of steel fibers requires, in general, more
vibration than a standard mix. External vibration of the forms
and exposed surfaces is preferable to internal vibration.
However, with proper precautions to avoid fiber segregation
internal vibration is acceptable. Because of the fiberous
nature of the concrete, rakes and hoes are more effective in
handling the mix than the usual shovels. In general, the use
of standard finishing tools is acceptable for fiberous concrete
(6,9,15,16,21).

CHAPTER 4 - MECHANICS OF BEHAVIOR

Compressive Strength

The effect on the static compression strength of concrete by the addition of steel fibers is significant. In a study by Williamson (24) the effect of steel fibers on static compression strength of concrete was studied. Using standard test cylinders 120 tests were conducted on mixes of 3/8" maximum aggregate and 3/4" maximum aggregate. The fiber volumes ranged from 1 to 2.5 percent. The results of these tests provided data that showed up to sixteen percent increase for the 3/8" maximum aggregate mix and up to a twenty-three percent increase in static strength on the 3/4" maximum aggregate mix. The test results are shown in Fig. 2. The actual percent increase was dependent on the volume percent of fiber with the larger the volume percent the greater percentage increase in static compressive strength (8,13,18,23).

It would be appropriate at this time to present the theory behind this increase in strength. Swamy, et al. (23) presented the theory that all concrete contains small flaws which begin to increase in size under load for stresses well below 50 percent of the ultimate. The coalescing of these flaws ultimately results in the concrete's failure. From the works of Glucklich, R. Jones and H. Neuber, it was shown that the primary failure mode is a result of cracks or flaws which grow under load, parallel to the direction of the applied stress (23). These flaws and/or cracks act as stress convertors in that the general compressive stresses create local tensile stresses in the vicinity of the crack tips. The cracks grow due to
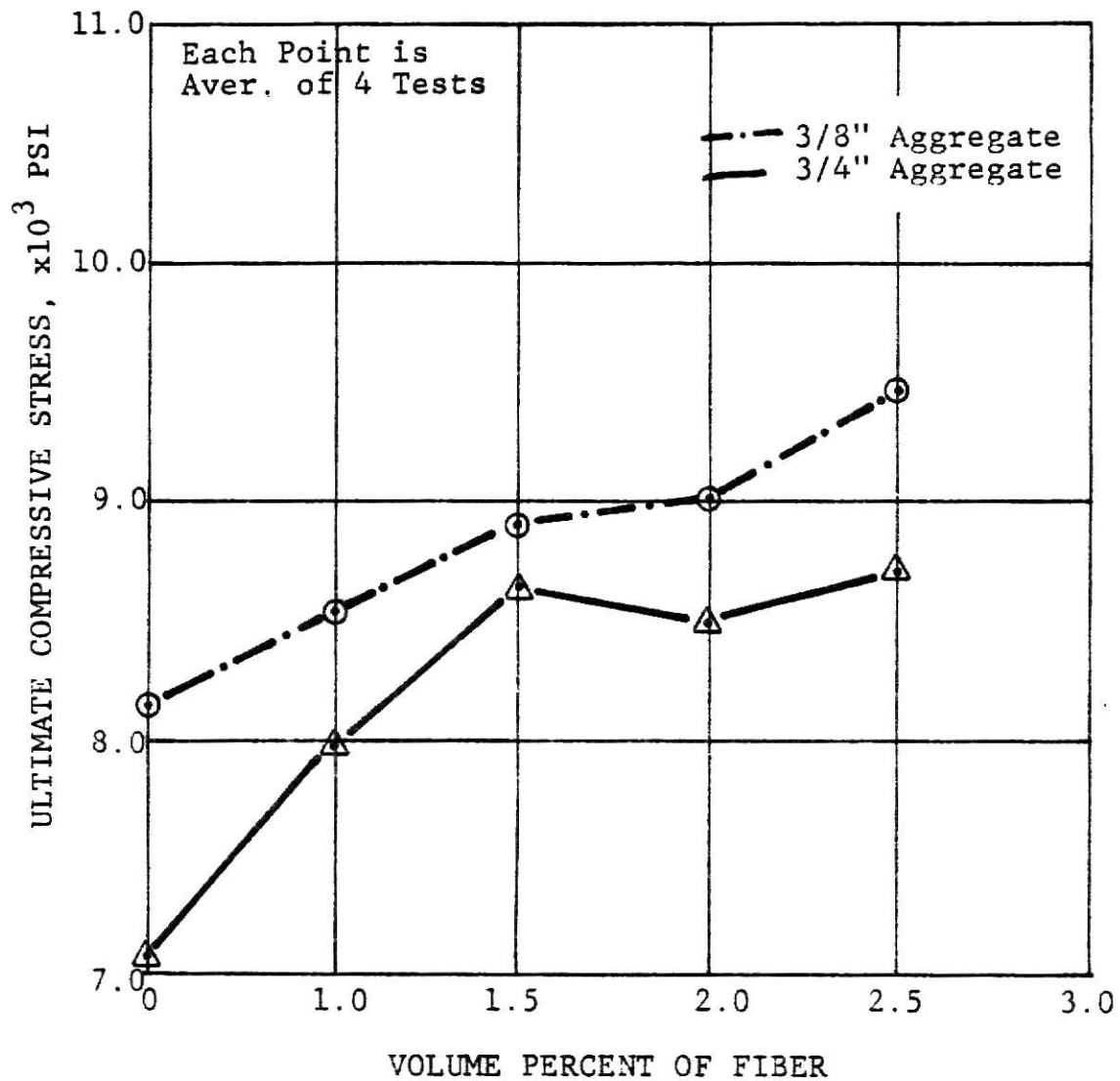
Fig. 2 - The Effect of Steel Fibers on the Compressive
Strength of 6" x 12" cylinders

