PERSONAL PROJECT APPLICATIONS OF FIBER REINFORCED CONCRETE – PAST, PRESENT, AND FUTURE

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Abstract:

Philosophical concepts are discussed about fiber reinforced concrete (FRC) and some of the prevailing issues for consideration in this business. Basic beliefs about concrete are challenged, considered, and reflected upon with significant events identified as moving the market. Personal projects are identified as key highlights about the benefits of FRC.

Keywords: : fiber reinforced concrete, FRC, synthetic FRC, theoretical mechanics, projects

1 Introduction

A good design for construction has to do with best fit, or conformance to the existing conditions, and results in a desired outcome by following a generally understood set of activities to establish some constraints and parameters. For a designer, this begins with determining the customer's softer issues such as needs, wants, and desires. From this then, hard measurable criteria are established to meet the project cost, schedule, and performance. The risk before the project begins is getting enough information about these issues without dictating to the customer the designer's preferences. When the materials have been chosen and design is complete, the information is usually transmitted to construction by contract (legal verbiage about relationship conduct) including specifications (criteria generally and specifically about materials and execution issues on pages, copies, cut sheets, etc.) and graphical representations (drawings, sketches, etc.) of the work to be done. By definition, the amount of these documents is the level of quality control the designer wants for the project. Further risks associated with the construction have to do with labor, equipment, materials, weather, and then also incorporating and ensuring the designer's intent.

The benefit associated with this entire process is that it can be repeated for other projects. Further benefits may also include additional customers, making a profit, and self-satisfaction of having done that work.

A person's philosophical understanding coupled with their belief systems will drive the process described above and just about anything else in his life. Further, a person's education and experience significantly influences this design construction process. The use of fiber reinforced concrete seems no less challenging to consider with a philosophical approach. Basically all education follows a similar axiom: if the philosophy is correct,

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then the rest of the details will generally follow, and even though a little off, are expected to have little consequence as the truth is robust enough for different understandings.

2 Past FRC

ACI Committee 544 Fiber Reinforced Concrete (FRC) cites in the 1966 State of the Art report that the concept of straw in mud from Biblical times seems tied to fiber reinforced concrete. Fig. 1 shows a photograph taken in Egypt in the 1990's of a straw and mud wall that was reported to the photographer as near 2,000 years old. Further, some comparisons of the 1966 and 1996 State of the Art reports from 544 FRC Committee show that nothing changes, although some of the issues will always be of concern. Basically then, nothing and yet everything changes.

Fig.1 Straw and mud personal photograph from Egypt in the 1990's

Maybe the axioms we are trying to work with are that matter cannot be created or destroyed. FRC was there years ago and is still here, so what has changed? Probably what changed are performance, schedule, and cost that bring definition to a project. Hence, FRC of years ago is probably the same in composition as today, but how FRC has been used in projects by changing the performance, schedule, and cost is where the innovation and change can be discussed. Hence, the great pyramids as an example could be built today, but the discussion would be about performance (would the new behave the same), schedule (would the new last as long and how long to build), and the costs would be significantly higher (is it worth it).

The perspective then will be to define fiber reinforced concrete and projects that use FRC according to performance, schedule, and cost. My perspective is taken from my education and various job roles and responsibilities: graduate student testing FRC, project engineer, design engineer, industrial project manager, senior testing firm engineer, product developer, technical service, consultant, and small contractor.

3 FRC Theoretical mechanics

Fig. 2 and 3 show the failure modes and behavior of brittle concrete cylinders in compression. Fig. 3 the cylinder has fibers in the concrete matrix and Fig. 2 the cylinder does not have fibers in the concrete. The fiber concrete material behavior can be categorized as follows: tough, ductile, load carrying after it cracks, holds broken brittle material together. Regardless of the words used to describe the observed phenomena, the next scientific method type question is why and from what theoretical basis can this be modeled or described.

Fig. 2 No fiber concrete cylinder break **Fig. 3 –** FRC extended cylinder break

The basic concepts about FRC theoretical mechanics and behavior are shown in Table 1. This is from the ACI 544 committee documents for teaching their short course on FRC. My experiences with explaining the features-advantages-benefits of FRC have made me realize there are some corollaries and subsets to this which follow: reinforced concrete, development length, engineering mechanics, materials engineering, structural engineering, and macro versus micro views. Frequently during discussions and extended times of reasoning, engineers will jump or cross over their own arguments regarding a belief in fracture mechanics or strength of materials. And upon further discussion, the basics or background of these two theoretical views, strength of materials and fracture mechanics, are not relationally understood with the corollaries and subsets listed above. Neither theoretical view is right or wrong, just different and again only theoretical! The purpose of illustrating these two worldviews of FRC is to add honesty to the conversation between the seller and buyer of FRC.

