ICC EVALUATION SERVICE

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June 1, 2009

TO: **PARTIES INTERESTED IN EVALUATION REPORTS ON SYNTHETIC FIBER REINFORCEMENT IN CONCRETE**

SUBJECT: Proposed Acceptance Criteria for Synthetic Fiber Reinforcement in Concrete, AC383-0609-R1 (ME/BG)

Dear Madam or Sir:

A new acceptance criteria, as presented in the attached draft, is being posted on the ICC-ES web site to allow for public comment. This draft was submitted by an interested party representing an evaluation report applicant.

The purpose of this acceptance criteria is to establish requirements for concrete with macro synthetic fibers to be recognized in an ICC Evaluation Service, Inc. (ICC-ES), evaluation report under the *2009 International Building Code*® (IBC), the 2009 *International Residential Code*® (IRC), the 2009 *International Plumbing Code*® (IPC), and the 1997 *Uniform Building Code*® (UBC). Synthetic fibers are added to concrete to be used in slabs on ground; sprayed (shotcrete) concrete; and concrete over steel deck construction, precast products, and septic tanks, for improving flexural toughness and post-cracking residual strength.

Staff has the following comments/questions:

1. Section 1.2 of the proposed AC383 states: “Synthetic fibers are added to concrete as reinforcement used in slabs-on-ground, sprayed (shotcrete) concrete, concrete over steel deck construction, precast products, and septic tanks for improving flexural toughness and the post-cracking residual strength.” Staff requests additional information, such as whether the test methods mentioned in this criteria are appropriate to qualify use of synthetic fibers as reinforcement in concrete, and whether this proposed criteria should also require full-scale load test demonstrations to verify that the fibers can be used in concrete as reinforcement for the uses cited above. As information, ACI 318-08, Section 11.4.6.1 provides precedence for use of steel fibers as a design alternative to shear reinforcement only, based on residual strength performance determined in accordance with ASTM C 1609.

2. Section 1.2 of the proposed criteria states: “Other issues, such as freeze-thaw durability of concrete with synthetic fibers, effect of synthetic fibers on

reinforcement bond strength, plastic shrinkage cracking, and compatibility with concrete shall be evaluated under the AC32 (ICC-ES Acceptance Criteria for Concrete with Synthetic Fibers)." The staff would prefer placing such items as those mentioned above within the criteria, and question whether we should simply mandate that applicants comply with AC32 in addition to the proposed draft criteria.

3. Staff sees a need for special training, inspection and testing to ensure that the fibers are added and distributed as intended. Staff's concern is that synthetic fibers under consideration in this criteria are intended to be used as reinforcement, and improper fiber distribution may create critical sections with low fiber content that may lead to a reduction in strength. Additional input on this topic is sought.

4. Staff requests public input in regard to the applicability of Annex A to typical design.

You are cordially invited to submit written comments, within 30 days of the date of this letter. Please use the comment form on the web site attaching any letters to the form. An explanation of the alternate criteria process can be found on our web site at http://www.icc-es.org/Criteria_Development/alternative_criteria_process.shtml.

All comments received in the 30-day comment period will be considered in preparing a proposed criteria that may be considered at a future Evaluation Committee meeting. Comments received will be posted on the web site shortly after the close of the comment period.

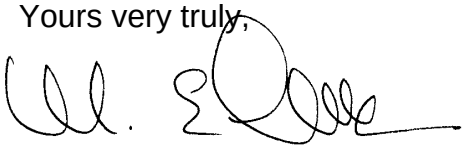
Your cooperation is requested in forwarding to the Los Angeles business/regional office all material directed to the Evaluation Committee. Parties interested in the deliberations of the committee should refrain from communicating, whether in writing or verbally, with committee members. The committee reserves the right to refuse communications that do not comply with this request.

Newly approved acceptance criteria may involve test methods or test protocols that are not currently included in the scope of testing services offered by accredited testing laboratories. As noted in the ICC-ES Rules of Procedure for Evaluation Reports, the scope of the laboratory's accreditation must include the type of testing that is to be reported to ICC-ES. We encourage accredited laboratories to expand their scopes of accreditation to include testing under newly approved acceptance criteria. Please note that testing laboratories must be accredited by the International Accreditation Service (IAS) or by another accreditation body that is a signatory to the International Laboratory Accreditation Cooperation Mutual Recognition Arrangement. For further information, please contact IAS at (562) 699-0541, extension 3309, or send an e-mail to pmccullen@iasonline.org.