Source: Williamson, Gilbert R., "The Effect of Steel
Fibers on the Compressive Strength of Concrete,"
Paper No. 11, Special Publication No. SP-44,
ACI, 1974, pp. 195-207.

these tensile stresses until a critical size is obtained, which results in a brittle type of failure in the concrete. The failure mode is shown here as primarily tensile. Therefore the arresting of the crack growth by the steel fibers would provide a basis for increased compressive strength of fiber reinforced concrete.

Crack Arrest

The original purpose of using fibers in concrete was to increase the first crack strength and resistance to crack propagation in concrete. Research by Romualdi, et al. (20), as well as Cox (4) and others, has shown that steel fibers added to concrete will increase the first crack strength, often referred to as toughness, and resist the propagation of existing cracks. The amount of crack arrest is dependent on the spacing or volume of fibers. Research by Snyder and Lankard (20) suggests an increase in first crack strength up to three-fold. The mechanism of resistance to crack propagation is illustrated by Swamy, et al. (23) in Fig. 3. The failure of fiber reinforced concrete is due to fiber pullout rather than the failure of the fibers. The growth of cracks is dependent on the force required to pull out the steel fiber. The greater the pullout resistance the greater the crack propagation resistance (11). A schematic representation of slow crack propagation is shown in Fig. 3 (8).

Shear

The failure of concrete subjected to shear forces is actually in the form of diagonal tension. Closely spaced

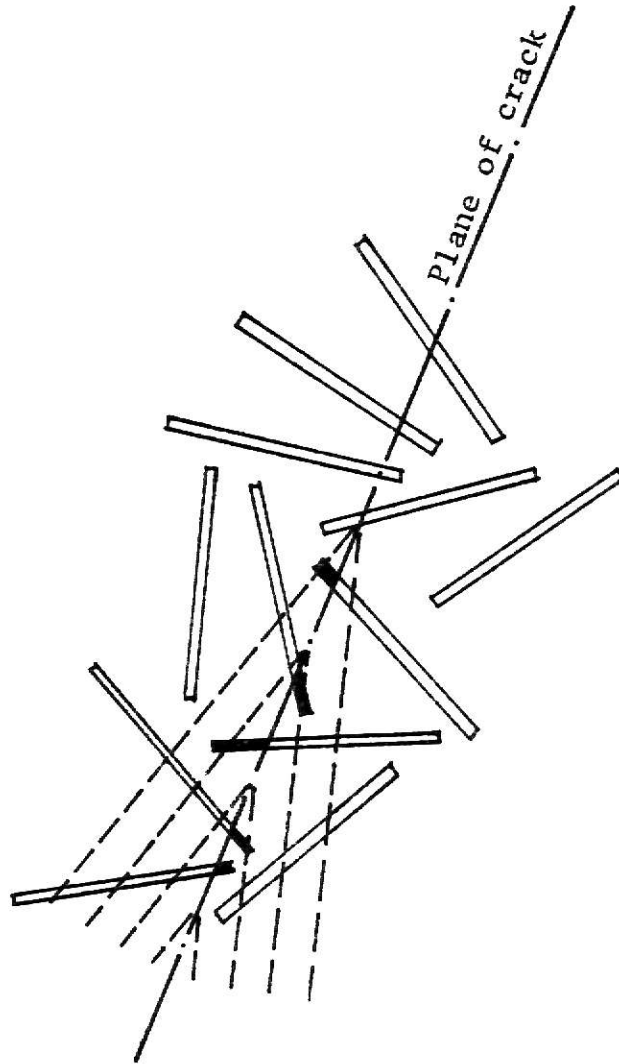Shaded portion shows debonded fiber

Plane of crack

Fig. 3 - Schematic Representation of Slow Crack Propagation and Progressive Debonding of Short Fibers

