2016 Design Training Expo

High-Strength Reinforcing & Fiber-Reinforced Concrete Design

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FDOT

HSR & FRC Design: **Outline**

Part 1: High-Strength Reinforcing (HSR)

- Introduction
- Types of HSR
- Design Rules
- Benefits
- Challenges
- Example Applications

Part 2: Fiber-Reinforced Concrete (FRC)

- Introduction
- What is FRC?
- Design and Testing
- Benefits
- Challenges
- Example Applications

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Part 1:

High-Strength Reinforcing (HSR) for Concrete Design

HSR & FRC Design: Introduction

High-Strength Reinforcing and Concrete Design… outlook:

- Designers will be challenged with greater expectations, and new responses for these enhanced materials.
- Traditional concepts of ductility and linear elastic-plastic response and analyses will be challenged. Probabilistic reliability and psuedo-ductility of composite structural systems may need to replace, traditional concepts of safety margins and minimum ductility requirements of component materials.
- Strain-based design is increasingly being used as a more consistent design approach across a variety of materials rather then the traditional stress-based design methods.

My Opinion

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HSR & FRC Design: Introduction (cont.)

- Structural Codes of Practice (AASHTO-BDS, ACI 318, AISC Steel Design Specifications, Eurocode 2, fib Model Code 2010, and many others worldwide) have already moved partially in this direction in the last 25-30 years with the adoption of LRFD based design specifications which set up a framework to implement and refine structural reliability concepts, through Strength Limit State calibration to past practice…
- In the U.S., AASHTO's SCOBS is currently involved in efforts to calibrate the Fatigue and Service Limit States to provide uniform levels of reliability for design. The Service Limit State is perhaps even more challenging than Strength and Fatigue Limit States since failure is defined by a broader range of responses some of which are somewhat arbitrarily defined based on successful past practice. These responses include: Deformations; Durability; Aesthetics; and even perceptions of safety and comfort (crack widths, vibrations, etc.).
- Replaceability, Resiliency and Sustainability are also becoming increasingly important to some owners. These are difficult to assign into our current Limit State categories and may require definition in the future of another if we want to consistently quantify them.

HSR & FRC Design: Introduction (cont.)

High Strength Reinforcing

- ***AASHTO-LRFD BDS*** adopted design provisions for use of 100 ksi reinforcing steel (for Seismic Zone 1) in the ***2013 Interims***:
  - *" **NCHRP Project 12-77** was initiated to provide an evaluation of existing* **AASHTO LRFD Bridge Design Specifications** *relevant to the use of high-strength reinforcing steel and other grades of reinforcing steel having no discernable yield plateau. An integrated experimental and analytical program to develop the data required to permit the integration of high-strength reinforcement into the LRFD Specification was performed…"* (AASHTO Bridge Committee, Ballot Item Background 11-29-2011)
  - Final project report was ***NCHRP Report 679*** *"Design of Concrete Structures Using High-Strength Steel Reinforcement"*
- ***SDG 1.4.1 -*** 2016 expanded to allow reinforcing for design :
  - ≤ Grade 75 for WWR;
  - with prior SDO approval > Grade 60 for ASTM A615, A955 & A1035 (100ksi)

HSR & FRC Design: Introduction (cont.)

High Strength Concrete

- ***AASHTO-LRFD BDS*** adopted provisions for use of 10 ksi – 15 ksi concrete in 2013 & 2015 Interims:
  - *NCHRP Report 595* - **Application of the LRFD Bridge Design Specifications to High-Strength Structural Concrete: Flexure and Compression Provisions (5/28/2007 NCHRP Project 12-64)**
  - *NCHRP Report 579* - **Application of the LRFD Bridge Design Specifications to High-Strength Structural Concrete: Shear Provisions (8/31/2006 – NCHRP Project 12-56)**
  - *NCHRP Report 603* - **Transfer, Development, and Splice Length for Strand/Reinforcement in High-Strength Concrete (5/28/2007 - NCHRP Project 12-60)**

- ***SDG 1.4.3 -*** 2016 added ***Table 1.4.3-2*** for Minimum 28-Day Compressive Strength for Design
  - $\leq$ 8.5 ksi for Conventional Projects (Design-Bid-Build)
  - $\leq$ 10 ksi* for Non-Conventional Projects (Design-Build, PPP, etc.)

  * No standard concrete class > 8.5 ksi in ***Specification 346.***

HSR & FRC Design: Introduction (cont.)

Structural Elements that may benefit from HSR:

1. Large difference between Strength and Service Loads
2. Not sensitive to modest increase in deflections:
3. Good Candidates:
   - ✓ Wind Loads govern (e.g. Noise Walls – Post and/or Panels)
   - ✓ Extreme Event controls (e.g. Traffic Railings; Truck-Impacted Bridge Column**; Ship-Impacted substructures;
   - ✓ Combined Axial-Flexure Designs = Heavily Congested Drilled Shafts.

     **Not Pile Bent and Piers Caps in Florida, due to 24 ksi Service III tension limit.
4. Poor Candidates:
   - ❖ Buried Structures (e.g. Box Culverts, Drainage Structures);
   - ❖ Bridge Pier Caps.

HSR & FRC Design: Types of HS Rebar

- Low-carbon Chromium Steel (ASTM A1035 – Grade 100 & 120)
- Stainless Steel (ASTM A276 or ASTM A955 – Grade 75)
- Welded Wire Reinf. (ASTM A1064 – Grades 65-75, 80+)
- Carbon-steel (ASTM A615/A706 Grade 75, 80 & 100)
- Carbon FRP Rebar (UTS 160 - 210 ksi)
- Glass FRP Rebar (UTS 80 - 125 ksi)
- Basalt FRP Rebar (UTS ~ 150 ksi)

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HSR & FRC Design: Types of HS Rebar

- FDOT ***Specifications*** Section 931:

931-1 Reinforcement Steel (for Pavement and Structures).

931-1.1 Steel Bars:

931-1.1.1 Carbon Steel Bars: ~~Unless otherwise shown in the Plans, billet~~Carbon steel bars for concrete reinforcement shall conform to the requirements of ASTM A615 Grades 60 or 75 except that the process of manufacture will not be restricted. For processes not included in ASTM A615 the phosphorus content will be limited to 0.08%.

931-1.1.2 Stainless Steel Bars: Stainless steel bars for concrete reinforcement shall conform to the requirements of ASTM A955, Grades 60 or 75; or ASTM A276, UNS S31653 or S31803.

931-1.1.3 Low-Carbon Chromium Steel Bars: Low-carbon chromium steel bars for concrete reinforcement shall conform to the requirements of ASTM A1035 Grade 100.

931-1.2.2 Stainless Steel Wire Reinforcement: Plain and deformed stainless steel wire reinforcement shall meet the requirements of ASTM A276, UNS S30400.

931-1.2.3 Acceptance of Wire Reinforcement: Acceptance of wire reinforcement shall be based on the manufacturer's certified mill analysis certifying that the test results meet the specification limits of the ASTM designation for the particular sizes and any additional requirements. Prior to use, submit to the Engineer the manufacturer's certified mill analysis for each heat and size per shipment.

931-1.3 Carbon Steel Welded Wire Reinforcement:

931-1.3.1 ~~Plain~~Carbon Steel Welded Wire Reinforceme~~ing~~ment ~~Steel~~: ~~Unless otherwise shown in the Plans, plain w~~Welded wire reinforcing steel shall meet the requirements of ASTM A1064.

HSR & FRC Design: Types of HS Rebar

- FDOT ***Specifications*** Section 932:

932-3 Fiber Reinforced Polymer (FRP) Reinforcing Bars.

932-3.1 General: Use only solid round thermoset pultruded glass fiber reinforced polymer (GFRP) or carbon fiber reinforced polymer (CFRP) reinforcing bars. All FRP reinforcing bars shall meet the requirements of ACI 440.6 following the test methods from ACI 440.3. Use only GFRP bars manufactured using glass fibers classified as E-CR or R that meet the requirements of ASTM D578. Meet the additional requirements of this Section following the sampling frequency and number of specimens required by ACI 440.6.

Table 3-1
Size and Strength of FRP reinforcing bars

Bar Size Designation	Nominal Bar Diameter (in)	Nominal Cross Sectional Area (in^2)	Maximum Cross Sectional Area (in^2)	f^*_{fu}, Guaranteed Ultimate Tensile Strength (ksi)	
				GFRP Bars	CFRP Bars
2	1/4	0.049	0.058	125	210
3	3/8	0.110	0.132	120	190
4	1/2	0.196	0.234	110	170
5	5/8	0.307	0.367	95	160
6	3/4	0.442	0.529	92.5	160
7	7/8	0.601	0.721	90	-
8	1	0.785	0.942	85	-
9	1-1/8	0.994	1.192	82.5	-
10	1-1/4	1.227	1.472	80	-

HSR & FRC Design: Types of HS Rebar

Unit Prices for Rebar

(Materials-only, except as noted; early 12)

	Cost/lb (U.N.O.*)
Black (#4)	.48
Epoxy (#4)	.70
Epoxy II	.50
Galvanized	.68-.73
Purple ECR (includes fabric.)	1.18
Z-bar (includes fabric. & transport.)	1.25-1.50

MMFX-2 (stock length)	.94
Solid SS (#7) (w/surcharge)	2.02-2.95
Basalt FRP (10 mm) ($$/ft)*	0.64 (19.2 kip)
FRP ($$/sq ft)* (#5 and #6) ($$/lin ft)*	5 -6.60 1. -1.44

Source: Louis N. Triandafilou, P.E. FHWA Office of Infrastructure R&D (2012)

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HSR & FRC Design: Design Rules

Basics of 100 ksi Steel Reinforcing:

- ASTM A1035 (Low-Carbon Chromium Reinforcing Steel is compatible (may be in direct contact) with ASTM A615 reinforcing
- Does not have a well defined yield plateau
  - Yield strength is determined by:
    - 0.2% offset
    - 0.35% or 0.5% extension
- Allowable Yield stress in tension and compression are not the same.
  - Tension yield = 100 ksi
  - Compression yield = 80 ksi
- At concrete ultimate design strain (0.0030), steel has not yielded (yield strain = 0.00345 – 0.004)

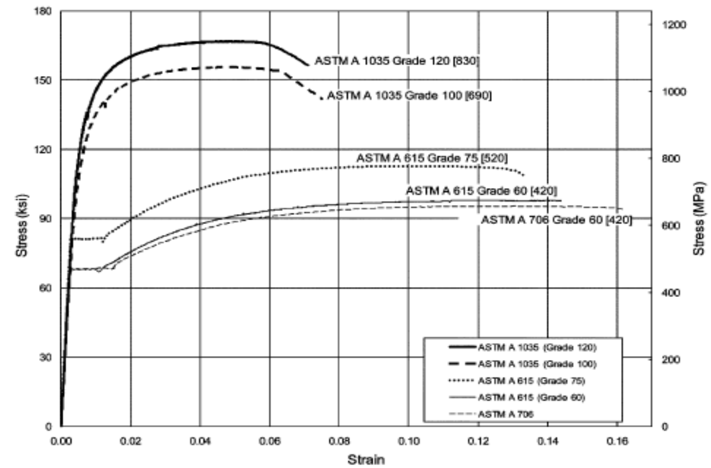


Fig. 1.1—Actual stress-strain curves for ASTM A615/A615M, ASTM A706/A706M, and ASTM A1035/A1035M reinforcing bars of different grades (WJE 2008).