Please submit all comments using the form on the web site. Attach any letters to the comment form. If you have any questions (not comments), please contact the

undersigned at (800) 423-6587, extension 3721, or Brian Gerber, at extension 3260. You may also reach us by e-mail at es@icc-es.org.

Yours very truly,



Mahmut Ekenel, Ph.D., P.E.
Staff Engineer

ME/raf

Enclosure

cc: Evaluation Committee

ICC EVALUATION SERVICE

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PROPOSED ACCEPTANCE CRITERIA FOR SYNTHETIC FIBER REINFORCEMENT IN CONCRETE

AC383

Proposed June 2009

PREFACE

Evaluation reports issued by ICC Evaluation Service, Inc. (ICC-ES), are based upon performance features of the International family of codes and other widely adopted code families, including the Uniform Codes, the BOCA National Codes, and the SBCCI Standard Codes. Section 104.11 of the *International Building Code*® reads as follows:

> **The provisions of this code are not intended to prevent the installation of any materials or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.**

Similar provisions are contained in the Uniform Codes, the National Codes, and the Standard Codes.

ICC-ES may consider alternate criteria, provided the report applicant submits valid data demonstrating that the alternate criteria are at least equivalent to the criteria proposed in this document, and otherwise meet the applicable performance requirements of the codes. Notwithstanding that a product, material, or type or method of construction meets the requirements of the criteria proposed in this document, or that it can be demonstrated that valid alternate criteria are equivalent to the criteria in this document and otherwise meet the applicable performance requirements of the codes, ICC-ES retains the right to refuse to issue or renew an evaluation report, if the product, material, or type or method of construction is such that either unusual care with its installation or use must be exercised for satisfactory performance, or malfunctioning is apt to cause unreasonable property damage or personal injury or sickness relative to the benefits to be achieved by the use of the product, material, or type or method of construction.

Acceptance criteria are developed for use solely for purposes of issuing ICC-ES evaluation reports.

PROPOSED ACCEPTANCE CRITERIA FOR SYNTHETIC FIBER REINFORCEMENT IN CONCRETE

1.0 INTRODUCTION

1.1 Purpose: The purpose of this acceptance criteria is to establish requirements for concrete with synthetic fibers to be recognized in an ICC Evaluation Service, Inc. (ICC-ES), evaluation report under the 2009 *International Building Code*® (IBC), the 2009 *International Residential Code*® (IRC), the 2009 *International Plumbing Code*®, (IPC), and the 1997 *Uniform Building Code*® (UBC). The bases of recognition are IBC Section 104.11 and IRC Section R104.11, UBC Section ???????, IPC Section ??????. Applicable code sections in the IBC are Sections 1901.2 (Plain and Reinforced Concrete), 1909 (Structural Plain Concrete), and 1910 (Minimum Slab Provisions). Applicable code sections in the IRC are Sections R506 (Concrete Floors on Ground) and Table ????. Applicable code sections in the UBC are ????. Applicable code sections in the IPC are ?????. The reason for this criterion is that the IBC IRC, UBC and IPC do not provide requirements for strength evaluation of concrete with synthetic fibers.

1.2 Scope: Synthetic fibers are added to concrete as reinforcement used in slabs-on-ground, sprayed (shotcrete) concrete, concrete over steel deck construction, precast products, and septic tanks for improving flexural toughness and the post-cracking residual strength. The intent of addition of fibers into the concrete matrix is to more effectively hinder the growth of micro-cracks, distribute micro-cracks, and hold broken concrete together. This is a change in scale from macro issues and purposes with macro reinforcement, i.e. conventional rebar and welded wire fabric.