Source: Krenchel, Herbert, "Fiber Reinforced Brittle Matrix Materials," Paper No. 3, Special Publication No. SP-44, ACI, 1974, pp. 45-79.

stirrups are usually used to prevent shear failures in concrete beams. Because the nature of the stress is tensile, steel fibers should provide effective reinforcement against shear failure. In fact, this is what Batson, Jenkins and Spatney (2) discovered in their research on fiberous shear reinforcement. There has not been a great deal of study in this area but from what has been done it appears that with the use of steel fiberous concrete with fiber volumes around 2 percent no additional shear reinforcement would be necessary.

Flexural and Tensile

Tensile and flexure tests on steel fiber reinforced concrete have shown an increase in ultimate strength of up to two times that for non-reinforced concrete. Research by Shah and Rangan (17,18,19), the results of which are shown in Table 3, show the relationships between aspect ratio, relative strength and toughness defined here as the resistance to crack propagation. The U. S. Army Corps of Engineers found an increase in 28 day flexural strength of about 2 times with a wire volume of 2 percent (4).

Snyder and Lankard (19) also experimented with the flexural strength in fiberous concrete by varying the fiber volume in a concrete mortar. The results showed an increase in flexural strength with increasing fiber volume from a twofold increase at about 2.3 percent to almost a threefold increase at 4 percent fiber volume.

Also examined was the effect of aggregate size on the flexural strength. The addition of coarse aggregate to a fiber mortar matrix decreased the strength. However, if the coarse

TABLE 3 - SUMMARY OF RESULTS - CONCRETE (1:2:3, 0.60)
SPECIMENS WITH 1.0 PERCENT BY VOLUME OF
REINFORCEMENT IN FLEXURE

Type of reinforcement	Aspect ratio L/d	Relative strength	Relative toughness
Effect of aspect ratio			
Plain concrete	0	1.00	1.0
	25	1.50	2.0
Random	50	1.60	8.0
fibers	75	1.70	10.5
	100	1.50	8.5
Effect of type of reinforcement			
Conventional tensile bar	--	3.15	--
random fibers	75	1.00	--

Fibers: 0.01 x 0.01 in. (0.25 x 0.25 mm); yield stress =
110 ksi (7740 kgf/cm^2; tensile strength = 120 ksi (8450
kgf/cm^2).

Tensile bar: Deformed wire, diameter = 0.233 in. (0.592 cm);
yield stress = 47 ksi (3300 kgf/cm^2); tensile strength =
91.7 ksi (6450 kgf/cm^2).

Source: Shah, Surendra P. and Rangan, B. V., "Fiber
Reinforced Concrete Properties," ACI Journal,
Proceedings, Vol. 68, No. 2, Feb. 1971, pp.
126-135.

aggregate is limited to 3/8 inch at 25 percent by weight of the mix there are no serious losses in flexure strength.

Properties

A short comment is in order to provide some additional information about fibrous concrete. The resistance of concrete to failure by dynamic or impact loads is tremendously enhanced with the use of fiber reinforcement. The addition of steel fibers provides a greater amount of crack control than classical steel reinforcement (4,6,9,15). The fibers are also more resistant to corrosive action than larger steel bar reinforcement because of the smaller cracks in fiberous concrete This aspect of fiber reinforced concrete is not one of major importance when considering fiber reinforced concrete. However, it should not be ignored. It should be apparent that the ductility of the concrete is increased by the fibers. Because of this the deflection before failure is considerably increased as compared to normal concrete (18).

In research by Ramy and McCabe (14) the fatigue strength of concrete was increased as a result of adding steel fibers.

CHAPTER 5 - METHOD OF ANALYSIS OF FIBER
REINFORCED CONCRETE BEAMS

Assumptions

1) Maximum allowable strain at the extreme compression fiber .003 in/in (.003 mm/mm). (See Fig. 4)

2) The compressive stress is represented by a rectangular stress block as used in ultimate strength design.

3) The tensile distribution of the steel fibers is represented by a tensile stress block equal to the force required to develop the dynamic bond stress of the fibers that are effective in that portion of the beam cross section.

