TECHNICAL NOTES

U.S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

STATE OFFICE STILLWATER, OKLAHOMA 74074

ENGINEERING TECHNICAL REFERENCES FOR IN SERVICE USE ONLY

January 26, 1993

Engineering OK-14

Re: Fiber Reinforced Concrete

This technical note provides guidance on the characteristics and use of fiber reinforced concrete (FRC). It also includes a copy of William H. Erion's paper on "Fiber Reinforced Concrete Slabs on Grade", dated May 1992.

FRC is a non-structural shrinkage reinforcement and is not a replacement for primary or structural reinforcement members. The principal of adding fibers to concrete is similar to adding straw to mud bricks or animal hair to plaster. Some known effects of the use of fiber in FRC include:

Advantages:

- Helps reduce damage due to impact (shatter) and abrasion. (Use of equipment such as front end loader shows reduced chipping).

- Reduces size of shrinkage cracks which reduces random planes of weakness. (Concrete may crack just as much, but cracks are very fine or hairline type).

- Helps control plastic settlement and shrinkage. (Fibers act as a cohesive element, binding the mix together).

- Reduces slump. (May cause contractor to want to add more water to mix which would reduce concrete strength. Instead, recommend he use a superplasticizer or a low range water reducer).

- Increases cohesiveness which decreases "bleeding" of water from concrete.

Disadvantages:

- Cannot control cracking due to external stress.

- Cannot control crack width.

- Cannot provide shear friction transfer across cracks.

- Does not allow increased joint spacing over non-reinforced concrete.

- Does not decrease slab thickness over non-reinforced concrete.

- Does not substitute for welded wire fabric (WWF) or reinforcing steel that is needed for load carrying components in concrete.

Only polypropylene fibers should be used. (Fiberglass fibers are presently not recommended for slabs on grade.) The polypropylene fibers are chemically inert and nonabsorptive. They do not sink or float. Normal use is 1.5 pounds of fibers in a water soluble bag per cubic yard of concrete. The fibers are generally 3/4 inch to 1 1/2 - inch lengths and twisted to insure no balling or segregation. The longer lengths are preferred as they provide a better mechanical bond and less chance to pull out under stress.

Conditions which must be met for use of FRC include:

- Use right design mix.
- Do not add more water to increase slump and improve workability.
- Use regular contraction joints.
- Adequate drainage.
- Good foundation.
- Do not use tined rake to move concrete.
- Cure properly.

Fiber reinforced concrete may be used for slab type pours on well drained sites with a firm foundation. FRC may not be approved for load carrying systems, locations with soft foundations or on highly plastic clay soils. Contraction joints should be installed on 12 feet spacing for 4-inch thick slabs and 15 feet spacing for 5-inch thick slabs. Sawed joints should be to a depth of approximately one-fourth of the slab thickness. Also, joints may be made with an appropriate grooving tool or by use of keyed joints.

The following cautions are noted for finishing FRC concrete:

- Wait until all water is gone off the top of the concrete before beginning the troweling operation. Use steel or magnesium trowels or floats. When hand troweling, trowel only in one direction so that surface fibers are not raised up which result in a fuzzy surface finish.

- Do not use tined garden rakes to move or place concrete as the tines will disrupt the three-dimensional fibrous distribution.

- Use approved 7-day concrete cure.

/s/ Larry W. Caldwell
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State Conservation Engineer

DIST: Area Offices, Project Offices, All Engineers

FIBER REINFORCED CONCRETE SLABS ON GRADE

William H. Erion **May, 1992**

Introduction

A literature search was undertaken to determine the acceptability of, and design parameters for, Fiber Reinforced Concrete (FRC) in the construction of slabs on grade. Initially this study was focused on the use of this composite material in agricultural waste structures at the request of Alabama SCS. This report summarizes the findings of these studies. These slabs are considered to be "nonstructural" concrete slabs in that tensile reinforcement for flexural capacity is not incorporated and the flexural resistance is provided by the tensile (and compressive) strength of the concrete composite itself. In order to be considered acceptable, the FRC slab must be competitive with a slab on grade containing "usual" amounts of welded wire mesh (WWM), not only from an economic standpoint but also with respect to durability, load carrying capacity, serviceability, and constructibility. The minimum (secondary) reinforcement for non structural concrete slabs in accord with CPS 313 is 6x6- 10x10ga WWM which is considered usual reinforcement.