Synthetic fibers in this criterion are considered as a type of reinforcement if justified by data complying with this criterion. Test Reports and calculations shall provide an Average Residual Strength (ARS) from ASTM C 1399. The fiber manufacturer shall submit recommendations that correlate compressive strength with that of the recommended dosage for the concrete with synthetic fibers for ARS. The criterion is intended to provide a process for determining ARS values to enable use of synthetic fibers as tensile and flexural strength reinforcement. Other issues such as, freeze-thaw durability of concrete with synthetic fibers, effect of synthetic fibers on reinforcement bond strength, plastic shrinkage cracking, and compatibility with concrete shall be evaluated under the AC32 (ICC-ES Acceptance Criteria for Concrete with Synthetic Fibers).

1.3 Referenced Standards: Where standards are referenced in this critera, these standards shall be applied consistently with the code upon which compliance is based.

1.3.1 Codes:

1.3.1.1 2009 *International Building Code*® (IBC), International Code Council.

1.3.1.2 2009 *International Residential Code*® (IRC), International Code Council.

1.3.1.3 2009 *International Plumbing Code*® (IPC), International Code Council.

1.3.1.4 1997 *Uniform Building Code*® (UBC), International Code Council.

1.3.2 ASTM International Standards:

1.3.2.1 ASTM C 31-06, Standard Practice for Method of Making and Curing Concrete Test Specimens in the Field.

1.3.2.2 ASTM C 39-05E1, Test Method for Compressive Strength of Cylindrical Concrete Specimens.

1.3.2.3 ASTM C 42-04, Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete.

1.3.2.4 ASTM C 78 -08, Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).

1.3.2.5 ASTM C 94-06, Standard Specification for Ready- Mixed Concrete.

1.3.2.6 ASTM C 172-04, Standard Practice for Sampling Freshly Mixed Concrete.

1.3.2.7 ASTM C 192-06, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory.

1.3.2.8 ASTM C 234-91a, Test Method for Bond Strength.

1.3.2.9 ASTM C 403-99, Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance.

1.3.2.10 ASTM C 494-05a, Standard Specification for Chemical Admixtures for Concrete.

1.3.2.11 ASTM C 470-02am, Standard Specification for Molds for Forming Concrete Test Cylinders Vertically.

1.3.2.12 ASTM C 823-00, Standard Practice for Examination and Sampling of Hardened Concrete in Construction.

1.3.2.13 ASTM C 1116-06, Specification for Fiber-Reinforced Concrete and Shotcrete.

1.3.2.14 ASTM C 1227-09, Specification for Precast Concrete Septic Tanks.

1.3.2.15 ASTM C 1399-07a: Standard Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete.

1.3.2.16 ASTM D 2256-02, Standard Test Method for Tensile Properties of Yarns by the Single-Strand Method.

1.3.2.17 ASTM E 119-07, Standard Test Methods for Fire Test of Building Construction and Materials.

1.3.3 Others:

1.3.3.1 ACI 318-08, Building Code requirements for Structural Concrete, American Concrete Institute.

1.4 Definitions:

1.4.1 Structural Plain Concrete: Structural plain concrete is defined in Section 1902 of the IBC and Section 2.1 of ACI 318.

1.4.2 Reinforced Concrete: Reinforced concrete is defined in Section 1902 of the IBC and Section 2.1 of ACI 318.

1.4.3 Reinforcement: Reinforcement is defined in Section 1907 of the IBC and Sections 3.5, Chapter 7 of ACI 318.

1.4.4 Plastic Shrinkage Cracking: Plastic shrinkage cracking is cracking that occurs in the surface of fresh concrete soon after it is placed and while it is still plastic.

1.4.5 Shrinkage and Temperature Cracking: Shrinkage and temperature cracking is cracking failure of concrete in tension due to a decrease in length or volume.

1.4.6 Synthetic Fibers: Synthetic fibers are fibers manufactured from polymer-based materials, i.e. polyolefin, polypropylene, and nylon. Fibers may be either “micro” or “macro”. “Micro” synthetic fibers (denier less than 100) are typically added by volume less than 0.1 percent. “Macro” synthetic fibers (denier more than 100) are typically added by volume greater than 0.1 percent.