4) Dynamic bond stress is taken as 380 psi, which gives fiber stresses in the range 48,000 psi to 85,000 psi (331,000 KN/m^2 to 586,000 KN/m^2), depending upon fiber length and diameter (5,11).

"Dynamic bond stress" is a term used to describe the bond stress that is developed during fiber pullout. The ultimate strength occurs along with considerable cracking which is evidence that fiber pullout is occurring at that point. The dynamic pullout load on fibers is somewhat less than the initial static or "breakout" load.

5) The tension is taken as the area of minimum tensile strain of σ_f/E_s in which σ_f = stress in the fiber at the assumed bond stress; pullout stress. E_s = modulus of elasticity of steel.

6) A bond efficiency factor of 1.0 is applied to smooth, straight, round or rectangular fibers. Other fibers such as duraformed fibers, are assumed a higher efficiency factor.
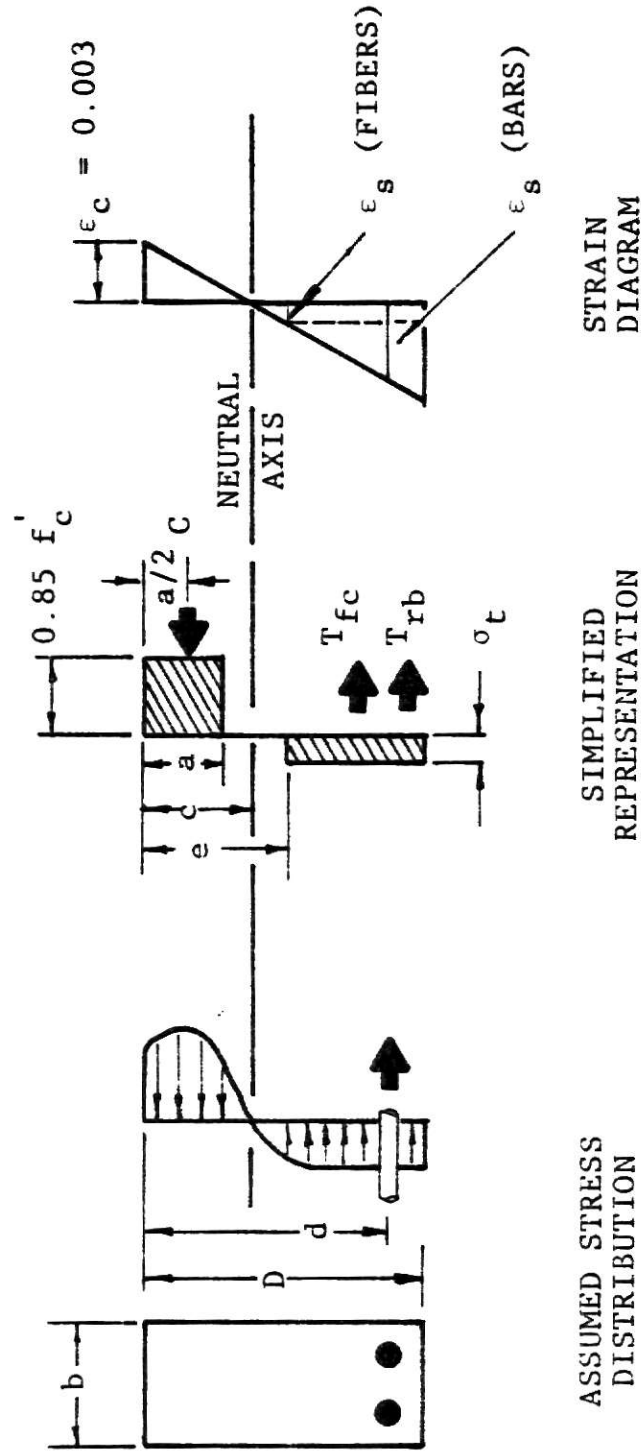
Fig. 4 - Basic Design Assumptions

The tensile stress developed within the individual fiber is dependent on the dynamic bond stress developed during pullout, the ratio of the fiber equivalent circumference to fiber equivalent cross sectional area and fiber bond efficiency. The dynamic bond stress is an emperical value developed by experimental fiber pullout tests. The value used, 380 psi, is considered to be a conservative value for dynamic bond stress (11). The ratio of the fiber equivalent circumference to equivalent cross sectional area actually reduces to two times the ratio of fiber length to equivalent diameter or the fiber aspect ratio. The bond efficiency factor provides for modification due to the physical type of fiber used, as shown in Table 5.