Discussion

As a benchmark for comparison, the load carrying capacity, durability and serviceability of the slab containing welded wire mesh will be discussed.

Slab with Welded Wire Mesh

The cross-sectional area of steel of typical welded wire mesh (WWM), located at, or above, mid-height of a slab, is insufficient to provide flexural reinforcement to a slab of usual thickness. The action of the WWM, sometimes referred to as "distribution steel," is primarily related to holding cracks together that develop in the concrete. As shown in figure 1, load carrying capacity of a typical slab containing WWM is the same as that of a plain concrete slab with equivalent thickness and strength. Thickness design is thus based on loading and subgrade conditions using the appropriate plain concrete design approach.

The durability of concrete is related to many factors, and a given concrete can be more or less durable depending on the environment to which it is subjected. The resistance to freeze-thaw action, usually the most damaging environmental factor, is effectively provided by air entrainment of the concrete paste, and the presence or absence of reinforcement has little effect. The permeability of concrete often has a significant effect on durability, as more impermeable concrete is less likely to transmit damaging fluid-borne constituents through the concrete slab. Permeability is a function of the porosity of the concrete paste and aggregates and the frequency of open cracks. Other factors being equal, the presence of cracks which are open to a sufficient degree to pass water results in an increase in permeability. If cracks are closed so tightly that water cannot pass through them, their presence does not contribute to the permeability of the concrete. Since the presence or absence of WWM has no effect on the porosity of the aggregate or paste, the focus is on cracking of the concrete. A discussion of the causes of cracking and control of crack opening afforded by WWM is in order. At the risk of oversimplification, it can be stated that a crack can occur whenever a tensile stress exceeds the tensile strength of the concrete at that location. This stress is normally due to the restraint of strain from volumetric change or imposed loads.

Cracking of concrete begins soon after it is placed (6). Plastic settlement cracks and plastic shrinkage cracks form when concrete is from 1 to 6 hours old. The plastic settlement cracks result from differential consolidation due to variation in thickness or depth of the concrete, embedded items, and rebar near the surface. Bleeding, which is the settlement of solid particles in concrete leaving water at the top, is also a form of plastic settlement. Plastic shrinkage results from capillary forces and changes in moisture content of plastic mortar similar to shrinkage observed in clay upon drying. This cracking is particularly severe when moisture evaporates from the surface faster than it can be replaced in the first several hours after placement. Plastic shrinkage and settlement cracking occurs when the concrete mortar has set but has little strength. Initially the mortar, in a plastic-liquid state, possesses no resistance to strains imposed by drying shrinkage or differential consolidation, thus no cracking results. A point is reached at later stages, with time and strength gain, where sufficient strength has been attained to resist cracking by the stresses resulting from these strains. There exists, therefore, in plain concrete a period of time during the first few hours after placement when the stress due to shrinkage and consolidation exceeds the tensile strength resulting in the formation of cracks. These stresses are not resisted by WWM or any other steel bar reinforcement in the cross section. The plastic shrinkage and settlement cracks are micro scale, invisible or barely visible to the naked eye, but are theorized to be the weak point where macro scale cracking from other sources is initiated.

Early thermal contraction resulting from volume change as the heat of hydration dissipates can cause cracking in massive concrete but is not usually a significant factor in slabs on grade when proper curing techniques are employed.

External loads produce flexural strain with resultant cracking in the tensile portion of the cross section. As stated above, WWM does not provide reinforcement to resist flexural stresses induced by external loadings. The WWM aids in keeping the flexural cracks together at the expense of smaller more closely spaced cracks.

Long term seasonal, diurnal, and extreme temperature changes result in volume changes which produce cracking. Shrinkage, due to the loss of pore water is typically a long term volume change effect contributing to cracking. The volume changes due to temperature and long term shrinkage effects produce tensile stresses of such a magnitude as to require steel bar reinforcement on the order of 0.2 to 0.3 percent of the gross cross-sectional area of the concrete for resistance. Experience with plain concrete has indicated "control joints," which are grooves cut or formed part way through the slab, are necessary. When spaced at intervals in feet of 2 to 3 times the slab thickness in inches (5, 1), they provide a plane where strain due to temperature and shrinkage is relieved and random cracking is greatly reduced. The current recommendation of Portland Cement Association is that control joint spacing for control of temperature and shrinkage is required at the same intervals in slabs with WWM as for plain concrete, since typical WWM provides only a small fraction of the required steel area of 0.2 to 0.3 percent concrete area. Recommendations that the control joint spacing be based on a "subgrade drag" approach are also made (1) which may result in greater control joint spacing.