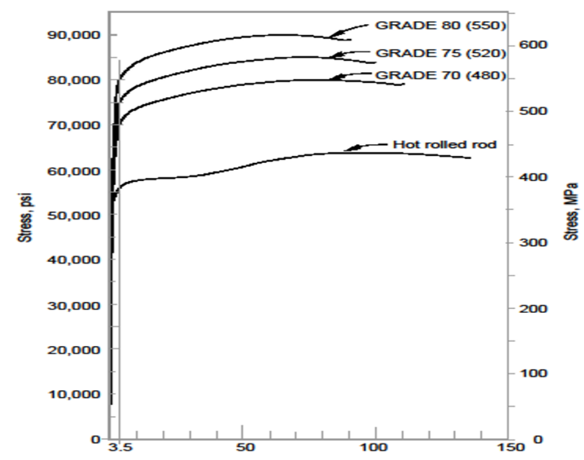
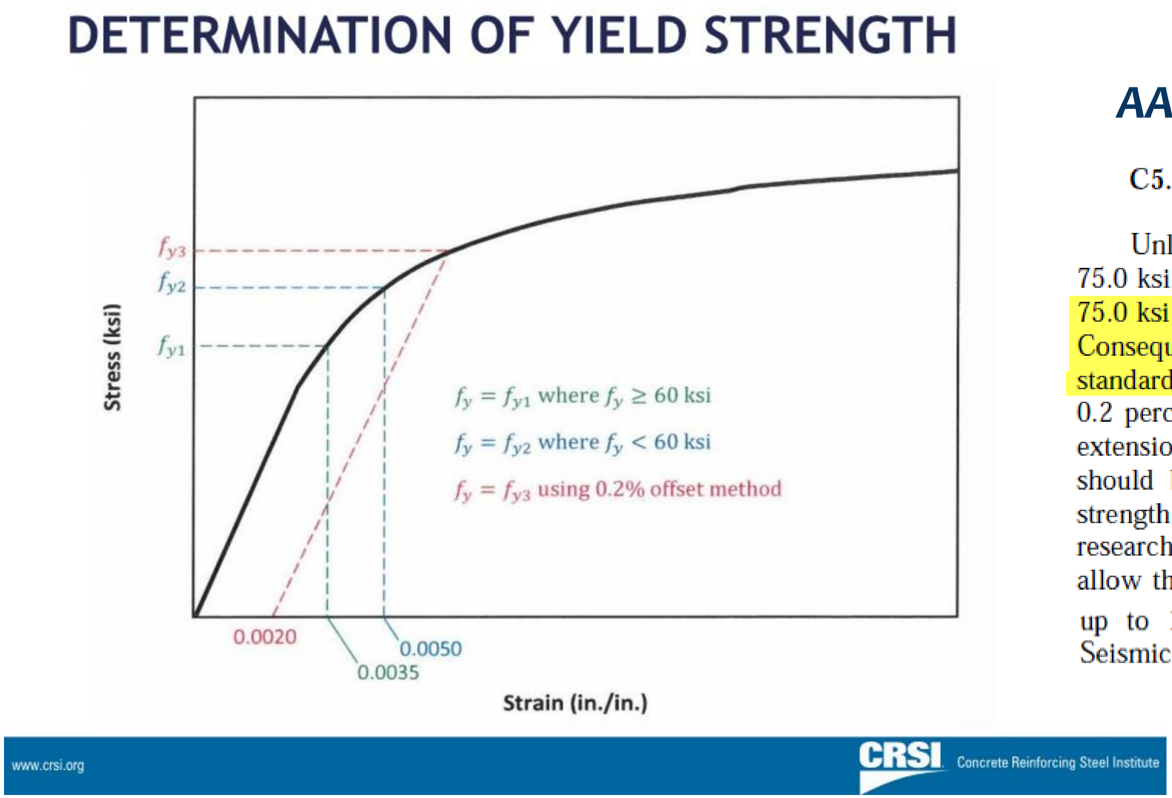


Figure 3.2 Idealized stress-strain curves for ASTM A 1064 / ASTM 1064M wire

HSR & FRC Design: Design Rules



AASHTO LRFD – Chapter 5

C5.4.3.1

Unlike reinforcing bars with yield strengths below 75.0 ksi, reinforcing bars with yield strengths exceeding 75.0 ksi usually do not have well-defined yield plateaus. Consequently, different methods are used in different standards to establish yield strengths. These include the 0.2 percent offset and the 0.35 percent or 0.50 percent extension methods. For design purposes, the value of f_y should be the same as the specified minimum yield strength defined in the material standard. Based on research by Shahrooz et al. (2011), certain articles now allow the use of reinforcing steels with yield strengths up to 100 ksi for all elements and connections in Seismic Zone 1.

HSR & FRC Design: Design Rules

Basics of 100 ksi Reinforcing:

- Added to ***AASHTO LRFD 6th Edition (2013 Interims)***
- Modulus of Elasticity (E_s) remains the same (29,000 ksi).
- Reduction of reinforcing (A_s) possible with the use of higher strength concretes.
- Bar Bending for the same diameter will be more difficult (field bending)
- Transverse reinforcing may require tighter spacing .
  - Confined concrete section to restrain longitudinal bars from buckling.
- Both tension and compression mild steel reinforcement must yield for accurate results:
  - Require equilibrium and strain compatibility to determine flexural resistance;
  - If $c \geq 3d_s$ and $f_y \leq 60$ ksi => f_s may be replaced by f_y;
  - If $c < 3d_s$ or $f_y > 60$ ksi => use strain compatibility or ignore compression reinforcement;
  - Maximum stress (f_s) is $\leq f_y$.

HSR & FRC Design: Design Rules

Basics of 100 ksi Reinforcing:

- ε_{cl} = 0.002 for yield strength of 60 ksi
- ε_{cl} = 0.004 for yield strength of 100 ksi
- ε_{cl} = linear interpolation based on specified min yield strength between 60 & 100 ksi.

Compressive strain limits

- ε_{tl} = 0.005 for yield $\leq$ 75 ksi
- ε_{tl} = 0.008 for yield of 100 ksi
- ε_{tl} = linear interpolation based on specified min. yield strength between 75 & 100 ksi

Tensile strain limits

HSR & FRC Design: Design Rules

Basics of 100 ksi Reinforcing:

- ***AASHTO LRFD*** 5.7.2 - Assumptions for Strength and Extreme Event Limit states

Table C5.7.2.1-1—Strain Limits for Nonprestressed Reinforcement

Specified Minimum Yield Strength, ksi	Strain Limits	
	Compression Control ε_{cl}	Tension Control ε_{tl}
60	0.0020	0.0050
75	0.0028	0.0050
80	0.0030	0.0056
100	0.0040	0.0080

Theoretical Yield strain based on E_s = 29,000 ksi

~ 0.0021

~ 0.0026

~ 0.0028 (7% more strain for ε_{cl})

~ 0.0034 (15% more strain for ε_{cl})

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HSR & FRC Design: **Design Rules**

Basics of 100 ksi Reinforcing:

- ***AASHTO LRFD*** - Resistance Factors Equations 5.5.4.2.1-1 & 5.5.4.2.1-2

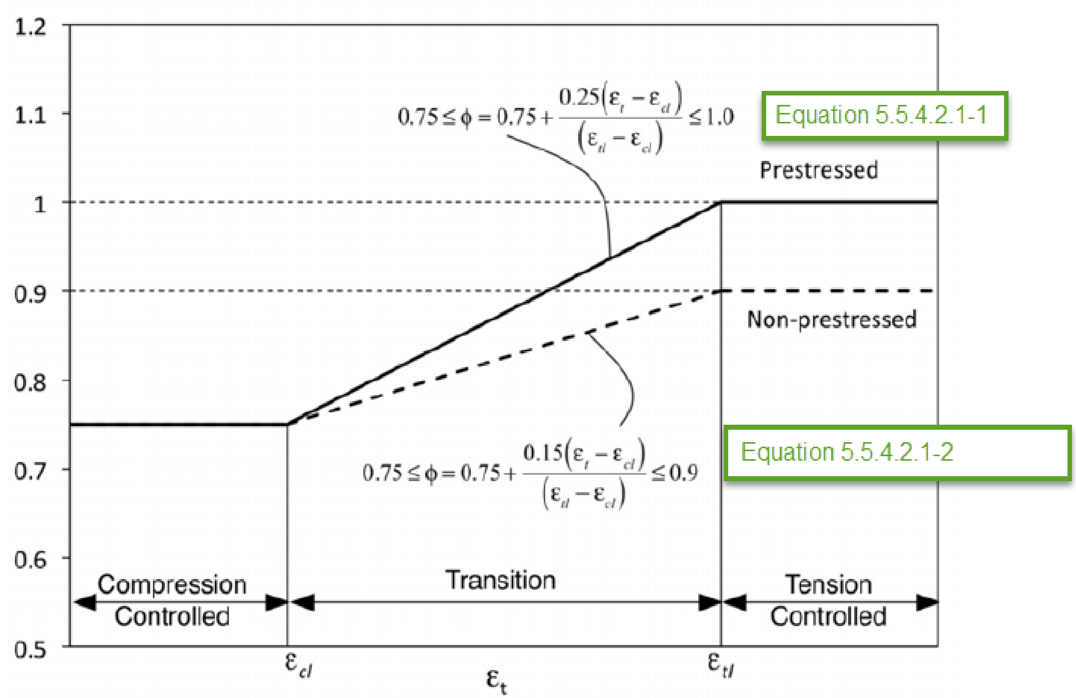

Figure C5.5.4.2.1-1—Variation of ϕ with Net Tensile Strain ε_t for Nonprestressed Reinforcement and for Prestressing Steel

HSR & FRC Design: Benefits

- Increased Flexural and Shear Strength;
- Reduced congestion;
- Reduced transportation and placement cost;
- Many high strength reinforcing materials also have improved durability properties.

HSR & FRC Design: **Challenges**

- Meeting Service Limit State crack control requirements
- Phi factors for M-N Interaction in FBMP can not be set to address transition and max. limits at different strains for different tensile materials;
- FRP bar bends




Strength of bent portion of a bar	ACI 440.3, Method B.5	>60% of straight portion of bar
Transverse Shear Strength	ASTM D7617	>22 ksi
Bond Strength	Block pull-out by ACI 440.3R, Method B.3	>1.1 ksi

932-3.4.1 Certification: Meet the testing requirements of Table 3-3 for product acceptance. Submit to the Engineer a certification from the producer of the FRP bars, confirming

HSR & FRC Design: Example Application

Noise Wall Posts:

- Current Index 5200 limits post spacing to 15’ for 20’-22’ tall wall in 150 mph wind zone.
- Designs are based on:
  - Use of a single post cross section shape;
  - Minimum bar spacing and concrete cover criteria;
  - Grade 60 reinforcing.

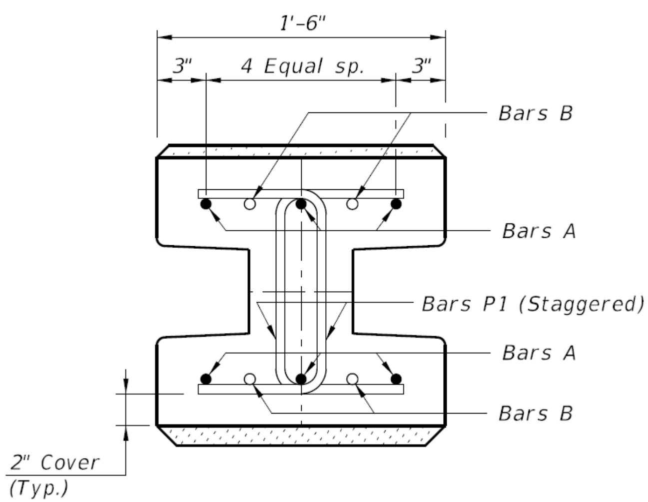

TABLE 3A - TABLE OF POST REINFORCING STEEL

WALL HEIGHT (Feet)	POST LENGTHS		WIND SPEED = 150 MPH											
			10'-0" POST SPACING						20'-0" POST SPACING					
	WITHOUT CAP	WITH CAP	BARS A	BARS B		BARS D	BARS E		BARS A	BARS B		BARS D	BARS E	
			SIZE	SIZE	DIM 'A'	SIZE	SIZE	DIM 'A'	SIZE	SIZE	DIM 'A'	SIZE	SIZE	DIM 'A'
12	13'-0½"	13'-2½"	#4	#4	9'-5"	#5	#5	10'-2"	#7	#7	10'-4"	#7	#7	8'-4"
13	14'-0½"	14'-2½"	#5	#5	11'-2"	#5	#5	10'-2"	#7	#7	10'-4"	#7	#7	8'-4"
14	15'-0½"	15'-2½"	#5	#5	11'-2"	#5	#5	10'-2"	#8	#8	11'-10"	#8	#8	9'-10"
15	16'-0½"	16'-2½"	#5	#5	11'-2"	#6	#6	11'-9"	#8	#8	11'-10"	#8	#8	9'-10"
16	17'-0½"	17'-2½"	#6	#6	13'-9"	#6	#6	11'-9"	#8	#9	11'-3"	#8	#9	9'-3"
17	18'-0½"	18'-2½"	#6	#6	13'-9"	#7	#7	13'-4"	#9	#8	12'-10"	#9	#8	10'-10"
18	19'-0½"	19'-2½"	#6	#6	13'-9"	#7	#7	13'-4"	#9	#10	11'-7"	#9	#10	9'-7"
19	20'-0½"	20'-2½"	#7	#7	15'-4"	#7	#7	13'-4"	#10	#9	14'-3"	#10	#9	12'-3"
									15'-0" POST SPACING					
20	21'-0½"	21'-2½"	#7	#7	15'-4"	#8	#8	14'-10"	#9	#9	15'-3"	#9	#9	12'-3"
21	22'-0½"	22'-2½"	#7	#8	14'-10"	#8	#8	14'-10"	#10	#9	15'-3"	#10	#9	14'-3"
22	23'-0½"	23'-2½"	#7	#8	14'-10"	#8	#8	14'-10"	#10	#10	16'-7"	#10	#10	13'-7"