The tensile stress in the fiberous concrete (σ_t) is based on the following equation presented by Henager and Doherty (5).

$$\sigma_t = 1.28 \; \ell/d_f \; p \; F_{be}$$

Based on the fraction of effective randomly distributed fibers as .41 and a bond factor of randomly distributed fibers as .82 and a dynamic bond stress of 380 psi for the complete mathematical formulation the reader is referred to Reference 5.

Example of fiberous reinforced beam analysis as discussed by Henager and Doherty (5) with some revisions:

$$\sigma_f = 2 \ \tau_d \ F_{be} \ \ell/d_f$$

$$\sigma_t = 1.28 \ \ell/d_f \ p \ F_{be}$$

The tensile strain in the steel is calculated by the use of similar triangles on the strain diagram in Fig. 4.

$$\varepsilon_s = \sigma_f/E_s$$

$$e = \frac{\varepsilon_s + .003}{.003} \ c$$

Solving for c,

$$c = (A_s f_y + \sigma_t \ bD)/(.85 \ f_c' \ b \ \beta_1 + \sigma_t \ b \ \frac{e}{c})$$

Where

$$a = \beta_1 \ c \quad \text{ACI-318-71 Definition}$$

And referring to Fig. 4

$$C = T_{f_c} + T_{R_b}$$

$$T_{R_b} = A_s f_y$$

$$T_{fc} = \sigma_t \ b \ (D-e)$$

The total theoretical moment strength is

$$M_T = A_s f_y \ (d - a/2) + \sigma_t \ b \ (D-e)(\frac{D}{2} + \frac{e}{2} - \frac{a}{2})$$

The equations for calculating the tensile stress developed in fibers during pullout σ_f, and the tensile stress in fiberous

concrete, σ_t, are formulas developed by Henager and Doherty (5) through emperical methods. Using these equations and experimental analysis they obtained the following results shown in Tables 4 and 5 (5).

TABLE 4 - COMPARISON OF CALCULATED MOMENTS AND TEST MOMENTS

Beam description (dimensions, in inches) (1)	Fiber aspect ratio, l/d_f (2)	Bond efficiency factor, F_{be} (3)	Test moment, in foot-pounds (4)	Calculated moment, in foot-pounds (5)	Ratio, M_{calc}/M_{test} (6)
Example beam--1.22% of 0.025-in. x 2-1/4-in. smooth fibers[a]	90	1.0	38,360	38,433	1.002
8-in. x 12-in. beam--1.51% of 0.020-in. x 1-1/2-in. Duoform fibers[a]	75	1.2	39,460	39,730	1.007
8-in. x 12-in. beam--1.36% of 0.014-in. x 1-5/8-in. crimped-end fibers[a]	125	1.0	40,830	40,760	0.998
4-in. x 6-in. beam--1.47% of 0.010-in. x 1-in. fibers[b]	100	1.0	3,143	3,056	0.972
4-in. x 6-in. beam--0.61% of 0.010-in. x 1-in. fibers[b]	60	1.0	4,763	4,981	1.046
4-in. x 6-in. beam--1.78% of 0.010-in. x 1-in. fibers[b]	60	1.0	5,000	5,314	1.063

Source: Henager, Charles H. and Doherty, Terrence J., "Analysis of Reinforced Fiberous Concrete Beams," Journal of the Structural Division, ASCE, Vol. 102, No. ST1, Jan. 1976, pp. 177-188.

[a]Tested in this experimental program.
[b]Tested in Ref. 5.
Note: 1 in. = 25.4 mm; 1 ft-lb = 1.356 N·m

TABLE 5 - BEAM LOADS AND MOMENTS AT ULTIMATE STRENGTH

Beam description (1)	Ultimate load, in pounds (2)	Ultimate moment, in foot-pounds (3)
Conventional reinforced beam	12,000	32,350
Reinforced fibrous, 2-1/4-in. x 0.025-in. fibers	14,600	38,360
Reinforced fibrous, 1-1/2-in. x 0.020-in. fibers	15,000	39,460
Reinforced fibrous, 1-5/8-in. x 0.014-in. fibers	15,500	40,830

Note: 1 in. = 25.4 mm; 1 lbf = 4.45 N; 1 ft-lb = 1.356 N·m.

Source: Henager, Charles H. and Doherty, Terrence J., "Analysis of Reinforced Fiberous Concrete Beams," Journal of the Structural Division, ASCE, Vol. 102, No. STI, Jan. 1976, pp. 177-188.