A concrete slab with some cracks remains serviceable for most purposes if shear on the slab can be transferred across the crack interface. This can be accomplished if the faces of the cracks remain sufficiently close together that shear is transferred across by friction and aggregate interlock. The WWM provides limited "doweling" effect and the tensile strength of the wire passing through the crack holds the crack faces in intimate contact, at least until forces are great enough to cause yielding of the steel wire (4). In a plain concrete slab this crack control mechanism is not available; although plain concrete slabs with adequately spaced control joints on uniform foundations with good placing and curing practices can remain fully serviceable. The optimum location of WWM is near the top of the slab 2 inches below the surface, but the unfortunate reality in practice is that it often ends up at the underside of the slab on the subgrade where its benefits are lost.

Slab with FRC

Polymeric synthetic, steel and glass fibers are used as reinforcement in cement concrete materials in various volume percentages for particular benefits. In cast in place concrete construction polypropylene and steel are the primary fibers used. The fibers can be introduced into the concrete at the batch plant or into the truck mixer at the site.

The most commonly used fiber for FRC is fibrillated polypropylene 1/2 to 2 inches in length. Several manufacturers sell the fibers prepackaged for usual dosage (0.1% by volume) per cubic yard for introduction in the mixer. These fibers are chemically inert and hydrophobic thus do not corrode or absorb water. Polypropylene does not bond well with concrete but in the fibrillated form has a large surface area and some mechanical anchorage to facilitate bonding with the cement matrix.

The fiber with the longest documented history of use in FRC is steel. Steel fibers have been used extensively in the decades of the 1960's and 1970's. Steel fiber reinforced concrete (SFRC) use has been well documented for industrial floor slab use in the 1980's (3). Steel fiber has also been used in stilling basin slabs as well as in highway and airport pavements. SFRC has superior resistance to abrasion as compared to other fiber reinforcement. Steel fibers are readily available from many manufacturers and come in typical lengths from 1/2 to 2 inches with aspect ratio (length/diameter) between 45 and 63 being common. Steel fibers can be obtained in both straight and deformed types and in both carbon and stainless grades. Low dosages of steel fibers that can be mixed easily in the field, have been shown to increase strength properties such as modulus of rupture slightly (approx. 10%) over plain concrete and FRC with polypropylene fibers. The disadvantages of steel fiber are that the cost of the fibers is greater than that of polypropylene fibers and that surface exposed fibers can corrode, are unsightly and can be injurious to foot traffic.

Glass fiber reinforced concrete has been used principally in building products such as building panels and is occasionally proposed for cast in place concrete construction. There is some question about the long term strength and durability of glass fiber reinforced concrete (GFRC). The glass fibers are reported to be subject to alkali attack when present in the concrete. Although alkali resistant glass fibers are presently available on the market, until more studies are done, glass fibers are not recommended for slabs on grade.

Fibers in the concrete mix have been shown to provide sufficient closely spaced and randomly oriented reinforcement to prevent cracking by plastic shrinkage and settlement during the early life of the concrete as demonstrated in fig.2. This is not available in plain concrete or concrete reinforced with WWM. In addition fibers decrease the slump and increase "cohesiveness" of the mix, reducing the tendency for bleeding.

Fibers provide little or no resistance to flexural stresses in the dosages used in cast in place construction. Some research has indicated nominal (about 10% for steel) tensile strength increases when compared to plain concrete while other reports indicate no increase.

With the control of plastic shrinkage and settlement cracking and some control of other forms of concrete cracking FRC has the potential for lower permeability than otherwise comparable plain concrete or concrete with WWM. In the literature FRC has been linked to reduced concrete permeability (Panarese).

In the volume percentages of polypropylene fibers common to concrete construction the fibers offer very little resistance to crack widening once the crack has formed. Considering the strength and number of fibers passing through a crack sufficient resistance force is not available to resist the volume change force causing the crack (Schupack and Stanley). Steel fibers can provide better crack control once the crack has formed than the polypropylene fibers. It can be argued that the presence of fibers in the concrete controlling the early shrinkage cracking results in a concrete mass free of random planes of weakness and thus less likely to crack when subjected to subsequent flexural and thermal stress. It can also be stated that measures can be taken to prevent or minimize the evaporation of moisture from the surface faster than it can be replaced, negating the need for fibers for controlling plastic shrinkage. These measures are easy to implement in a cool, moist and calm environment, but almost impossible to accomplish under hot, dry and windy conditions.