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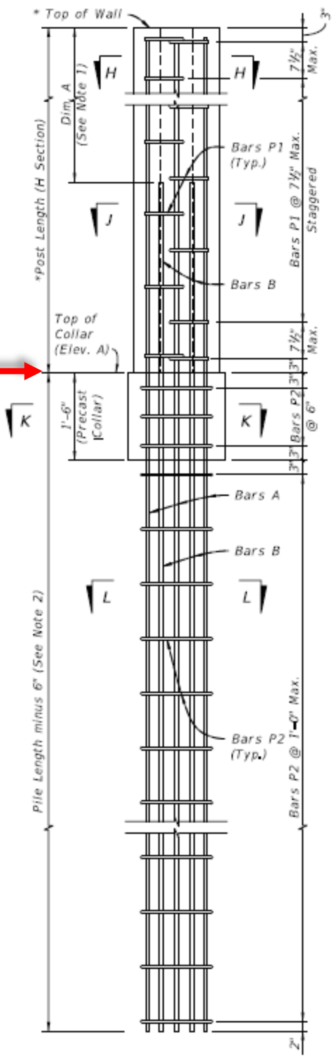
HSR & FRC Design: Example Application

Noise Wall Posts:

- Summary of Strength III Loads for 20' Post Spacing

20 foot Spacing - Strength III

SHEARS			MOMENTS		
V110 (k)	V130 (k)	V150 (k)	M110 (k*ft)	M130 (k*ft)	M150 (k*ft)
9.78	13.65	18.18	63.54	88.75	118.16
10.53	14.70	19.58	73.69	102.93	137.03
11.28	15.75	20.97	84.60	118.16	157.31
12.03	16.80	22.37	96.25	134.44	178.98
12.79	17.87	23.79	108.81	151.98	202.34
13.56	18.94	25.22	122.30	170.82	227.42
14.34	20.03	26.67	136.72	190.96	254.24
15.13	21.14	28.14	152.09	212.42	282.81
15.93	22.25	29.62	168.40	235.20	313.14
16.74	23.38	31.12	185.67	259.32	345.25
17.55	24.51	32.64	203.89	284.78	379.14



TYPICAL POST

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HSR & FRC Design: Example Application

Noise Wall Posts:

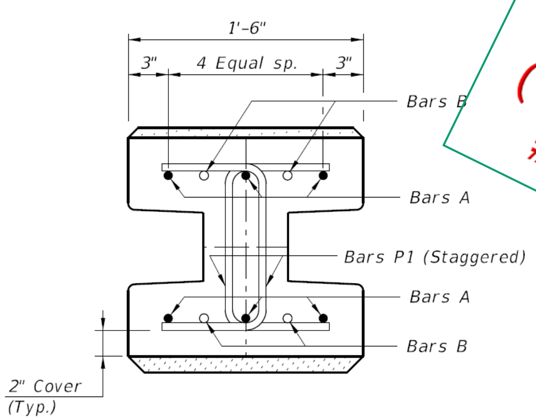
- Compare design for Grade 60 with no limits on bar spacing;
- Reinforcing cost difference per 1000 ft. of wall;
- 20’ spacing vs. 15’ spacing *:

20’ = $ 7,100

21’ = $ 18,300

22’ = $ 42,000

* Larger bar sizes, and same cost/lb. Reinforcing cost is increase at 20 foot spacing, but 25% (16) less shafts (cost saving not included).



60 ksi at 15’ spacing: φ = 0.90 all

- 20’ = $72,000 (As = 5.00 in^2) Mu = 245 kip-ft.
- 21’ = $88,100 (As = 5.81 in^2) Mu = 270 kip-ft.
- 22’ = $97,400 (As = 6.35 in^2) Mu = 295 kip-ft.

60 ksi at 20’ spacing

- 20’ = $79,100 (As = 6.93 in^2) Mu = 313 kip-ft. & φ = 0.82
- 21’ = $106,400 (As = 9.18 in^2) Mu = 345 kip-ft. & φ = 0.75
- 22’ = $139,400 (As = 11.25 in^2) Mu = 379 kip-ft. & φ = 0.75

Fictitous Design
(would need to widen post for #11 &/or #14 Bars in flange)

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HSR & FRC Design: Example Application

Noise Wall Posts:

- Compare design for Grade 100 vs. Grade 60;
- Reinforcing cost difference per 1000 ft. of wall;
- 20' spacing (Gr. 100) vs. 15' spacing (Gr. 60):

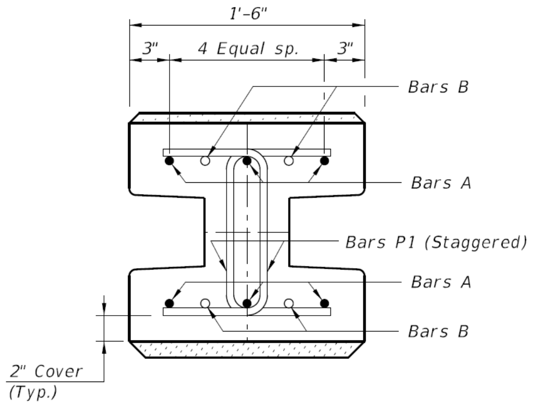
  20' = $ 4,400 (6%) - savings

  21' = $ 10,200 (12%) - savings

  22' = $ -10,700 (11%)*

*** 20% reduction in weight, but 11% increase in cost,** However, 25% (16) less shafts (cost saving not included).

- Cost per Pound (Installed) ***SDG 9.2.1 F***
  - Carbon Steel (60 ksi) = **$0.90/lb.**
  - Low-Carbon Chromium (100 ksi) = **$1.25/lb.**



60 ksi at 15' spacing: φ = 0.90 all

- 20' = $72,000 (As = 5.00 in^2) Mu = 245 kip-ft.
- 21' = $88,100 (As = 5.81 in^2) Mu = 270 kip-ft.
- 22' = $97,400 (As = 6.35 in^2) Mu = 295 kip-ft.

100 ksi at 20' spacing:

- 20' = $67,600 (As = 3.00 in^2) Mu =313 kip-ft.
- 21' = $77,900 (As = 3.95 in^2) Mu =345 kip-ft.
- 22' = $108,100 (As = 5.81 in^2) Mu =379 kip-ft. & φ = 0.80

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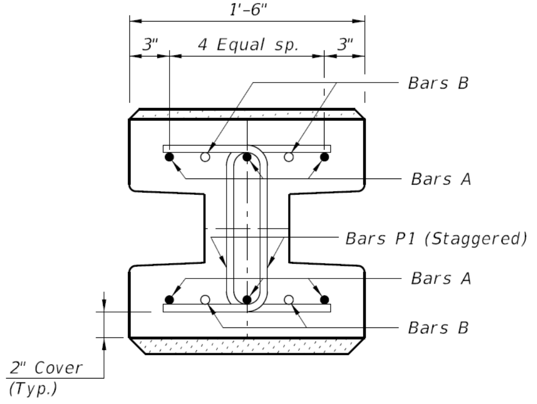
HSR & FRC Design: Example Application

Noise Wall Posts - Summary:

- Break even point for cost of 100 ksi vs. 60 ksi reinforcing:
  - < 28% reduction in weight at given costs ($0.90, & $1.25 per lb.)
- 100 ksi is more cost effective with higher strength concrete mixes
- Deflection may increase (less rigid with smaller bar sizes)
- More transverse reinforcing may be necessary (compression controlled sections).
- Development lengths: Depending on bar diameters, concrete compressive strength and yield strength, more (or less) length may be required.



HSR & FRC Design:

Recommended Reading Resources:

- Applied Technology Council: **ATC 115** *Roadmap for the Use of High-Strength Reinforcement in Concrete Design* (2014);
- **ACI ITG-6R-10** *Design Guide for the Use of ASTM A1035/A1035M Grade 100 (690) Steel Bars for Structural Concrete*. ACI Innovation Task Group 6, August 2010;
- **NCHRP Report 679** *Design of Concrete Structures Using High-Strength Steel Reinforcement* (2011);
- **NCHRP 2014-D-09** **Research Needs Statement** - *Ductility of Concrete compression Members made with High Strength Reinforcement with minimum yield strength up to 100 ksi to Seismic Loading* (2015).

Part 2:

Fiber-Reinforced Concrete (FRC) Design

HSR & **FRC** Design: **Introduction**

1. What is FRC?
2. Benefits
3. Design and Testing
4. Example Applications
5. Challenges

What is Fiber-Reinforced Concrete (FRC)?

Types of Fibers:

- Materials - Steel, Basalt, Carbon, Glass, Polymeric (acrylic, aramid, nylon, polyethylene, polyester, polypropylene, PVA), Cellulose…
- Shape - Straight, Hooked, Twisted & Flat, Round, or Polygon cross sections;
- Size – Macro and Micro

Type of Concrete:

- Usually conventional concrete;
- SCC possible;
- Admixtures – usually on need a superplasticizer (HWRA)

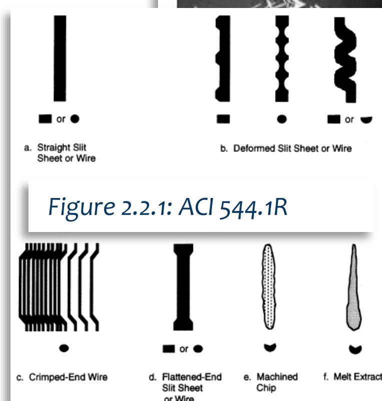
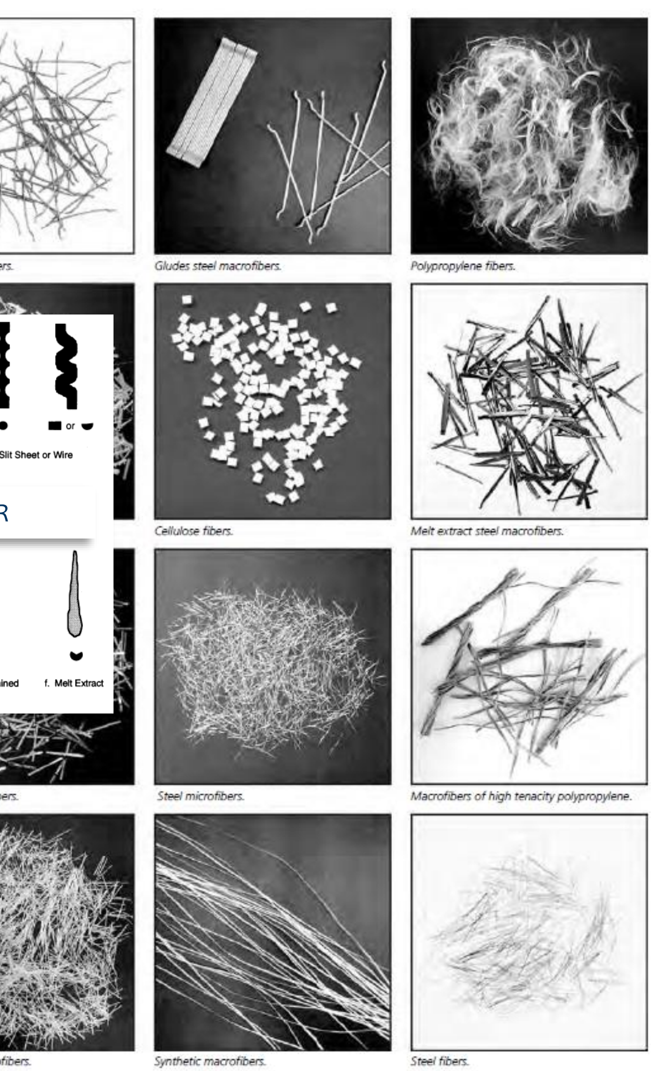


Figure 2.2.1: ACI 544.1R

Photo: ACI 544.1R



Photos: Courtesy of Maccaferri Technical Manual "Fibers as Structural Element for the Reinforcement of Concrete".