1.4.7 Denier: Denier is the weight in grams of 9000 meters (9,842.5 yard) of a single fiber.

2.0 BASIC INFORMATION

2.1 General: The following information shall be submitted:

2.1.1 Product Description: information concerning the fiber material and fiber configuration, MSDS specifications, including fiber length nominal denier and nominal fiber tensile strength.

2.1.2 Installation Instructions: Printed instructions for mixing and dosage rates, as provided with the packaging of the product.

2.1.3 Packaging and Identification: A description of the type of packaging and field identification of the synthetic fibers. Identification provisions shall include the evaluation report number and, optionally, the name or logo of the inspection agency consistent with Section 8.2 of ASTM C 1116

2.2 Testing Laboratories: Testing laboratories shall comply with Section 2.0 of the ICC-ES Acceptance Criteria for Test Reports (AC85) and Section 4.2 of the ICC-ES Rules of Procedure for Evaluation Reports.

2.3 Test Reports: Test reports shall comply with AC85. Test reports shall include the following: description of type of synthetic fiber; description of test procedure; and where applicable a statement on passing or failing.

2.4 Product Sampling: Products shall be sampled in accordance with Section 3.0 of AC85.

3.0 TEST AND PERFORMANCE REQUIREMENTS

3.1 General: Consideration shall be given to the dosage or volume, nominal denier, and type of fibers used; concrete type (normal-weight, structural lightweight). Extrapolation to other dosages, volumes, deniers, and types of synthetic fibers shall be justified.

3.2 Recognition in Evaluation Reports: Based upon Average Residual Strength (ARS) values obtained from testing in accordance with ASTM C 1399, the evaluation report may recognize the use of synthetic fibers in slabs on ground, sprayed (shotcrete) concrete, concrete over steel deck construction, and fire-resistive composite over steel decks, precast products, and septic tanks.

3.3 Test Requirements:

3.3.1 For recognition of use of synthetic fibers in concrete slabs on ground, precast products, septic tanks and shotcrete, results of tests conducted in accordance with Sections 4.1 through 4.4, inclusive, are required.

3.3.2 For recognition of use of synthetic fibers in concrete over steel decks, results of tests conducted in accordance with Section 4.1 through 4.5 inclusive are required.

3.3.3 For recognition of use of synthetic fibers in fire-resistance-rated assemblies consisting of concrete composite over steel deck, results of tests conducted in accordance with Section 4.1 through 4.6 inclusive are required. For non-composite concrete placement over steel decks, compliance with Section 4.6 may be omitted.

4.0 TEST METHODS

4.1 Purpose: Tests are intended to compare synthetic fiber-reinforced concrete and plain (no reinforcement) concrete at a specified nominal concrete compressive strength of plain concrete.

4.2 Mix Designs: All tests shall be conducted using appropriate sections of the reference mix outlined in Sections 11 through 15 of ASTM C 494.

4.3 Test Specimens:

4.3.1 Specimens with Fibers: Test specimens shall be prepared and tested in accordance with ASTM C 1399, ASTM C 78, and ASTM C 39. For each fiber dosage and a nominal concrete compressive strength, a minimum of six (6) beams shall be tested per ASTM C 1399, three (3) beams per ASTM C 78, and three (3) cylinders per ASTM C 39.

4.3.1.1 Dosage: The fiber dosage in pounds per cubic yard (pcy) or by volume shall be as recommended by the fiber manufacturer. Fibers shall comply with ASTM C 1116.

4.3.2 Control Specimens (No fibers): Test specimens shall be prepared and tested in accordance with Sections 4.4.1, 4.4.2 and 4.4.3. A minimum of three beams in accordance with ASTM C 78 and three cylinders in accordance with ASTM C 39 are required for each nominal concrete compressive strength.

4.4 Tests

4.4.1 Average Residual Strength (ARS):

4.4.1.1 General: Purpose of the test is to (1) evaluate the contribution of synthetic fibers to the average residual strength (ARS) of the concrete, and (2) determine the correlation between a certain dosage of fibers in a concrete mixture and the resulting average residual strength (ARS) by ASTM C 1399.

4.4.1.2 Dosage: For a nominal concrete compressive strength, a minimum of three different dosages is required for interpolation only, no extrapolation, of ARS values. If test data is to be plotted, ARS and dosage with one curve per compressive strength of concrete is required.

