

Recent Developments in Fiber Reinforced Concrete and Their Effect on Concrete Columns Analysis

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ABSTRACT: This paper presents the developments in Fiber Reinforced Concrete during the past ten years and the consequent necessity of adopting a new approach in the analysis of columns made of this new material. Fiber Concrete is an ideal solution to the problem of steel congestion in concrete members such as columns, for which the ductility may be highly required. Recent investigations mainly draw attention to mechanical properties, constitutive models and structural behavior of the concrete reinforced by steel fibers, mineral or naturally occurring fibers. Based on previous experimental and analytical studies available, a rectangular stress block is proposed for analysis of Steel Fiber Reinforced Concrete Column.

KEYWORDS:-Fiber reinforced concrete, constitutive model, Column analysis.

I. INTRODUCTION

Today concrete is the number one structural material in the world. However mainly due to its inherent tensile weakness, much of this concrete is cracked. Research efforts aiming to improve the mechanical properties of such attractive material led to the founding of prestressed concrete, high and ultrahigh-strength concrete. Concrete with high strength exhibits brittleness. Therefore, Fiber Reinforced Concrete has been suggested as alternative solution to the problem of cracking by making concrete tougher and more ductile. Reinforcing brittle matrices with steel bars to improve their mechanical properties is an old age Concept.

However, the modern development of Fiber Reinforced-concrete dates back only to the 1960s. Fiber reinforcement can be steel but also stainless steel, polymeric and mineral materials, and naturally occurring fibers. Fibers bring the required durability of the composite by preventing microcracks from becoming working cracks, and thus protect the porous concrete from further aggressive environmental attack.

In recent years, researchers have conducted studies on the ductility improvement for concrete structures designed to work in the seismic areas. Sufficient ductility provision required very often a big amount of transverse reinforcement, leading to steel congestion problem. Fiber concrete with random small fibers has been found very effective due to its large postpeak behavior on the stress-strain curve. Although fiber reinforced concrete was primarily used for pavement and industrial floors, researches conducted confirm its possible use in structural members such as beams, columns, connections, plates and prestressed concrete structures. Columns as important compression structural members must be designed to behave in ductile manner especially in seismic regions.

Experimental studies demonstrated the advantages of combining conventional steel bars and fibers. During an earthquake, conventional reinforced concrete first loses the concrete cover over the rebar. Pieces of concrete wedged in between the rebar crumble and fall out, causing a loss of stiffness and structural integrity. With fiber reinforced-concrete, there is a very little spalling, and more energy is needed to loose the concrete wedged in between the rebar. The fibers add a toughness that maintains the structural stiffness. This additional ductility of fiber reinforced-concrete makes safer buildings in earthquake zones. Studies have also conducted for the use of fiber reinforced-concrete in column's retrofitting. At the same time, researches showed a necessity of change of concrete column's design concepts when fibers are used as reinforcement.

This paper presents the new developments in fiber reinforced- concrete and the concrete column's analysis as the fiber reinforced concrete is being progressively implemented in structural engineering.

II RELATED WORK

Fiber reinforced concrete is a composite material made of cement-based matrix mixed with metallic or non-metallic fibers, sometimes, admixtures, additives and polymers are added. Cement-based matrix is primarily composed of cement, water, fine and coarse aggregates. The metallic fibers are made of steel or stainless steel. The non-metallic fibers can be polymer, mineral and naturally occurring fibers. Additives such as fly ash or condensed silica fume can be added to improve the quality of the concrete composite. During the last ten years, many experimental studies related to fiber reinforced concrete structures have been conducted.

In 1990, G.Chanviliard, N.Banthia and P.-C.Aitcin proposed in their work normalized load-deflection curve for fiber reinforced- concrete under flexure as a simple and practical technique of treating the load versus deflection plots. The effect of fibers is quantified by the toughness index.

The load-deflection curve is redrawn with the assigned values of both the load and displacement at first crack. The curve is convenient to assess the residual strength of a member and to conceptualize the efficiency of a given fiber in the context of its structural performance.