What is FRC… History

Horse hair in Mortar & Straw in clay. Oldest house in USA is adobe built in $\pm$1540

Egyptians used straw to reinforce mud bricks

First application: airfields in World War I

1911 SFRC first patented in USA

1970 Hooked end fibers developed by Bekaert

1973 bundled (glued) fibers - by Bekaert

Today - floors, pavements, overlays, shotcrete, tunnels, refractory, precast..

1600 1700 1800 1900 2000

Source: Bekaert Presentation "*Steel Fiber Reinforced Concrete Design & Construction*" (2014)

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What is FRC… Manufactures

ReforceTech™
Basalt Fiber Reinforcement Technology

FORTA®

Royal
ENTERPRISES AMERICA™

abcpolymer™
an international plastics group

Fabpro
Performance Concrete Products

BEKAERT
better together

BASF
We create chemistry

FibraShield® Max
Synthetic Macro Fiber

HELIX™

Propex™ Fibermesh®

NYCON

FRC
INDUSTRIES

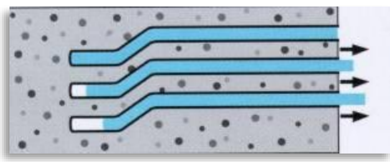
GRACE
Talent | Technology | Trust™

BUILDING TRUST
Sika®

EUCLID CHEMICAL

What is FRC… Basic Principles

The Performance of Structural Fibers Depends On :



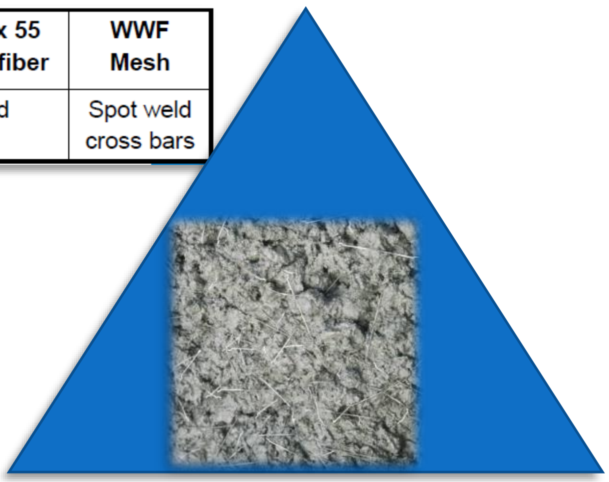
Anchorage mechanism
(shape, surface friction, adhesion)

RC80/30BP Steel fiber	RC65/60BN Steel fiber	WiremixW40 Steel Fiber	Synmix 55 Plastic fiber	WWF Mesh
Hooked	Hooked	Continuous deformed	Bond	Spot weld cross bars

Aspect Ratio

Performance Concrete

Dosage Rates



Tensile strength of the fiber material

RC80/30BP Steel fiber	RC65/60BN Steel fiber	WiremixW40 Steel Fiber	Synmix 55 Plastic fiber	WWF Mesh
445 ksi	161 ksi	105 ksi	100 ksi	72 ksi

Aspect Ratio: Length to Diameter ratio L/D

	RC80/30BP	RC65/60BN	RL45/50BN
Length	1.18 in (30mm)	2.36 in (60mm)	1.97 in (50mm)
Diameter	0.015 in (0.38mm)	0.038 in (0.9mm)	0.041 in (1.05mm)
Aspect Ratio	80	67	47

Source: Bekaert Presentation "*Steel Fiber Reinforced Concrete Design & Construction*" (2014)

What is FRC… Hybrid Systems

The Performance of Structural Systems can be enhanced with multi-component synergy:

Concrete:
(Cementitious = OPC -strength, Flyash -heat/packing, Slag-heat/packing, Silica Fume -high density;
Aggregates = Fine NWA/LWA -IC, Course NWA/LWA -weight;
Admixtures=SRA,HRWA -workability/W/C -permeability)

Longitudinal Tensile Reinforcing:
(Steel/GFRP/ CFRP rebar and/or prestressing)

Fibers:
(micro = Polymer -*shrinkage/ anchorage of macro fibers*;
macro = Polymer -*fire resistance,* & Steel -*crack control, ultimate strength*)

HSR & FRC Design: Benefits

1. Reduction or elimination of bar reinforcing;
2. Less congestion;
3. Lower labor costs;
4. Smaller crack sizes;
5. Better distribution of localized stresses;
6. Can provide additional confinement;

HSR & **FRC** Design: **Design and Testing**

- FRC Design & Testing Guidelines
  - European vs. USA
  - *fib* vs. ACI & ASTM
- Fiber Manufacturer Research:
- *Structures Manual (SDG)*

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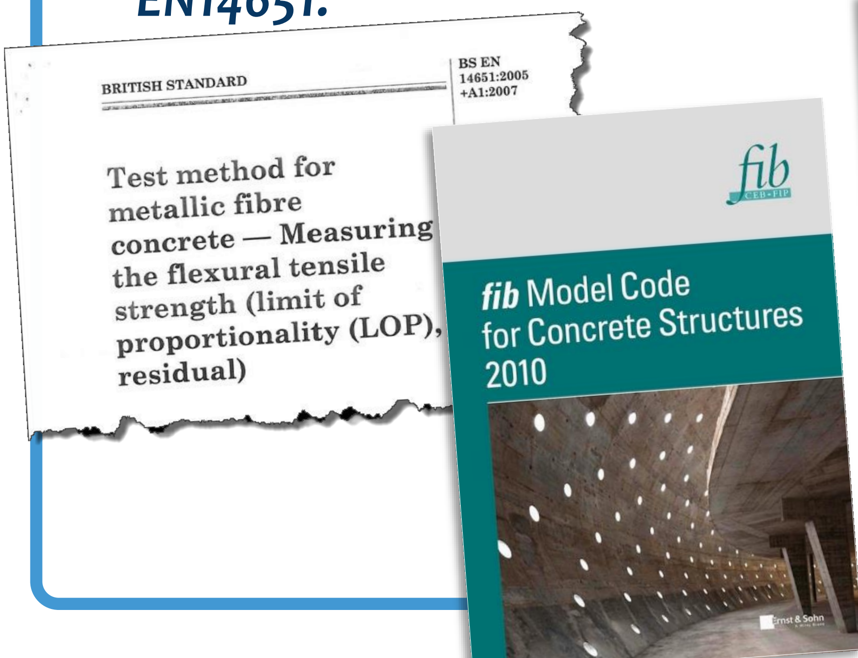
FRC Design & Testing Guidelines

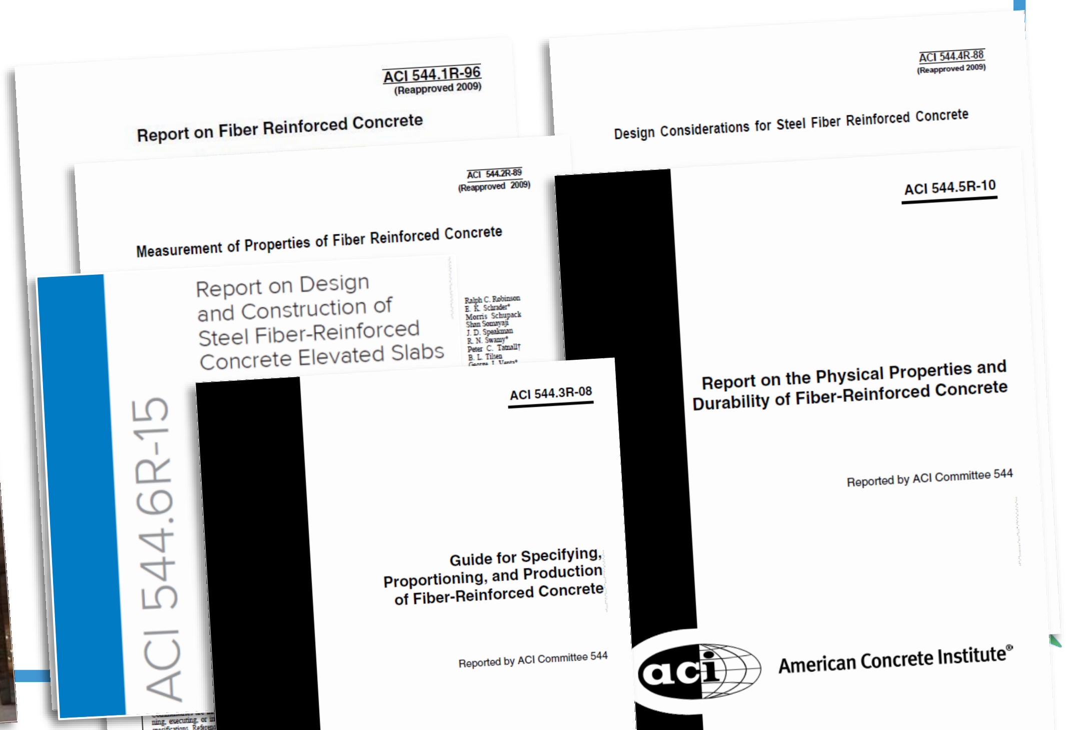
fib Model Code 2010 (CEB-FIP Europe):

- Rational design method based on characteristic material properties;
- Simplified (rigid-plastic)or refined (linear post-cracking) methods;
- Material testing requirements ***EN14651.***

ACI 544 (USA):

- No codified Design Specification, but good background information;
- ARS is empirical design method;
- ASTM test methods do not adequately characterize properties for ultimate strength design.