4.4.1.3 Test Specimens:

4.4.1.3.1 Preparation: Test specimens shall be prepared in accordance with ASTM C 192.

4.4.1.3.2 Specimen with Fibers: Tests shall be conducted on six specimens for each fiber dosage.

4.4.1.3.3 Control Specimen: No tests shall be conducted because by definition of this test, with no fiber in the concrete, this has no ARS.

4.4.1.4 Condition of Acceptance: For each dosage, the average residual strength (ARS) of the specimen containing fibers shall be determined and reported in accordance with the requirements of ASTM C 1399. The values of the reported ARS can be used to determine the contribution of fibers to the required strength of an application as illustrated in Annex A.

4.4.2 Concrete Compressive Strength:

4.4.2.1 General: The purpose of the test is to evaluate how the addition of fibers to a concrete mixture affects the compressive strength. Comparative tests shall be conducted in accordance with ASTM C 39. Tests shall be conducted on three concrete specimens with synthetic fibers, and three specimens without fibers (control).

4.4.2.2 Test Specimens:

4.4.2.2.1 Preparation: Test specimens shall be prepared in accordance with ASTM C 192.

4.4.2.2.2 Specimen with Fibers: Tests shall be conducted on three specimens for each fiber dosage.

4.4.2.2.3 Control Specimen: Tests shall be conducted on three specimens for a nominal concrete compressive strength.

4.4.2.3 Conditions of Acceptance: The average compressive strength of the three specimens with fibers shall be compared to the average compressive strength of the control specimens. Slight deviations, due to variations in testing, may be considered. If average compressive strengths for the two sets of specimens (with and

without fibers) differ by more than 10 percent, then the registered design professional shall consider the difference and amend the design accordingly.

4.4.3 Concrete Flexural Strength:

4.4.3.1 Purpose: The purpose of the test is to evaluate how the addition of fibers to a concrete mixture affects the flexural strength. Comparative tests shall be conducted in accordance with ASTM C 78. Tests shall be conducted on three concrete specimens with synthetic fibers, and three specimens without fibers (control).

4.4.3.2 Test Specimens:

4.4.3.2.1 Preparation: Test specimens shall be prepared in accordance with ASTM C 192.

4.4.3.2.2 Specimen with Fibers: Tests shall be conducted on three specimens for each fiber dosage.

4.4.3.2.3 Control Specimen: Tests shall be conducted on three specimens for a nominal concrete compressive strength.

4.4.3.3 Conditions of Acceptance: The average flexural strength of the three specimens with fibers shall be compared to the average flexural strength of the control specimens. Slight deviations, due to variations in testing, may be considered. If average flexural strengths for the two sets of specimens (with and without fibers) differ by more than 10 percent, then the registered design professional shall consider the difference and amend the design accordingly.

4.5 Concrete Cover Composite Steel Deck Test

4.5.1 General: The purpose of the test is to evaluate whether the addition of fibers to a concrete mix placed over steel deck adversely affects the shear bond between the concrete and steel deck construction. Results of full-scale superimposed load tests (see Figure 1) providing comparative load capacity and deflection information shall be submitted. A minimum of two decks for each reinforcement method shall be tested. Consideration shall be given to the dosages, volume, type, and maximum dernier of fibers used. Extrapolation to other dosages, volumes, types, and deniers shall be justified.

4.5.2 Procedure (see Figure 1):

4.5.2.1 A No. 20 gage [0.0359 inch (0.91 mm)] steel deck (ASTM A 653 Structural Steel Grade 33), 3 inches (76 mm) deep with 12-inch (304.8 mm) rib spacing, designed for composite use, shall be used.

4.5.2.2 Two and one-half inches (63.5 mm) of concrete fill having a specified compressive strength of 3,000 psi (20.7 MPa) shall be used. Specimens shall include:

1. One set of specimens containing concrete fill with 6 x 6—W1.4 x W1.4 (WWF), 1 inch (25.4 mm) below the top of the slab.
2. One set of specimens containing concrete fill with fibers.