That method has been found useful to practicing engineers. Natural fibers such as jute, coin, banana, sisal, cotton, pineapple, palm-tree frond and coconut tree based fibers incorporated in low modulus matrix like polyester yield materials with better properties, suitable for various applications. However, although their poor strength due to low density they can lead to high specific strength properties if incorporated in a polymeric matrix. Moreover, they have also high resistance to crack propagation. For the 93 years, we can mention the work of Seung Bum Park studying mechanical properties together with the creep behavior of the carbon fiber reinforced polymer-impregnated cement composites. Treating the steel fiber concrete as an orthotropic material having different properties in the principal directions, the authors derived a constitutive relation based on a total stress-strain formulation. The biaxial compressive strength for steel fiber concrete can be obtained by considering an analogous plain concrete under triaxial stress state. The influence of steel fibers is modeled by applying a confining pressure equal to the post-cracking tensile strength of the steel fiber concrete in the direction perpendicular to the plane of two principal stresses. The biaxial compressive strength is given by the failure envelope, which is defined in terms of stress invariants.

Composites reinforced with carbon fibers are found with high tensile strength and elastic modulus, chemical inertness and strong bond with the cement matrix. The reported algorithm is capable of predicting both immediate and long-term behavior of tested beams. Many researchers have demonstrated potential applications of natural and mineral fibers in past years, steel fiber reinforced concrete has also attracted the investigators such as. Richard E. Smith and Robert E. Wilde and O. Challal, S. Thibodeau, J. Lescelieur and P. Malenfant. A description of the use of steel fiber reinforced - concrete in thin overlay applications and concrete shear walls respectively is presented as structurally more advantageous than the use of conventional steel reinforcement. Fatigue characteristics of high -performance fiber-reinforced concrete were investigated by A.E. Naaman & H. Hammoud. With high range of fiber content (1 and 2 vol. % of concrete), in addition to the minimum specified target compressive strength, the main purpose of the investigation was to achieve post-cracking strength in bending (a modulus of rupture) higher than the cracking strength so as to minimize crack widths and insure a sufficient resistance to repeated loads after cracking. This is typically a characteristic of high performance fiber reinforced cement composites. It led to a load-deflection response with a post-cracking resistance above the cracking load level, at deflections up to five times the deflection at cracking. It implied a ductile behavior in bending otherwise not present in the control specimens without fibers or with very small fiber contents.

Experimental studies showed that fiber reinforced concrete containing two vol. of hooked steel fibers could sustain cyclic fatigue stresses (in absolute values) more than twice those of plain concrete without fibers could. Conventional concrete reinforced with discrete steel fiber exhibits some unusual behavior, which is not displayed by plain concrete when it is subjected to flexural loading.

Addition of high-strength fibers with good anchorage or surface features to conventional concrete leads to increased flexural strain capacity, higher tensile and shear strengths, and improved impact resistance and energy absorption. In

predicting the behavior of steel fiber reinforced concrete, an understanding of characteristic features of the fibrous material subjected to flexural force is essential. Because, for many engineering structures are designed to resist loads that cause bending; the attendant tensile stresses developing at critical sections of structural member must be limited and SFR concrete could provide the solution to many practical problems. In the reported work, the investigators also derived moment-curvature relationships. Effectiveness of crack control at early age on the corrosion of steel bars in low modulus sisal and coconut fiber-reinforced concrete is reported. The experimental study revealed that the addition of silica fume enhanced the impact resistance of polypropylene fiber reinforced concrete but has no effect on the unreinforced concrete.

The effect of fibers on the deflection, cracking behavior and ductility of steel fiber reinforced concrete beams were studied. It was confirmed that steel fiber could increase flexural rigidity of high-strength-concrete beams before yielding stage. The main objective of the investigation was to obtain experimental data on the deformation characteristics and strength of reinforced concrete T-beams with different percentages of steel fibers. The study showed that the presence of steel fibers effectively reduced the deflection; width of cracks and improved the ductility, and flexural rigidity of the concrete beams. Research on natural fibers have been conducted. Recent studies show that *Eucalyptus grandis* waste have an acceptable performance as reinforcement in cement-based composite materials for low-cost housing applications. This fact confirms again the potential applications of concrete reinforced with natural fibers, which are very abundant in developing countries.

As previously mentioned, columns are important structural members of buildings, bridges and other engineering structures. They are very often subjected to axial or eccentric compression loading. Because of their importance and for avoiding or minimizing the losses in case of their failure, sufficient longitudinal and lateral reinforcement is needed especially when columns have to undergo earthquake motion where special measures must be taken to attain ductile column's behavior. Sufficient ductility requires much conventional steel reinforcing bars, which unfortunately leads to steel congestion.