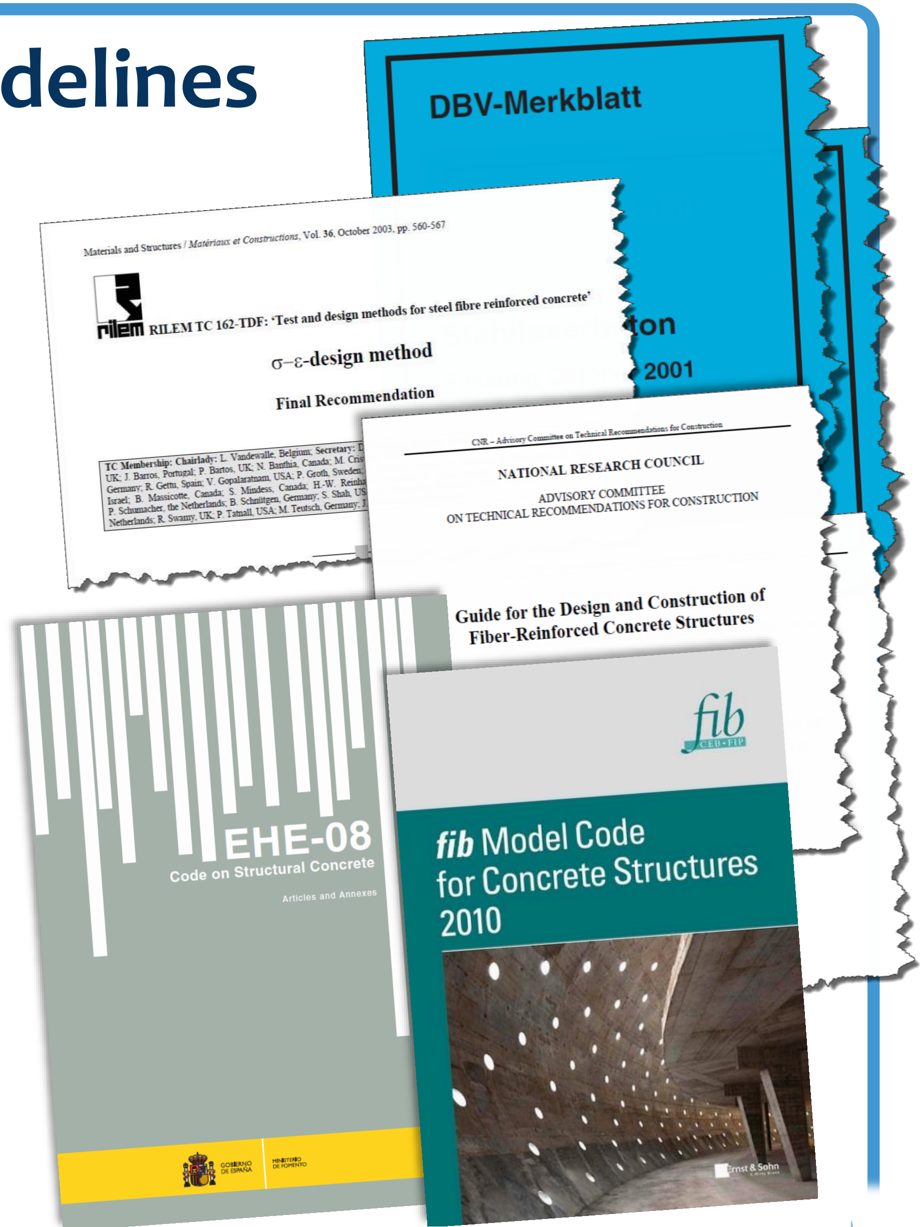




FRC Design & Testing Guidelines

European Code Development :

- 2001 - **DBV** Merkblatt Stahlfaserbeton, Deutsche Beton Vereins, Germany
- 2003 - **RILEM TC 162-TDF**. Test and design methods for steel fibre reinforced concrete - σ-ε design method
- 2006 - **CNR-DT 204**. Istruzioni per la Progettazione, l'Esecuzione ed il Controllo di Strutture Fibrorinforzato, Consiglio Nazionale delle Riserche, Italy.
- 2008 - **EHE-08** Instrucción del Hormigón Estructural, Comisión Permanente del Hormigón (Ministerio de Fomento), Spain
- 2013 - **Model Code 2010**, Comité Euro-International du Beton-Federation (*fib*)



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FRC Design & Testing Guidelines

fib Model Code 2010 (CEB-FIP Europe):

- Design …

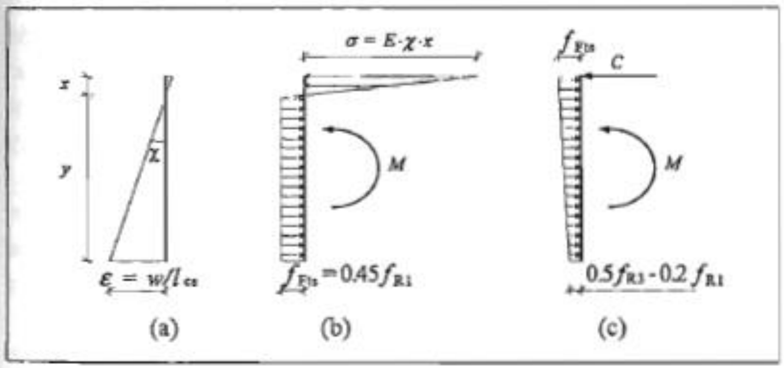
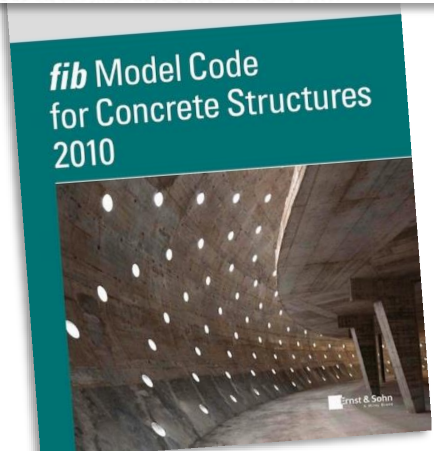
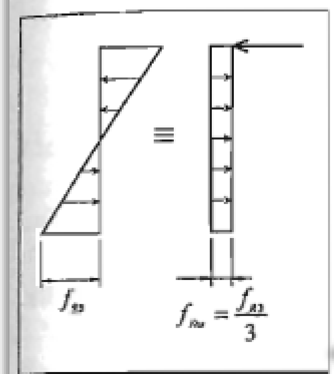


Figure 5.6-9: Stress diagrams for the determination of the residual tensile strength f_{Fts} (b) and f_{Ftu} (c) for the linear model, respectively



$$M_u = \frac{f_{R3} b h_{sp}^2}{6} = \frac{f_{Ftu} b h_{sp}^2}{2}$$



← Rigid-Plastic Model

Figure 5.6-8: Simplified model adopted to compute the ultimate residual tensile strength in uniaxial tension f_{Ftu} by means of the residual nominal bending strength f_{R3}

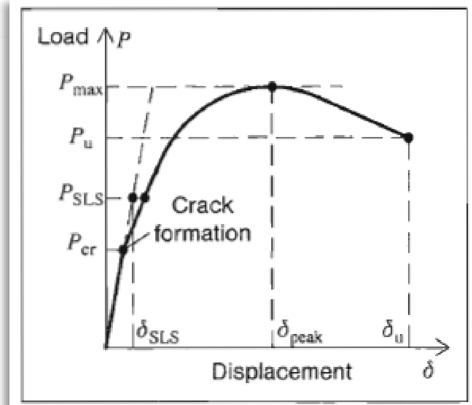


Figure 7.7-1: Typical load (P) – displacement (δ) curve for a FRC structure

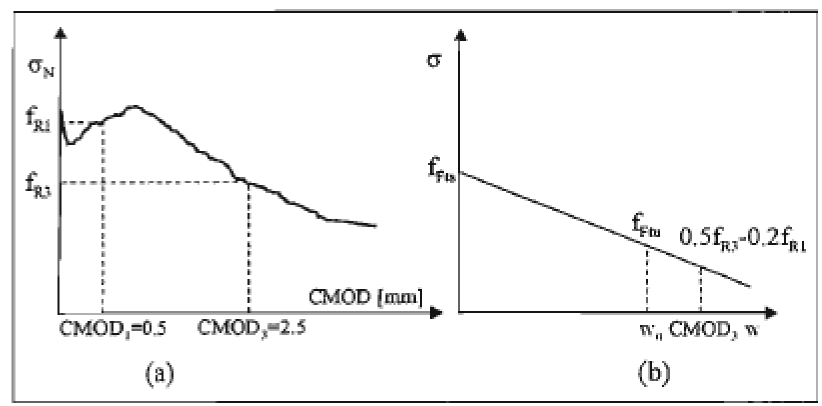


Figure 5.6-10: Typical results from a bending test on a softening material (a); linear post-cracking constitutive law (b)

FRC Design & Testing Guidelines

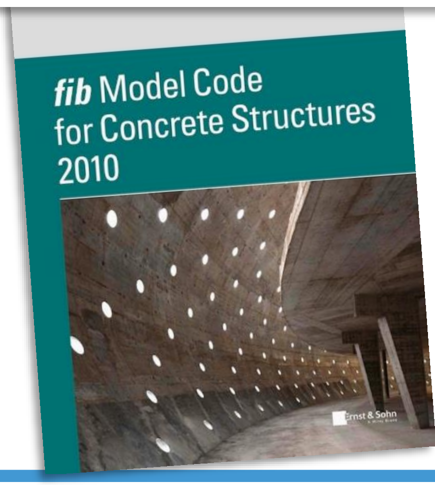
fib Model Code 2010 (CEB-FIP Europe):

- … Design

Table 5.6-1: Partial safety factor

Material	Partial safety factors
FRC in compression	As plain concrete
FRC in tension (limit of linearity)	As plain concrete
FRC in tension (residual strength)	$\gamma_F = 1.5$

For serviceability limit states (SLS), the partial factors should be taken as 1.0



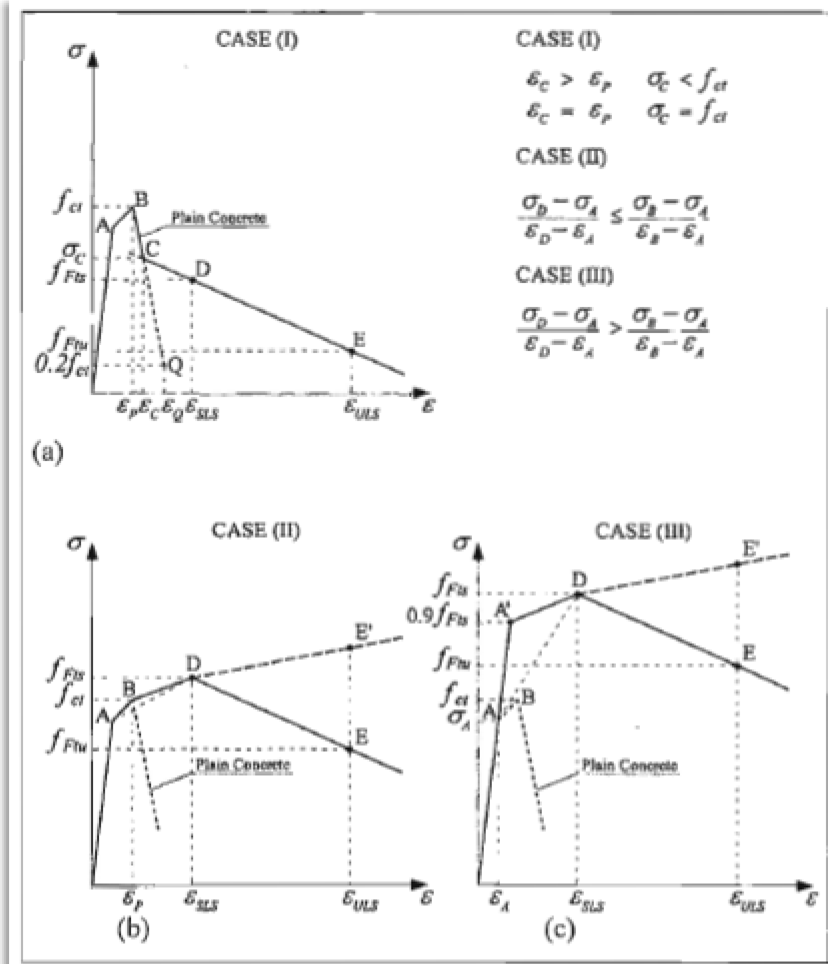


Figure 5.6-11: Stress–strain relations at SLS for softening (a) and softening or hardening (b, c) behaviour of FRC

FRC Design & Testing Guidelines

EN 14651
(European Standard):

- Testing….


EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 14651

June 2005

ICS 91.100.30

English version

Test method for metallic fibered concrete - Measuring the flexural tensile strength (limit of proportionality (LOP), residual)

Méthode d'essai du béton de fibres métalliques - Mesurage de la résistance à la traction par flexion (limite de proportionnalité (LOP), résistance résiduelle)

Prüfverfahren für Beton mit metallischen Fasern - Bestimmung der Biegezugfestigkeit (Proportionalitätsgrenze, residuelle Biegezugfestigkeit)

This European Standard was approved by CEN on 3 April 2005.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

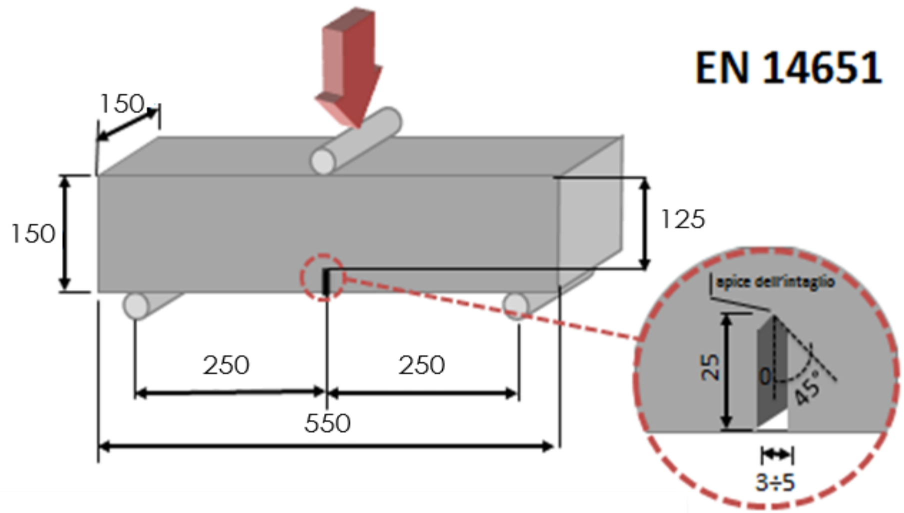
This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

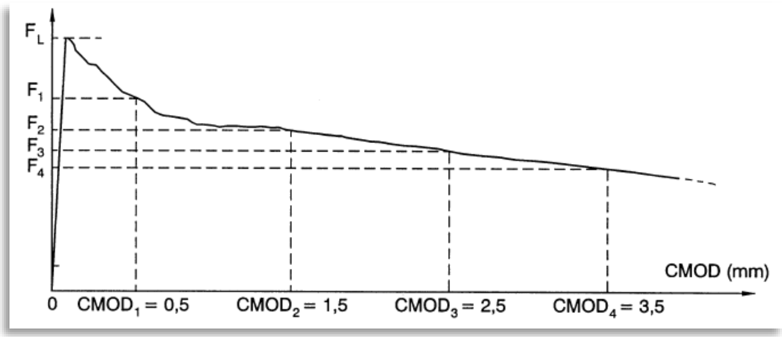
CEN members are the national standards bodies of Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 14651:2005: E





Units: mm

Source: EN 14651-05

Residual Strength:

$$f_{R,j} = \frac{3LF_j}{2bh_{sp}^2}$$

Limit of proportionality:

$$LOP = \frac{3LF_L}{2bh_{sp}^2}$$

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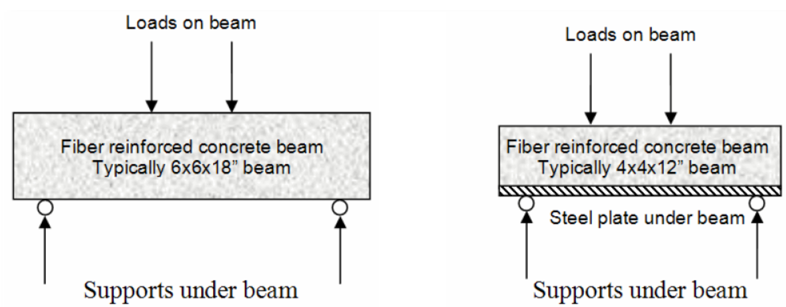
FRC Design & Testing Guidelines

ASTM's for FRC:

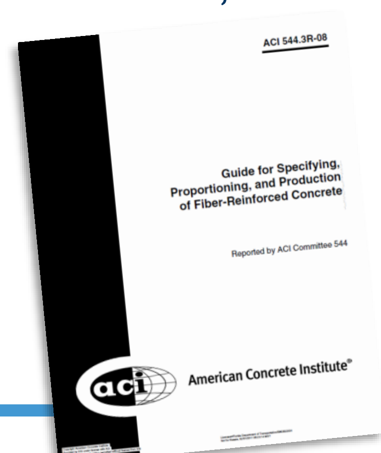
- ASTM C1116 *– Standard Specification for FRC;*
  - ASTM C820 - *Standard Specification for Steel Fibers for FRC;*
  - ASTM C1399 *– Standard Test Method for Obtaining ARS;*
  - ASTM C1550 *– Standard Test Method for Flexural Toughness (Using Centrally Loaded Round Panel);*
  - ASTM C1609 *– Standard Test Method for Flexural Performance of FRC (Using Beam with Third-Point Loading.*



ASTM C1609 ASTM C1399

ACI 544 (USA):

- ACI 544-1R-96(09) *– Report of FRC;*
- ACI 544-2R-89(09) *– Measurement of Properties of FRC;*
- ACI 544-3R-08 *– Guide for Specifying, Proportioning, and Production of FRC;*
- ACI 544-4R-88(09) *– Design Considerations for Steel FRC;*
- ACI 544-5R-10 *– Report on the Physical Properties and Durability of FRC;*
- ACI 544-6R-15 *– Report on the Design and Construction of Steel FRC Elevated Slabs.*

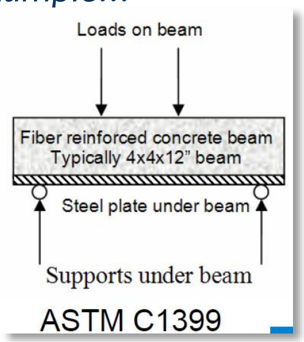


FRC Design & Testing Guidelines

ASTM's for FRC:

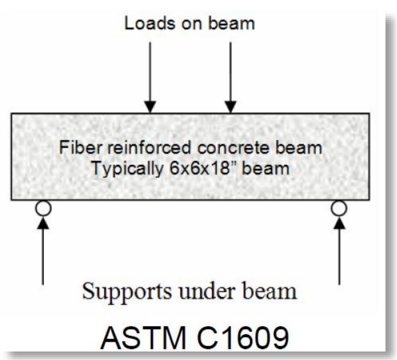
- ASTM C1399 *– ARS calculation*

example…



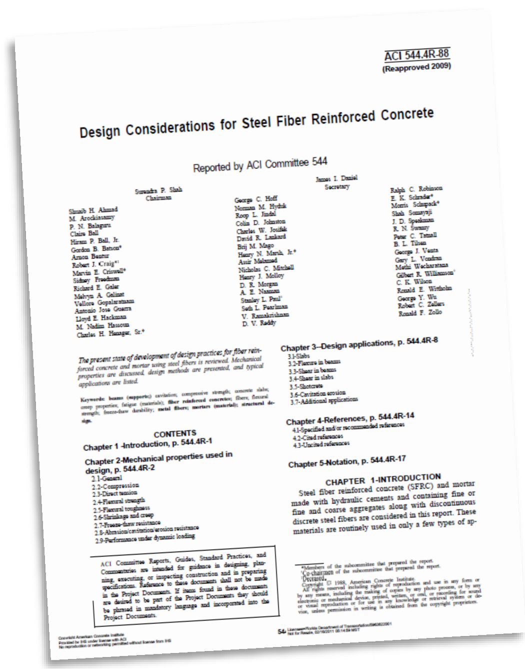
- ASTM C1609 *– Toughness calculation*

example…



ACI 544 (USA):

- ACI 544-4R-88(09) *– Design Considerations for Steel FRC:*
  - *Typical Design for Flexure…*
  - *Typical Design for Shear*


ACI 544.4R-88
(Reapproved 2009)

Design Considerations for Steel Fiber Reinforced Concrete

Reported by ACI Committee 544

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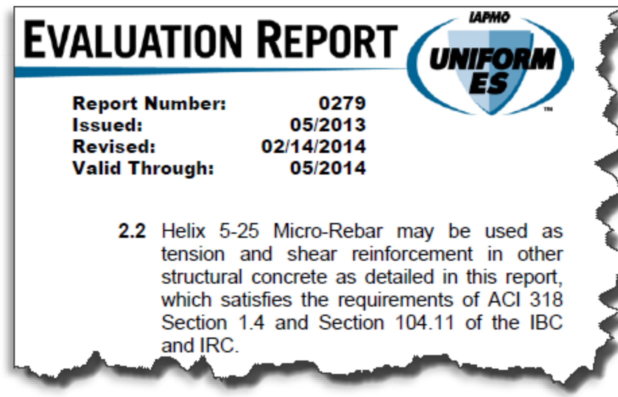
HSR & FRC Design: Design and Testing

Fiber Manufacturer Research:

- Dramix (Bekaert) - Example ***ASTM 1609*** results for Equivalent Flexural Strength (EFS) for Slabs- on-Ground (not ***fib-MC2010*** compliant):

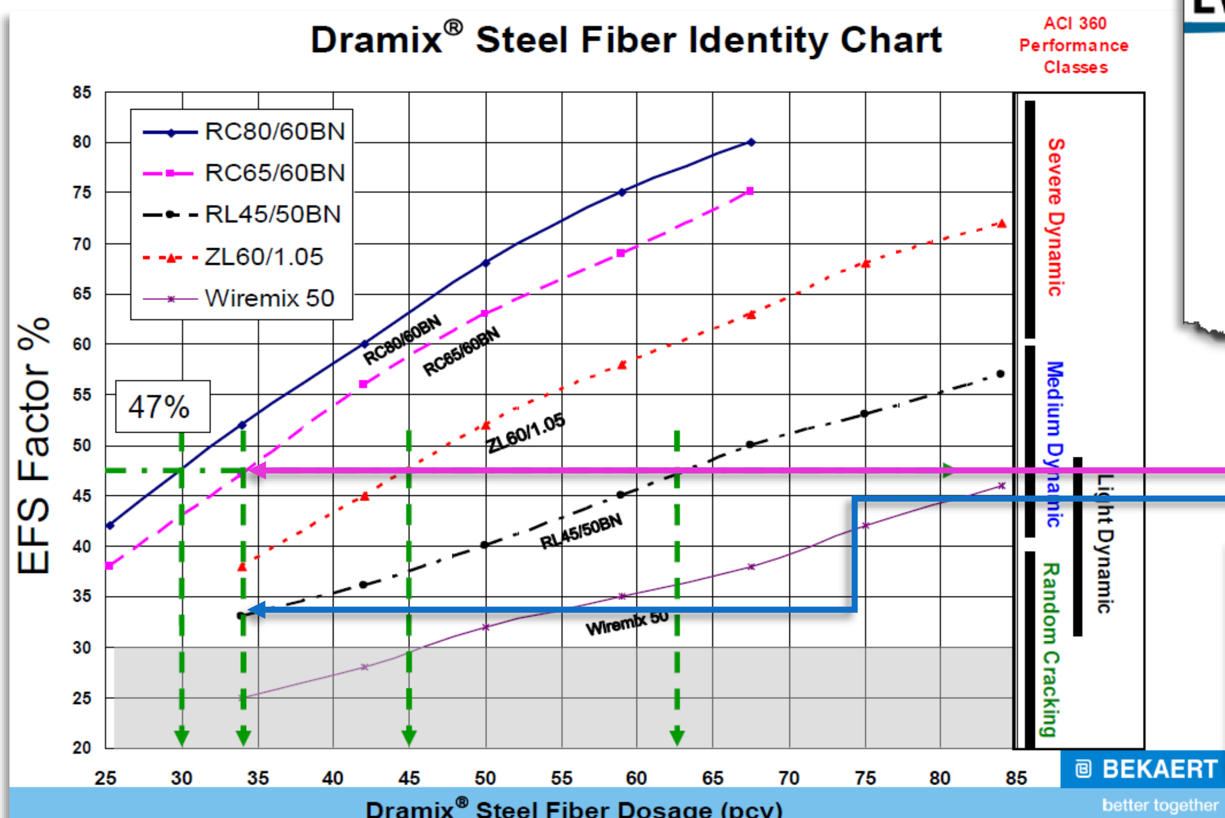
- Helix – ***ACI 318*** (Shear & Tension reinforcing), ***ACI 360R-10*** (Flexural Load Capacity) & ***IBC/IRC*** with a Evaluation Report from an accredited provider.


EVALUATION REPORT

IAPMO UNIFORM ES

Report Number: 0279
Issued: 05/2013
Revised: 02/14/2014
Valid Through: 05/2014

2.2 Helix 5-25 Micro-Rebar may be used as tension and shear reinforcement in other structural concrete as detailed in this report, which satisfies the requirements of ACI 318 Section 1.4 and Section 104.11 of the IBC and IRC.