Numerical Analysis Example

Determine the maximum moment capacity of a fiber reinforced concrete beam in addition to normal tensile reinforcement.

$$b = 8" \quad D = 12" \quad d = 9.75"$$

$$A_s = 2 \; \#6 = .88 \text{ sq. in.}$$

Fibers: Dramix registered trademark of N. V. Bekaert SA

Deformed fibers = 1.18" length, .016" diameter

$$\ell/d_f = 73.75$$

Percent volume fibers; $p = 2.0\%$

$$F_{be} = 1.2 \text{ deformed fiber}$$

$$\tau_d = 380 \text{ psi}$$

$$f_c' = 6000 \text{ psi}$$

$$f_y = 50,000 \text{ psi}$$

$$\beta_1 = .75$$

$$\sigma_f = \frac{2 \; \tau_d \; F_{be} \; \ell}{d_f}$$

$$= \frac{2(380)(1.2)1.18}{.016}$$

$$= 67,260 \text{ psi}$$

$$\sigma_t = 1.28 \; \frac{\ell}{d_r} \; p \; F_{be}$$

$$= 1.28 \; (\frac{1.18}{.016})(2.0)1.2$$

$$= 226.56 \text{ psi}$$

$$\varepsilon_s = \frac{\sigma_f}{E_s}$$

$$\varepsilon_s = \frac{67,260}{29 \times 10^6}$$

$$= .0023$$

$$e = \frac{\varepsilon_s + .003}{.003} c$$

$$= \frac{.0023 + .003}{.003} c$$

$$= 1.77 \, c$$

$$c = \frac{A_s f_y + \sigma_t \, b \, D}{.85 \, f'_c \, b \, \beta_1 + \sigma_t \, b \, \frac{e}{c}}$$

$$= \frac{(.88) \, 50,000 + 226.56 \, (8)(12)}{.85 \, (6000)(8) \, .75 + 226.56 \, (8)(1.77)}$$

$$c = 1.945$$

$$a = .75 \, c$$

$$= .75 \, (1.945)$$

$$= 1.459$$

$$e = 1.77 \, c$$

$$= 1.77 \, (1.945)$$

$$= 3.443$$

$$M_T = A_s f_y \left(d - \frac{a}{2} \right) + \sigma_t \, b \, (D-e) \left(\frac{D}{2} + \frac{e}{2} - \frac{a}{2} \right)$$

$$= .88 \times 50,000 \times \left(9.75 - \frac{1.459}{2} \right) + 226.56 \times 8 \times (12 - 3.443) \times$$

$$\left(\frac{12}{2} + \frac{3.443}{2} - \frac{1.459}{2} \right)$$

$$= 396,902 + 108,442$$

$$= 505,343 \text{ "-\#}$$

$$= 42,112 \text{ ft-\#}$$

$$= 42.1 \text{ K-ft.}$$

The same beam is analyzed but with no fiber reinforcement.

$$b = 8" \quad D = 12" \quad d = 9.75"$$

$$A_s = 2 \text{ #6 Bars } .88 \text{ sq. in.}$$

$$f_y = 50,000 \text{ psi}, \quad f_c' = 6,000 \text{ psi}$$

U.S.D. Method

p = steel ratio

$$p = A_s/bd$$

$$= .88/8 \ (9.75)$$

$$= .0113 > \frac{200}{f_y} < p_{max}$$

$$a = \frac{A_s f_y}{.85 \ f_c' \ b}$$

$$= \frac{p \ f_y \ d}{.85 \ f_c'}$$

$$= \frac{(.0113)(50,000)(9.25)}{(.85)(6,000)}$$

$$= 1.08"$$

$$M_T = A_s f_y \ (d - \frac{a}{2})$$

$$= .88 \times 50,000 \times (9.75 - \frac{1.08}{2})$$

$$= 405,240 \ \#"$$

$$= 33,770 \ \#'$$

$$= 33.77 \ \text{K-ft.}$$

Fiber reinforced concrete presents a variety of problems in developing an actual design procedure. In normal reinforced concrete the unknowns are the area of steel, A_s; the width of section, b; the depth to the centroid of the steel reinforcing, d; whereupon an additional cover usually 3 in. is provided for the steel, determining the overall beam depth, D. However, for fiberous concrete there are additional parameters of fiber volume percentage, p; fiber dimensions, d_f, ℓ; and the type of fiber used, deformed or straight.