When fiber concrete is used, required confinement column is provided by the fibers. The primary purpose of adding fibers to concrete is to improve the column's ductility. This aspect is very important in earthquake-resistant design. Design concepts used for normal reinforced concrete can be used for fibrous reinforced concrete with appropriate modifications. Many researchers showed that the fibers in reinforced concrete columns do not appreciably increase the compressive strength but alter the deformation characteristics especially in the post-peak region. Therefore the strength design methods based on ultimate capacity for concrete columns with conventional reinforcement will depend not only on strength but also on the deformation characteristics in case of using fibers as reinforcement. Researchers have established constitutive compressive and tensile stress-strain relationships for fiber reinforced concrete.

As previously mentioned, steel fibers contribute to increase the ductility of the reinforced concrete column which is especially required in seismic regions. Traditionally, structural engineers often used to design spiral concrete columns as the more ductile than rectangular or square-shaped columns. With steel fiber reinforcement, square or rectangular-shaped concrete columns can provide the required ductility to sustain earthquake motions. Studies have demonstrated that a combination of fibers and reinforcing bars in structural elements produces a synergistic effect between the two forms of reinforcement, and the fibers permit a more efficient use of the continuous reinforcement. The combination not only improves the performance and durability, but also enhances the constructability and reduces costs. Previous research showed that square or rectangular concrete columns, reinforced with steel fibers and steel bars can be analyzed using rectangular stress-block. Indeed, the strength-based method of analysis can be used but with some modifications accounting the fibers contribution. Let us remember that for conventional steel reinforced concrete structures under eccentric compression, the concrete tensile strength is neglected in the analysis; in case of fiber reinforcement the tensile strength must be considered, because of the great contribution of fibers in tension, working with concrete as one material.

III. ANALYSIS

Given a rectangular reinforced concrete with steel fibers and bars in the figure given below. Determine the nominal compressive strength P_n .

- Loading eccentricity $e=470\text{mm}$.
- Rectangular cross section: $300 \times 500\text{mm}$;
- Concrete cover: 70mm
- Fiber concrete volume concentration: 1.5% .
- Aspect ratio: $L/D=100$;
- Concrete compressive strength: $f'_c=18.89\text{Mpa}$.
- Ultimate tensile strength: $f_t=4.1\text{Mpa}$.
- Ultimate concrete compressive strain $\epsilon_{cu}=0.004$
- Bond strength: $T_d=4.05\text{MPa}$.
- Fiber orientation factor: $\eta=0.405$
- Steel bars: Longitudinal reinforcing bars: A-III $\phi 16$;
- $f_y=R_s=R_{sc}=365\text{MPa}$ $A_s=A_s=4.02\text{cm}^2$ (A-III $2\phi 16$).
- Modulus of elasticity $E_s=200000\text{MPa}$.
- Transverse reinforcement: A-I $\phi 8$