	RL45/50BN	RC65/60BN
Tensile Strength	161 ksi	168
Anchorage	Hooked	Hooked
Aspect Ratio	50	67
EFS @ 34 pcy	34%	47%

Source: Bekaert Presentation *"Steel Fiber Reinforced Concrete Design & Construction"* (2014)

HSR & FRC Design: Design and Testing

Example Manufacturer Designs:

- Helix – ER-0279 … .

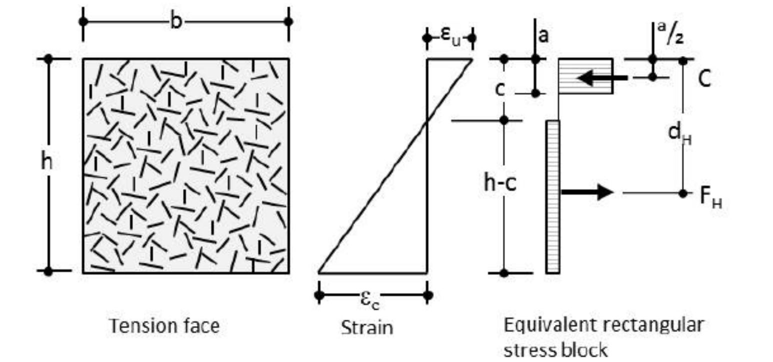


Figure 2 – Helix Force Equilibrium and Strain Compatibility Diagram

Table 1: Helix micro rebar replacement - Imperial

Fy = 60 ksi	Nominal number of Helix Micro Rebar required					
Nominal area of steel in tension As (in²/ft)	3000 psi		4000 psi		5000 psi	
	Class A & B	Class C & Cs	Class A & B	Class C & Cs	Class A & B	Class C & Cs
0.028						
0.040						
0.050						
0.060						
0.080						
0.090						
0.100						
0.110						
0.120						
0.150						
0.160						
0.170						
0.180						
0.200						

Table 2: Helix micro rebar dosage rate - Imperial

Number of Helix per unit area in tension (Helix/in²)	Helix dosage rate, ϕH_d (lb/yd³)		
	3000 psi	4000 psi	5000 psi
1.18			
1.25			
1.43			
1.50			
1.53			
1.75			
2.00			
2.25			
2.50			
2.75			
3.00			
3.25			
3.50			

Table 3: Helix micro rebar tensile force - Imperial

Number of Helix per unit area in tension (Helix/in²)	Provided Helix unit tensile stress, ϕF_{ht} (psi)											
	3000 psi				4000 psi				5000 psi			
	Class A	Class B	Class C	Class C_S	Class A	Class B	Class C	Class C_S	Class A	Class B	Class C	Class C_S
1.18	46.2	62.8	23.8	19.2	50.3	68.4	28.9	23.4	54.5	74.7	34.0	27.6
1.25	49.4	67.1	25.8	20.8	53.5	72.7	30.8	25.0	57.7	79.0	35.9	29.2
1.43	57.6	78.2	30.8	24.9	61.7	83.8	35.8	29.1	65.9	90.3	40.9	33.3
1.50	60.8	82.2	32.6	26.5	64.9	87.8	37.7	30.7	69.1	94.7	42.7	34.9
1.53	62.1	83.9	33.4	27.2	66.3	89.5	38.5	31.4	70.5	96.5	43.5	35.6
1.75	72.2	96.2	39.2	32.2	76.4	101.8	44.2	36.4	80.5	108.8	49.2	40.6
2.00	83.6	110.0	45.7	38.0	87.8	115.4	50.7	42.1	91.9	122.6	55.7	46.3
2.25	95.0	123.4	52.1	43.7	99.2	128.9	57.0	47.8	103.3	136.0	62.0	52.0
2.50	106.4	136.7	58.4	49.4	110.6	142.0	63.3	53.5	114.7	149.0	68.2	57.7

Structures Manual – Volume 1,
Structures Design Guidelines (SDG) **design and approval criteria summary**

SDG 3.17.11 Fiber Reinforced Concrete Design:

- Design per *fib* ***Model Code 2010***
- Allow Evaluation Service Reports for alternate design method from recognized Providers (***IAPMO Uniform ES*** and ***ICC-ES***)

HSR & FRC Design: Design and Testing

Structures Design Guidelines (SDG)

3.17.11 Structural Fiber Reinforcement (Rev. 01/16)

A. Design structures utilizing structural fiber reinforcement in accordance with Sections 5.6 and 7.7 of the *fib* Model Code 2010 (CEB-FIP). As an alternative to the *fib* Model Code 2010 design method and testing criteria, certain minor precast structure types can utilize fiber reinforced concrete design methods based on Evaluation Reports (ER) from providers accredited to ISO/IEC Guide 65 (including ICC-ES and IAPMO ES).


IAPMO UNIFORM ES

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Ontario, California – USA 91761-2816
Ph: 909.472.4100 | Fax: 909-472-4171
http://www.uniform-es.org

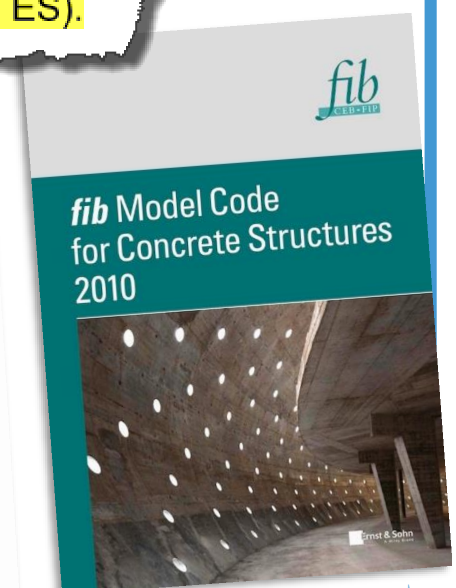
INTERNATIONAL ASSOCIATION OF PLUMBING
AND MECHANICAL OFFICIALS, UNIFORM EVALUATION SERVICES

EVALUATION CRITERIA FOR
TWISTED STEEL MICRO-REBAR (TSMR) IN CONCRETE

EC 015 – 2013
(Adopted - December 2013)

1.0 INTRODUCTION

1.1 **Purpose:** The purpose of this evaluation criteria is to establish requirements for Twisted Steel Micro Rebar (TSMR) in an independently reviewed evaluation report under the 2012 and 2009 *International Building Code*® (IBC) and the 2012 and *International Residential Code*® (IRC). Bases of recognition are IBC Section 104.11 and IRC Section R104.11.



HSR & FRC Design: Design and Testing

Structures Design Guidelines (SDG)

The residual strength of fiber–reinforced concrete test beams will be determined in accordance with ASTM C 1399 (Standard Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete).The walls and bottom slabs of the following structure types can be designed using an equivalent strength basis when Evaluation Reports are provided to the EOR:

1. Type P Structures Bottoms (***Design Standards*** Index 200);
2. Manhole Risers, Grade Rings and Conical Tops equal or less than 4'-6" diameter (***Design Standards*** Index 201 Type 8)
3. Drainage Inlet Bottoms with inside wall lengths equal or less than 4'-6" (***Design Standards*** Indexes 212, 213, 217-Types 1 & 2, and 218 - 221);
4. Ditch Bottom Inlets Types A, B, C, D, E, F & J (***Design Standards*** Index 230, 231, 232, 233 & 234);
5. U-Type Concrete Endwalls (***Design Standards*** Index 261);
6. Flared End Sections (***Design Standards*** Index 270).

HSR & FRC Design: Design and Testing

Structures Design Guidelines (SDG)

B. Plain carbon steel fibers are allowed in slightly and moderately aggressive environments. Galvanized, stainless steel, or carbon FRP fibers are permitted in all environmental classifications. Other non-corrosive fiber materials such as basalt may be considered when approved by the State Materials Office. Polymer fibers are not permitted as primary structural reinforcement for buried structures due to the potential for long term creep.

C. A Technical Special Provision (TSP), reviewed and approved by the State Materials Office, will be required for the Contract Documents to establish and verify the characteristic material properties such as the residual flexural tensile strength corresponding to the load-crack mouth opening displacement (CMOD) of the fiber-reinforced concrete mix design. For precast concrete elements, producers must submit shop drawings for design approval to the State Drainage Engineer based on an approved FRC Mix Design and include a technical specification to establish and verify the characteristic material properties in lieu of a TSP. These documents and any other necessary guidelines for production and quality control will be maintained as an addendum to the producer's Quality Control Plan.

D. These requirements are intended for wet-cast concrete only.

Materials Manual

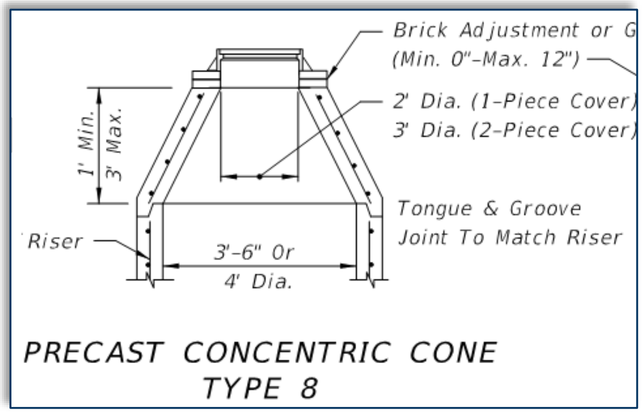
Chapter 6 – Manufactured Drainage Products (Volume II):

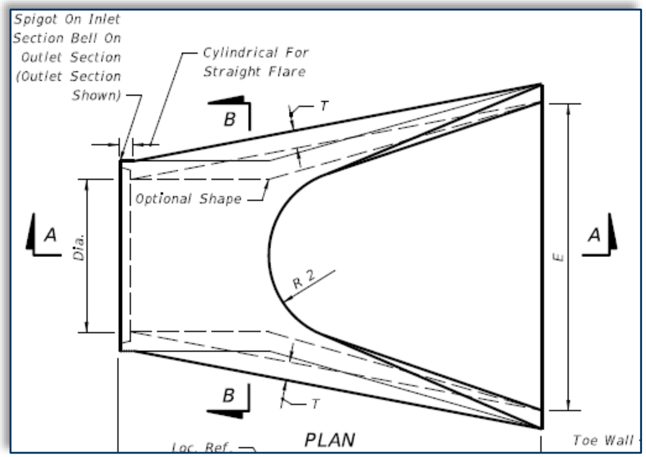
- Section 6.3.7.4.11
- Mix Design Approval
- Shop Drawing Approval
- Certifications
- Trial Batching
- Field Demonstration
- Post Fabrication Inspection
- Production Requirements
- Quality Control Plan Requirements

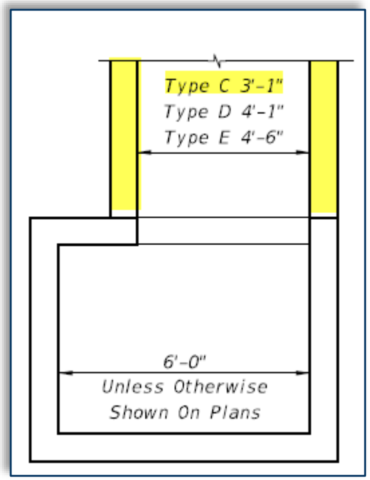
HSR & FRC Design: Example Applications

FRC for Precast Drainage Structures

- Minor drainage structures:
- Type P Bottoms (Index 200)
- Manhole Risers and Conical Tops (Index 201 – Type 8)
- Inlets & DBI's with wall lengths < 4'-6"
- Flared End Sections (Index 270)
- U-Walls (Index 261)







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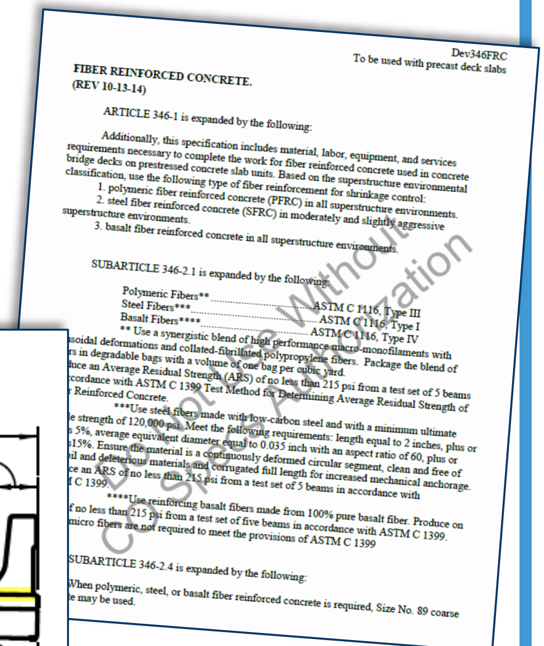
HSR & FRC Design: Example Applications

PSU Concrete Overlay

- Non-structural application
- ***Developmental Specification*** Dev346FRC
- Uses ARS for acceptance (215 psi)


Dev346FRC
To be used with precast deck slabs

FIBER REINFORCED CONCRETE.
(REV 10-13-14)

ARTICLE 346-1 is expanded by the following:

Additionally, this specification includes material, labor, equipment, and services requirements necessary to complete the work for fiber reinforced concrete used in concrete bridge decks on prestressed concrete slab units. Based on the superstructure environmental classification, use the following type of fiber reinforcement for shrinkage control:

1. polymeric fiber reinforced concrete (PFRC) in all superstructure environments.
2. steel fiber reinforced concrete (SFRC) in moderately and slightly aggressive superstructure environments.
3. basalt fiber reinforced concrete in all superstructure environments.