The number of parameters involved suggests a design procedure of trial and correction. A suggested procedure would be to design a normal reinforced beam then either reduce the physical dimensions, or the area of steel and analyze as though using fiberous concrete assuming fiber type, size, and volume percentages. This is a more time consuming method, however, in situations where space is at a premium, fiberous concrete may provide a unique solution.

An economic evaluation of the use of steel fibers is outside the scope of this report. However, it is appropriate to present an approximate cost of steel fibers. According to the Bekaert Steel Wire Corporation the current price delivered to Manhattan, Kansas is around $47.50 per 100 lbs., depending on the type of steel fiber. The price is anticipated to decrease when fiber production begins within the United States (3).

CHAPTER 6 - CONCLUSION

The addition of randomly dispersed short discontinuous steel fibers to standard concrete mixtures provides a noticeable improvement of material properties. The steel fiber reinforcement improves concrete's resistance to crack propagation and impact damage considerably. The compression and flexure strength is increased, the actual amount dependent on the physical shape of the fibers, volume percentage and fiber aspect ratio. The effect of fibers on the mechanical properties is also dependent on the actual concrete mix materials. The greatest advantage for practical application is realized by the use of 3/8 inch (9.53 mm) crushed aggregate with a sand cement mortar.

The method of analysis presented has been verified by experimental data by Henager and Doherty (5). They established that the use of fiberous concrete would increase the flexural strength in the order of 25 percent. The analysis presented in this report showed a moment capacity increase of a simple supported beam of approximately 25 percent.

Steel fiber reinforced concrete is not appropriate for all concrete structures. However, the addition of steel fibers to concrete provides a greater resistance to impact loads, crack propagation and an increase in structural strength.

The volume of material available on fiber reinforced concrete has increased in the last ten years. Although there has been a good deal of research, the knowledge of fiberous

concrete is still in an embryonic state. There are a number of areas that could be investigated further.

Standard procedures should be developed to insure results that can be easily compared with respect to the data on physical properties. This would help in the development of new design methods or proper modifications of existing design methods. A standardization of mix types and properties would be necessary for job specifications.

A clearer understanding of the fiber bond forces, and crack control characteristics as related to freeze-thaw exposure also needs to be examined. An indepth economic analysis would provide the design engineer with necessary information to evaluate the usefulness of the addition of steel fibers to reinforced concrete structural members.

APPENDIX A

DEFINITIONS OF TERMS

Following are the definitions of terms for the illustration depicting design assumptions:

a = depth of rectangular stress block

b = width of beam

c = distance from extreme compression fiber to neutral axis

d = distance from extreme compression fiber to centroid of tensile bar reinforcement

e = distance from extreme compression fiber to top of tensile stress block of fibrous concrete

ε_s = tensile strain in steel

ε_c = compressive strain in concrete

f'_c = compressive strength in concrete

f_y = yield strength of reinforcing bar steel

A_s = area of tension bar reinforcement

C = compressive force

D = total depth of beam

σ_t = tensile stress in fibrous concrete (psi)

E_s = modulus of elasticity of steel

$T_{f_c} = \sigma_t\, b(D-e)$ = tensile force of fibrous concrete

$T_{r_b} = A_s f_y$ = tensile force of bar reinforcement

τ_d = 380 psi as found by Norman and Shah the dynamic bond stress (11)

d_f = fiber diameter, or equivalent diameter

ℓ = length of fiber

F_{be} = bond efficiency factor

p = percentage by volume of fibers

σ_f = tensile stress developed in fiber during pullout (psi)

BIBLIOGRAPHY

1) Batson, G., Ball, C., Bailey, L., Landers, E., and Hooks, J., "Flexural Fatigue Strength of Steel Fiber Reinforced Concrete Beams," ACI Journal, Proceedings, Vol. 69, No. 11, Nov. 1972, pp. 673-677.

2) Batson, G., Jenkins, E., and Spatney, R., "Steel Fibers as Steel Reinforcement in Beams," ACI Journal, Proceedings, Vol. 69, No. 10, Oct. 1972, pp. 640-644.

3) Bekaert Steel Wire Corporation, 245 Park Avenue, New York, N.Y., 1977.

4) Cox, Frank B., Crack-Arrest Techniques in Reinforced Concrete Structural Elements, Technical Report C-74-7, U. S. Army Engineers Waterways Experiment Station, Vicksburg, Miss., Nov. 1974.

5) Henager, Charles H. and Doherty, Terrence J., "Analysis of Reinforced Fiberous Concrete Beams," Journal of the Structural Division, ASCE, Vol. 102, No. ST1, Jan. 1976, pp. 177-188.