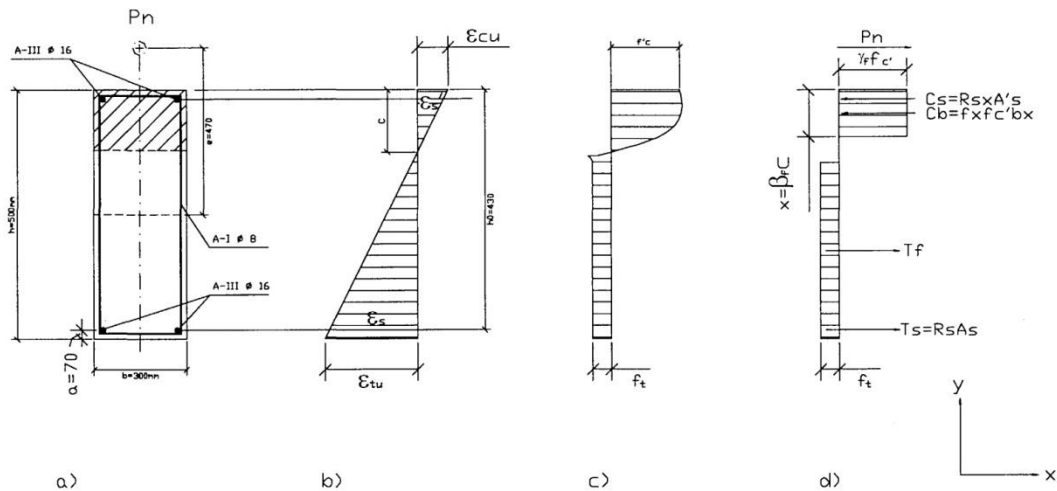


Fig 1.: STRAIN & STRESS DISTRIBUTION FOR THE SFRC COLUMN

- Column cross section
- Strain distribution
- Real stress distribution
- Equivalent rectangular stress block

Solution

Coefficient accounting the Influence of fibers on concrete compression

$$\gamma_f = 0.85 + 0.03(WL/D)/450 \leq 0.88,$$

where WL/D is the percentage of steel fiber by weight.

Here, $\gamma_f = 0.88$

The factor defining the depth of the equivalent rectangular stress block for fiber reinforced concrete,

$$\beta_f = 0.85 + 0.05(WL/D)/450 \leq 0.90 \text{ for } f_c' \leq 27.56 \text{ MPa,}$$

$$\beta_f = 0.85 + 0.05(WL/D)/450 - [1 + 0.25(WL/D)/450] [0.05 (f_c' - 27.58)/6.895] \text{ for } 27.56 \leq f_c' \leq 56.16 \text{ MPa}$$

$$\beta_f = 0.65 \text{ for } f_c' \geq 56.16 \text{ MPa}$$

Here, $\beta_f = 0.900$

The strain in the reinforcing steel, $\epsilon_y = f_y / E_s = 0.001825$

The depth of the compressive zone = $\epsilon_{cu} (\epsilon_{cu} + \epsilon_y) h_o = 295.279 \text{ mm}$, where h_o is the effective depth

The depth of the equivalent rectangular compressive block.

$$X = \beta_f c = 265.751 \text{ mm}$$

Projection of all forces on the X-axis gives:

$$\Sigma X = P_n - C_s - C_b + T_s + T_f = 0$$

$$P_n = C_s + C_b - T_s - T_f \quad (1)$$

$$C_s = R_s A_s = 365 \times 4.02 \times 0.01 = 146.73 \text{ KN}$$

$$C_b = \gamma_f f_c' b x = 0.88 \times 39.3 \times 300 \times 0.001 x = 10.375 x$$

$$T_s = R_s A_s = 365 \times 4.02 \times 0.1 = 146.73 \text{ KN}$$

$$T_f = f_t b (h - c) = 3.76 \times 300 \times 0.001 \times 250 = 282 \text{ KN}$$

$$P_n = 10.375 x - 282 \quad (1)'$$

$$C_s = T_s, \text{ hence } P_n = C_b - T_f \quad (2)$$

$$C_b = \gamma_f f_c' b X = 1.32 \text{ MN}$$

$$T_f = f_t b (h - c) = 0.252 \text{ MN}$$

Consequently the nominal compressive strength $P_n = C_b - T_f = 1068 \text{ kN}$

IV. CONCLUSION

Traditionally, fiber reinforced -concrete has been effectively used in industrial floors to resist impact and dynamic loads. Analysis of recent developments in fiber reinforced- concrete shows a progressive implementation of that structural material in concrete structures especially where high ductility is needed. Many experimental studies concerning the use of fiber reinforced- concrete with different types of fibers have been reported. Problem of steel congestion can be avoided with steel fiber incorporation in the concrete matrix.

Therefore, analysis and design concepts must be modified when analyzed structure is made of fiber reinforced - concrete. Design and analysis methods will have to be based not only on strength but also on deformation characteristics. Researchers have previously proposed different stress-strain relationships for fiber concrete. It is well known that columns are very important structural members for which high level of ductility is required, especially if they have to sustain earthquake loading. Association of steel fibers and steel bars has been found very effective in increasing column's ductility.

Unfortunately, previous developments demonstrate that only a few studies on analysis of such columns are available. Through an illustrative example, this paper shows how the rectangular stress block method should be used to analyze a concrete column reinforced with steel fibers and bars. However, more studies are necessary to make the approach more efficient and practical.

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