4.5.3 The composite deck shall be loaded at the quarter points in approximately eight equal increments until failure. Increments can be determined from the theoretical load capacity of the composite construction.

4.5.4 Ultimate flexural load capacity shall be determined for each set. At least three dial gauges equally spaced at mid-span shall be used for deflection readings. Deflection readings shall be reported.

4.5.5 Conditions of Acceptance:

Average ultimate flexural capacity of the decks with fibers shall equal or exceed the average ultimate flexural capacity of the decks with WWF. The average mean shear transfer coefficient (VT) for the decks with the fibers shall equal or exceed the mean or average shear transfer coefficient for the deck with the WWF.

4.6 Fire-resistance Test: The purpose of the test is to evaluate whether the addition of fibers in a concrete mix will affect the fire resistance of steel deck assemblies. Consideration shall be given to the dosage, volume, type, and nominal denier of fiber used. Extrapolation to other dosages, volumes, types, and nominal deniers shall be justified. Tests shall be conducted in accordance with ASTM E 119.

4.7 Septic Tank Test: In addition to determination of average residual strength in accordance with Section 4.3, septic tanks shall be vacuum tested. The number of specimens and condition of acceptance shall be in accordance with ASTM C 1227.

5.0 QUALITY CONTROL

5.1 A quality control manual complying with the ICC-ES Acceptance Criteria for Quality Documentation (AC10) shall be submitted.

5.2 Third-party follow-up inspections are not required under this acceptance criterion.

6.0 EVALUATION REPORT RECOGNITION

6.1 If the report applicant purchases the fibers from a fiber manufacturer, evidence is needed of an agreement between the fiber manufacturer and the applicant indicating that the manufacturer will inform the applicant of any changes to the fiber. The applicant shall then notify ICC-ES.

6.2 The evaluation report shall include the condition that the registered design professional approves the use of the fibers.

6.3 For reinforced concrete including precast concrete, the evaluation report shall indicate that reinforcement in accordance with Section 1907.12 of the IBC is to be provided, unless it is demonstrated by registered design professional based on the test results and Annex A, that the synthetic fiber-reinforced concrete provides a minimum ARS.

6.4 For shotcrete applications, the evaluation report shall indicate that reinforcement, in accordance with Section 1913.5 of the IBC shall be provided, unless it is demonstrated by registered design professional based on the test results and Annex A, that the synthetic fiber-reinforced concrete provides a minimum ARS.

6.5 For concrete over steel deck construction, the evaluation report shall indicate that reinforcement in accordance with ANSI/SDI C1.0 Section 6a, is to be provided, unless it is demonstrated by registered design professional based on the test results and Annex A that the synthetic fiber-reinforced concrete provides a minimum ARS.

6.6 For concrete used in fire-resistance-rated composite over steel deck assemblies, in addition to the requirements of Section 6.7 of this criterion, fire test

results in accordance with ASTM E 119 shall be provided to the code official for approval.

6.7 If recognition for other types of concrete, such as lightweight, is desired, results of tests conducted in accordance with this criterion shall be submitted for each type.

6.8 A batch ticket, signed by a ready-mix representative, shall be available to the code official upon request. The delivery ticket shall include, in addition to the items noted in Section 16.1 of ASTM C 94, the type and dosage of fibers added to the concrete mix.

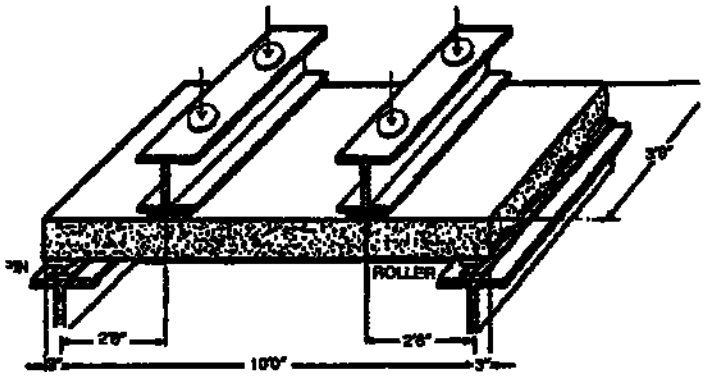

FIGURE 1 – TEST ASSEMBLY FOR SECTION 4.8 WITH 10-FOOT SPAN

A1. Definition of Stress:

Stress = Force/Area $\sigma = \frac{P}{A} = \frac{P}{bd}$, MPa (psi) **(1)**

Where

P = applied force, N, (lbf)

b = width of beam, mm (in.)

d = depth of beam, mm (in.)