Control joint spacing recommendations for FRC *in* slabs on grade are the same as those cited above for plain concrete. Good compaction of the concrete matrix is necessary to realize the benefits of the fibers.

It has been demonstrated that FRC has a greater toughness or ductility than plain or conventionally reinforced concrete. This property enables the FRC to be more fatigue resistant when subjected to repeated loadings and to be more resistant to shatter from impact loadings (1, others) . Studies have also shown the FRC to be more resistant to abrasion than plain or bar reinforced concrete (1). The impact and abrasion resistance features are of value in slabs on which small equipment is operated to move and scoop up material on the slab such as the au waste facilities.

From the economic standpoint the material and placement cost for laying the WWM readily offsets the cost of the fibers.

It is reported the finishing of FRC requires somewhat different techniques but once learned is no more difficult than that required for concrete slabs with WWM. The decreased slump of FRC leads to a tendency to add water at the time of placement which must be avoided. The decreased slump of FRC can also be advantageous when placing concrete on a steep slope as the tendency to flow downhill is reduced. Constructibility using FRC is comparable to, if not easier than, slabs on grade using WWM.

As the use of FRC has increased in recent years discussions in the construction literature have appeared on the validity of replacement of WWM in slabs on grade with fibers or on the suitability of FRC use in applications where concrete with WWM has traditionally been the standard. These discussions are generally biased to support the position of the industry segment the discusser represents. However, one report citing case studies of synthetic FRC use (4) provides a factual look at both favorable and unfavorable FRC applications with some discussion of WWM use.

Conclusion

It is evident that the secondary reinforcement action of fibers and WWM are different, therefore the question is not whether FRC is a replacement for WWM in concrete slabs on grade. "Are there conditions where FRC can provide an equally serviceable (or more serviceable) slab at a cost competitive with a slab with WWM?" is the more pertinent question. From a serviceability standpoint, toughness with impact resistance is attributed to the FRC while better control of crack width and transfer of shear across cracks is afforded by the WWM.

The Portland Cement Association and others (4) propose that no reinforcement of any kind is needed for non structural slabs given a sound, uniform foundation, properly designed and supplied mix, good placing, finishing and curing practices and properly designed and installed control joints. Where the quality of some of these items is borderline, the use of properly installed WWM or FRC may increase long term performance in given situations. The conditions under which most of the ag waste facilities are to be constructed are likely to be less than ideal. The potential for non uniform subgrade, placement by inexperienced personnel, unavailability of consistently high quality concrete, poor weather and lack of inspection can result in a substandard end product. Based on more site specific information the designer, with an understanding of the capacities and limitations presented, can select the slab secondary reinforcing system to best meet the project requirements.

In summary, FRC can control plastic settlement and shrinkage cracking, provide impact and shatter resistance, and be easily placed on steep slopes. FRC can not control cracking resulting from external stress, control crack width, provide shear friction transfer of shear across cracks, allow for increased control joint spacing or decreased slab thickness over plain concrete, or provide increased flexural strength. WWM can provide for the control and distribution of cracking due to external stress, provide limited doweling effect and shear friction to transfer shear across cracks, and allow increased control joint spacing for some design methods when compared to plain concrete. WWM does not provide increased flexural strength, control plastic settlement and shrinkage cracking, or permit decrease in slab thickness when compared to plain concrete.

It is apparent with proper design, foundation preparation, quality concrete, proper placement and curing techniques an economical, durable, serviceable slab can be obtained using WWM, FRC or even plain concrete.

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(4) Schupack, Morris, and Stanley, William R., "Seven Case Studies of Synthetic Fiber Reinforced Slabs", Concrete International, Vol 14, No. 2, Feb 1992, American Concrete Institute, Detroit, MI

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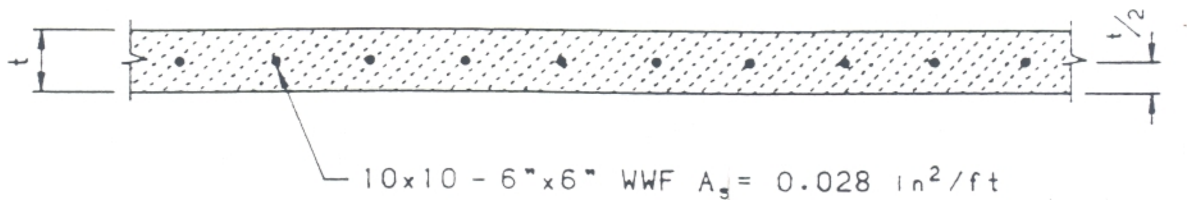
FLEXURE FOR REINFORCED AND PLAIN CONCRETE SECTIONS