Tab. 1 Aspects and 2 theories of FRC theoretical mechanics

FRC Theoretical Mechanics		
Aspects	Theory 1	Theory 2
Basic Conceptions	Reinforcement	Fracture toughening
Background	Strength of Materials	Fracture Mechanics
Emphasis	Bond and anchorage	Energy absorption
Requirement	Strong stiff fibers	Adequate numbers of fibers
Fiber Functions	Spans over cracks	Matter states and ages
Resultant Objective	Significant matrix damage	Matrix integrity
Force Conductors	FIBERS	MATRIX

A simple reinforcement model is shown in Fig.4. The question “is this simple” should not be misunderstood because it is a model. Just as in reinforced concrete, the reinforcement can slip or grab, stretch or break, but only so much because there is a “ditch on both sides of the road.” Both behaviors are desired, not exclusively one or the other. There is only a scale difference between this model of reinforced concrete and fiber reinforced concrete.

The definition and features of fibers for reinforced concrete is small (significantly less than conventional reinforcing steel), discrete (discontinuous), higher aspect ratio (length divided by width), distributed 3 dimensionally and homogeneously, imparts isotropic (uniformly consistent not significantly separate) behavior to the concrete, and just like conventional reinforcing, carries load after the concrete cracks.

4 Significant FRC developments

A concrete project responsibility and process life is shown in Table 2. The purpose of this table is to broadly outline steps and commitments in the project, and to show how affecting the performance-schedule-cost in these areas for those responsible for projects can define value to the fiber industry.

Tab. 2 Successive responsibility and process life of a generalized concrete project

Generalized Concrete Project: Successive Responsibility and Process Life			
Designer	Supplier	Constructor	Owner
Material selection	Mixture proportions	Placing	Service
Design and analysis	Batching	Finishing	Repair
Materials	Mixing	Curing	Removal
	Delivery	Testing	Recycling
			Disposal

In 1977, I was in graduate school and we tested glued, side-by-side, steel fibers. The significant difference between this and other available steel fibers that were also tested was fiber efficiency and ease of batching. The loose fibers, ‘not collated’ or glued, had to be hand shuffled into the mixer, like cards, in small quantities to inhibit balling and clumping of the fibers. The collated or glued fibers were easily added, dumped, or just put into the mixer ‘all-at-once.’ This fiber collation significantly reduced time for the batching and mixing of the fiber concrete. The significant performance improvement, or increased fiber efficiency, was accomplished by improved anchorage of the steel fiber in the concrete matrix. The cost difference between the steel fibers was insignificant compared to the added performance and to the reduced time that translated into added assurance that what was desired was more easily obtainable.

In about 1993, the first work was done with synthetic fibers that mimicked the concrete load carrying behavior after cracking of steel fibers. Previous attempts at increasing the synthetic fiber dosage were like the 1977 steel fiber batching and addition issues, balling and clumping of fibers. A dispersible circumferential wrap of paper to encase the synthetic fibers overcame the batching addition issues of these larger synthetic fibers. The notable performance issue with the synthetic fibers was no corrosion. The schedule or time difference was comparable to the 1977 improvements by the similar collation approach, wrap versus glue. Fig. 5 shows left to right, loose steel fibers, wrapped synthetic fibers, and glued steel fibers.

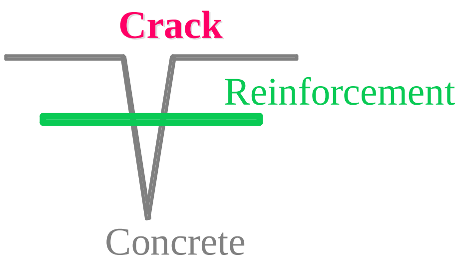

Fig. 4 Simple? Reinforcement Model

Fig. 5 Fibers loose, circumferentially wrapped, and glued side by side

5 FRC Project benefits

From Table 2, the concrete project responsibilities and project process life were significantly affected in all areas by the 1977 and 1993 improvements to FRC but could be focused as remarkable and outstanding in design and analysis, materials, batching, and testing. The other areas were affected like most goal driven methodologies, there were some affects and trade-offs, but very little was compromised overall regarding performance, schedule, and cost, which generally improved the projects.