Figure 1

A2. ASTM C 1399 – Definition of Average Residual Strength (ARS)

ARS = $P\,k = \frac{PL}{bd^2} = \frac{P}{bd} \times \frac{L}{d}$, MPa (psi)

Where k = $\frac{L}{bd^2}$, mm^{-2} ($in.^{-2}$)

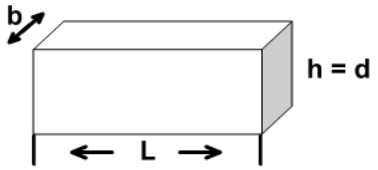

Figure 2

and P = $\frac{(P_a+P_b+P_c+P_d)}{4}$

L = span length, mm (in.)

b = average width of beam, mm (in.)

d = average depth of beam,mm (in.)

∴ (ARS) can be considered a factored stress

(ARS) = $\left(\frac{L}{d}\right) \times \frac{P}{bd}$, MPa (psi) **(2)**

Where

$\left(\frac{L}{d}\right)$ = ratio of length (L) to depth (d) of beam

and $\frac{P}{bd}$ = stress , MPa (psi)

A3. Tensile Strength of Fiber-reinforced Section

Let P = T in Equation (1)

Stress = $\sigma = \frac{T}{A} = \frac{T}{bd}$, MPa (psi) **(1a)**

Substitute factored stress (ARS) into Equation (1a)

(ARS) = $\frac{T}{bd}$, MPa (psi)

Rewrite:

T = (ARS)(bh) , N (lbf) **(3)**

Where

ARS = average residual strength from testing of a particular dosage of a particular fiber or combination of fibers. MPa (psi)

b = width of section, mm (in.)

h = depth of section,mm (in.)

A4. Flexural Strength / Moment Capacity (M_f) of Fiber-reinforced Rectangular Section

From strength of materials:

Moment of Inertia: $I = \frac{bh^3}{12}$, mm^4 (in.^{4})

Depth to Neutral Axis: $c = \frac{h}{2}$, mm (in.)

Section Modulus: $S = \frac{I}{C} = \left(\frac{bh^3}{12}\right)\left(\frac{2}{h}\right) = \frac{bh^2}{6}$, mm^3 (in.^{3})

Stress $\sigma = \frac{M_f}{S}$, N–mm/mm^3 (in.-lb/in.^{3}), MPa (psi)

Moment $M = \sigma \times \frac{bh^2}{6}$, N-mm (in.-lb)

For fiber-reinforced beam

$$\mathbf{M_f = (ARS) \times \frac{bh^2}{6}}, \text{ N-mm (in.-lb)} \quad \mathbf{(4)}$$

Where

M_f = moment capacity of fiber-reinforced section (flexural strength), N-mm (in-lb)
ARS = factored stress from ASTM C 1399,,MPa (psi)
b = width of beam, mm (in.)
h = depth of beam, mm (in.)

A5. Total Moment for steel- and fiber-reinforced concrete section

From concrete design and Whitney Stress Block:

M_n = Nominal flexural strength at section (ACI 318 definition)

$$\mathbf{M_n = A_s f_y\left(d - \frac{a}{2}\right)}, \text{ N-mm (in.-lb)} \quad \mathbf{(5)}$$

M_f = Nominal flexural strength due to fibers

$$\mathbf{M_f = (ARS) \times \frac{bh^2}{6}}, \text{ N-mm (in.-lb)} \quad \mathbf{(4)}$$

Maximum moment capacity = $\phi(M_n + M_f)$

Where

ϕ = strength reduction factor

M_u = Factored Moment at section (ACI 318)

and $$\mathbf{\phi(M_n + M_f) \geq M_u} \quad \mathbf{(6)}$$