A. Moment capacity reinforced section, assume design steel strength = f_s = 40 ksi

$$M = A_s f_s jd = 0.028 \quad (40\ ksi)\ (7/8)\ (t/2) = 0.49t \text{ in-k/ft width.}$$

B. Moment capacity plain concrete. Assume design tensile strength = f_t = 300 psl

$$M = f_t \ I/C = \frac{0.300\ ksi\ (12'')(t)^3}{12\ (t/2)} = 0.6t^2 \text{ in- k/ft width.}$$

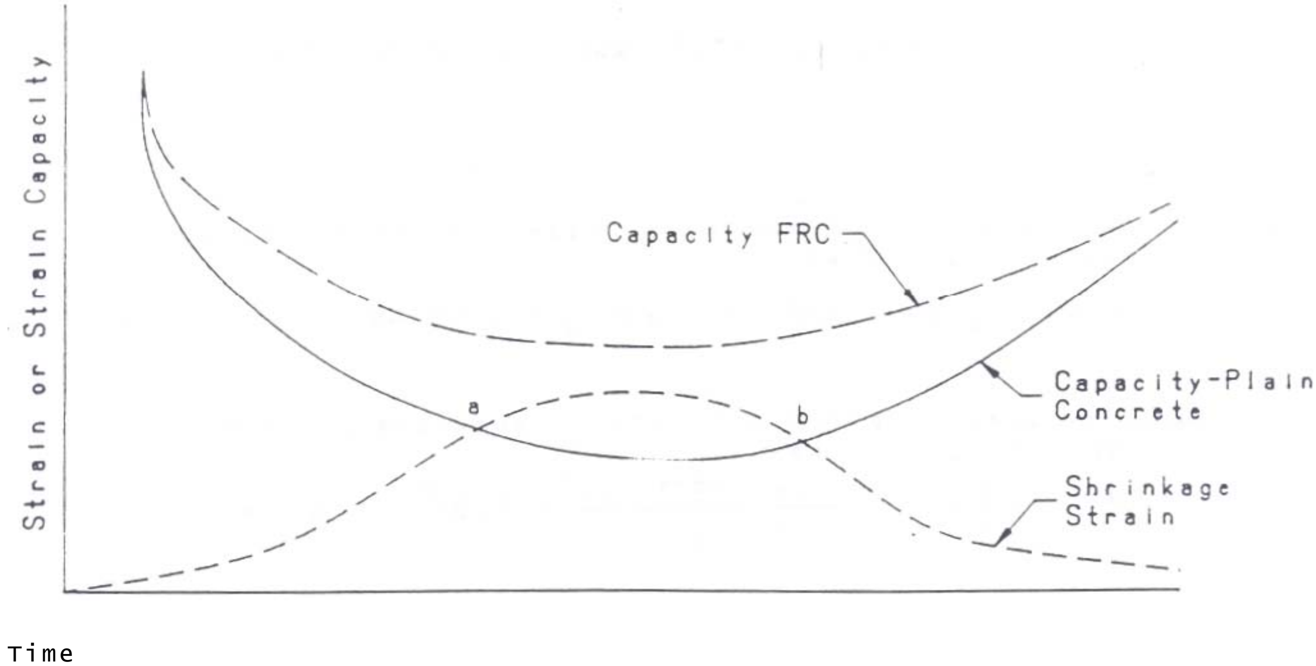
Moment Capacity (in- k/ft width)

thickness t(in)	reinforced section	Plain Concrete
4	2.0	9.6
5	2.5	15.0
6	3.0	21.6

Since the plain concrete section must fall in flexural tension before the load can be carried in flexure by the reinforcement the plain concrete capacity governs.

FIGURE 1

PLASTIC SHRINKAGE



Between point a and b the shrinkage strain exceeds the strain capacity of the plain concrete resulting in plastic shrinkage cracking while the strain capacity of the FRC exceeds the shrinkage strain resulting in no plastic shrinkage cracking.

<u>FIGURE 2</u>