The following applications illustrate the improvements when compared to alternate means to accomplish these improved results:

5.1 Warehouse slab on ground

The warehouse slab on ground was 6 inches thick (150 millimeters), and had no joints and no significant cracks in the 60 by 130 foot layout (18 by 40 meter). The slab had 0.5% synthetic fiber dosage (7.5 pcy - 4.5 kcm). The adjacent 85 by 115 foot layout (26 by 35 meter) had one mid panel crack due to settlement from fill materials. The performance of the slab has been outstanding – no cracks and a better fork truck ride – and the costs were significantly reduced by no saw cuts (1,850 feet – 565 meters).

5.2 Jersey barrier (Fig. 6)

Three types of concrete were placed into two jersey barriers on the sides of one bridge: no fibers, 1.3% and 1.7% synthetic fibers. No conventional steel reinforcement was removed. Crack width histograms showed significantly reduced crack widths and incidents with increasing fiber dosage. The crack widths were compared to an ACI 224 table regarding cracks in concrete for serviceability.

5.3 Truck station bonded overlay

A truck station bonded overly was 60 by 20 feet (18.3 by 6.1 meters) and 1.5 inches thick (37 millimeters) and used 1.7% synthetic fibers (25 pcy – 15 kcm). Even though there are wheel stops through the overlay, there is only a superficial crack in the middle of the overlay and off one corner of a wheel stop. The apron transition to the adjacent asphalt was hand mixed using 6.5% synthetic fibers (100 pcy – 59 kcm). The apron was wedge shaped in cross section 5 by 20 feet (1.5 by 6.1 meters) and was from 0.37 to 1.5 inch thick (5 to 37 millimeters). There are no cracks in this overlay and no surface preparation was done except to power water wash the base concrete.

5.4 Ultra thin whitetopping residential driveway (Fig. 7)

An ultra thin whitetopping of a residential driveway was done on a 17% slope, 1.5 inch thick (37 millimeters), 250 feet long (76.2 meters) and about 9.5 feet wide (3 meters). There are no saw cuts and minimal cracking from using a 0.67% synthetic fiber dosage (10 pcy – 6 kcm). No surface preparation was used for adhering the concrete except to blow off the leaves.

Fig. 6 Steel reinforced jersey barrier

Fig. 7 UTW residential driveway

6 FRC Future and conclusion

Future improvements in FRC will come and are inevitable and will focus just as in the past on performance, schedule, and cost. These issues and how they benefit the various parties involved in the concrete project process life will no doubt be significant and involve words associated with FRC theoretical mechanics such as nano-technology or improved testing to understand the behaviors and refine the models. Since concrete is second to water as the most widely consumed material in the world, there appears to be no shortage of future opportunities.

References

[1] White, R. N., "Improved Teaching of Structural Concrete Design," SP-213, The Art and Science of Structural Concrete Design - A Symposium Honoring Richard W. Furlong, American Concrete Institute, Detroit, pp. 19-42.

[2] Farney, James A., "Concrete Floors on Ground," 3rd Edition, Portland Cement Association, Skokie, Illinois, USA, 2001.

[3] Wang, Chu-Kia and Salmon, Charles G., "Reinforced Concrete Design," 2nd Edition, New York, USA, 1973.

[4] MacDonald, Clifford N., "Case Studies about Design, Construction, and Performance of High Volume Synthetic Fiber Reinforced Concrete in Slab on Ground Applications," Proceedings of the Third International Conference on Construction Materials, 22-24 August 2005, Vancouver, Canada.

[5] MacDonald, C. N., (1984), "Plastic and Steel Fiber-Reinforced Concrete Applications", Transportation Research Record 1003, TRB, Washington, DC.

[6] Ramakrishnan, V., (1995), "Concrete Fiber Composites for the Twenty-First Century", Proceedings of the Fifth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Milwaukee, USA.

[7] Ramakrishnan, V., (1997), "Performance characteristics and Application of High-Performance Polyolefin Fiber Reinforced Concretes", SP-171, Proceedings of the third CANMET/ACI International Conference - Advances in Concrete Technology, American Concrete Institute, Detroit, pp. 671-692.

[8] Patents 5,807,458 and 5,897,928 about methods and articles for reinforcing castable compositions through the use of reinforcing elements in a dispersible containment means.