6) Hoff, George C., "Use of Fiber-Reinforced Concrete in Hydraulic Structures and Marine Environments," Miscellaneous Paper C-75-4, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., June 1975.

7) Johnston, Colin D., "Steel Fiber Reinforced Mortar and Concrete: A Review of Mechanical Properties," Paper No. 7, Special Publication No. SP-44, ACI, 1974, pp. 127-142.

8) Krenchel, Herbert, "Fiber Reinforced Brittle Matrix Materials," Paper No. 3, Special Publication No. SP-44, ACI, 1974, pp. 45-79.

9) Lankard, David R. and Walker, Alvin J., "Pavement and Bridge Deck Overlays With Steel Fibrous Concrete," Paper No. 22, Special Publication No. SP-44, ACI, 1974, pp. 375-391.

10) Luke, Clare E., Waterhouse, Bruce L., and Wooldridge, James F., "Steel Fiber Reinforced Concrete Optimization and Applications," Paper No. 23, Special Publication No. SP-44, ACI, 1974, pp. 393-413.

11) Naaman, Antoine E. and Shah, Surendre P., "Pull-out Mechanism in Steel Fiber-Reinforced Concrete," Journal of the Structural Division, ASCE, Vol. 102, No. ST-8, Aug. 1976, pp. 1537-1548.

12) Neville, A. M., *Properties of Concrete*, John Wiley and Sons, New York, New York, 1975.

13) O'Leary, David, Dave, Nalin, and Saunders, John, "Steel Fibers in Partially Prestressed Composite Concrete Beams," Paper No. 27, Special Publication No. SP-44, *ACI*, 1974, pp. 477-495.

14) Ramey, Melvin R. and McCabe, Patrick J., "Compression Fatigue of Fiber Reinforced Concrete," *Journal* of the Engineering Mechanics Division, ASCE, Vol. 100, No. EM2, April 1974, pp. 139-149.

15) Romualdi, J. P., Ramey, M., and Sandry, S. C., "Prevention and Control of Cracking by Use of Short Random Fibers," Paper No. 10, Special Publication No. 20, *ACI*, 1968, pp. 197-203.

16) Sather, William R., "Fiberous Concrete Field Batching Sequences," *ACI Journal*, Proceedings, Vol. 71, No. 10, Oct. 1974, pp. 504-505.

17) Shah, Surendra P., "New Reinforcing Materials in Concrete," *ACI Journal*, Proceedings, Vol. 71, May 1974, pp. 257-262.

18) Shah, Surendra P. and Rangan, B. V., "Effects of Reinforcements on Ductility of Concrete," *Journal* of the Structural Division, ASCE, Vol. 96, No. ST-6, June 1970, pp. 1167-1184.

19) Shah, Surendra P. and Rangan, B. V., "Fiber Reinforced Concrete Properties," *ACI Journal*, Proceedings, Vol. 68, No. 2, Feb. 1971, pp. 126-135.

20) Snyder, M. J. and Lamrard, D. R., "Factors Affecting the Flexural Strength of Steel Fiberous Concrete," *ACI Journal*, Proceedings, Vol. 69, No. 2, Feb. 1972, pp. 96-100.

21) "State of the Art Report on Fiber Reinforced Concrete," *ACI Journal*, Committee 544, Proceedings, Vol. 70, No. 11, Nov. 1973, pp. 729-744.

22) Swamy, R. N. and Kent, Brian, "Some Practical Structural Applications of Steel Fiber Reinforced Concrete," Paper No. 18, Special Publication No. SP-44, 1974, pp. 317-336.

23) Swamy, R. N., Mangat, P. S., and Rao, C. V. S. K., "The Mechanics of Fiber Reinforcement of Cement Matrices," Paper No. 1, Special Publication No. SP-44, ACI, 1974, pp. 1-28.

24) Williamson, Gilbert R., "The Effect of Steel Fibers on the Compressive Strength of Concrete," Paper No. 11, Special Publication No. SP-44, <u>ACI</u>, 1974, pp. 195-207.

25) Winter, George and Nilson, Arthur H., <u>Design of Concrete Structures</u>, McGraw-Hill, New York, 1972.

A STUDY OF R/C BEAMS ADDITIONALLY
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by

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B.S., Kansas State University, 1976

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AN ABSTRACT OF A MASTER'S REPORT

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requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

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ABSTRACT

The purpose of this report is to provide a brief summary describing steel fiber reinforced concrete. This report contains the historical development of fiber reinforced concrete, the modern application, mix procedure and analysis and design procedure of steel fibers in conjunction with normal concrete reinforcement.