SUBARTICLE 346-2.1 is expanded by the following:

Polymeric Fibers** .... ASTM C 1116, Type III
Steel Fibers*** .... ASTM C 1116, Type I
Basalt Fibers**** .... ASTM C 1116, Type IV

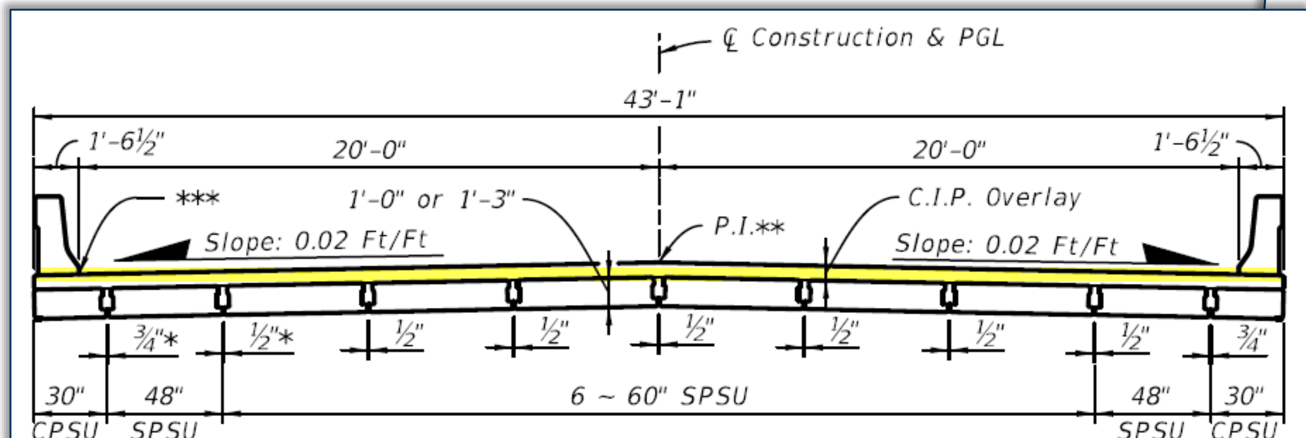
** Use a synergistic blend of high performance macro-monofilaments with
...soidal deformations and collated-fibrillated polypropylene fibers. Package the blend of
...rs in degradable bags with a volume of one bag per cubic yard.
...duce an Average Residual Strength (ARS) of no less than 215 psi from a test set of 5 beams
...cordance with ASTM C 1399 Test Method for Determining Average Residual Strength of
...r Reinforced Concrete.

***Use steel fibers made with low-carbon steel and with a minimum ultimate
...le strength of 120,000 psi. Meet the following requirements: length equal to 2 inches, plus or
...s 5%, average equivalent diameter equal to 0.035 inch with an aspect ratio of 60, plus or
...s15%. Ensure the material is a continuously deformed circular segment, clean and free of
...il and deleterious materials and corrugated full length for increased mechanical anchorage.
...ce an ARS of no less than 215 psi from a test set of 5 beams in accordance with
...M C 1399.

****Use reinforcing basalt fibers made from 100% pure basalt fiber. Produce on
...f no less than 215 psi from a test set of five beams in accordance with ASTM C 1399.
...micro fibers are not required to meet the provisions of ASTM C 1399

SUBARTICLE 346-2.4 is expanded by the following:

...When polymeric, steel, or basalt fiber reinforced concrete is required, Size No. 89 coarse
...e may be used.



EXAMPLE SECTION NO. 2
(SYMMETRICAL CROWNED BRIDGE SECTION)

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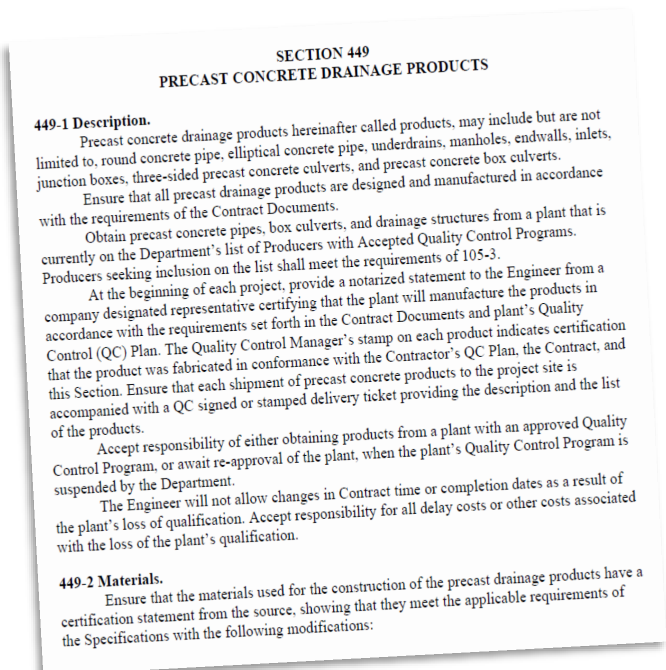
HSR & FRC Design: **Example Applications**

Structural Steel Fibers in Precast Pipe (*ASTM C1765*)

- FDOT will be adding ***ASTM C1765*** to Specification Section 449 once design life curves are established.



SECTION 449
PRECAST CONCRETE DRAINAGE PRODUCTS

449-1 Description.

Precast concrete drainage products hereinafter called products, may include but are not limited to, round concrete pipe, elliptical concrete pipe, underdrains, manholes, endwalls, inlets, junction boxes, three-sided precast concrete culverts, and precast concrete box culverts.

Ensure that all precast drainage products are designed and manufactured in accordance with the requirements of the Contract Documents.

Obtain precast concrete pipes, box culverts, and drainage structures from a plant that is currently on the Department's list of Producers with Accepted Quality Control Programs. Producers seeking inclusion on the list shall meet the requirements of 105-3.

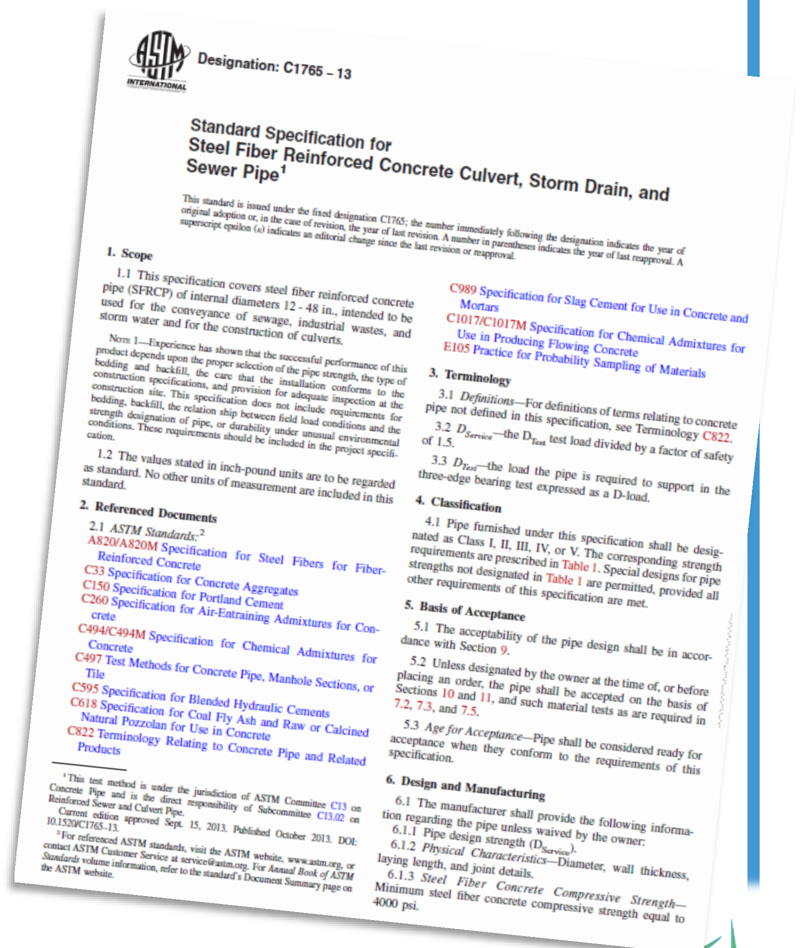
At the beginning of each project, provide a notarized statement to the Engineer from a company designated representative certifying that the plant will manufacture the products in accordance with the requirements set forth in the Contract Documents and plant's Quality Control (QC) Plan. The Quality Control Manager's stamp on each product indicates certification that the product was fabricated in conformance with the Contractor's QC Plan, the Contract, and this Section. Ensure that each shipment of precast concrete products to the project site is accompanied with a QC signed or stamped delivery ticket providing the description and the list of the products.

Accept responsibility of either obtaining products from a plant with an approved Quality Control Program, or await re-approval of the plant, when the plant's Quality Control Program is suspended by the Department.

The Engineer will not allow changes in Contract time or completion dates as a result of the plant's loss of qualification. Accept responsibility for all delay costs or other costs associated with the loss of the plant's qualification.

449-2 Materials.

Ensure that the materials used for the construction of the precast drainage products have a certification statement from the source, showing that they meet the applicable requirements of the Specifications with the following modifications:



ASTM INTERNATIONAL **Designation: C1765 – 13**

Standard Specification for Steel Fiber Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe[1]

This standard is issued under the fixed designation C1765; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers steel fiber reinforced concrete pipe (SFRCP) of internal diameters 12 - 48 in., intended to be used for the conveyance of sewage, industrial wastes, and storm water and for the construction of culverts.

NOTE 1—Experience has shown that the successful performance of this product depends upon the proper selection of the pipe strength, the type of bedding and backfill, the care that the installation conforms to the construction specifications, and provision for adequate inspection at the construction site. This specification does not include requirements for bedding, backfill, the relation ship between field load conditions and the strength designation of pipe, or durability under unusual environmental conditions. These requirements should be included in the project specification.

1.2 The values stated in inch-pound units are to be regarded as standard. No other units of measurement are included in this standard.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A820/A820M Specification for Steel Fibers for Fiber-Reinforced Concrete
C33 Specification for Concrete Aggregates
C150 Specification for Portland Cement
C260 Specification for Air-Entraining Admixtures for Concrete
C494/C494M Specification for Chemical Admixtures for Concrete
C497 Test Methods for Concrete Pipe, Manhole Sections, or Tile
C595 Specification for Blended Hydraulic Cements
C618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C822 Terminology Relating to Concrete Pipe and Related Products
C989 Specification for Slag Cement for Use in Concrete and Mortars
C1017/C1017M Specification for Chemical Admixtures for Use in Producing Flowing Concrete
E105 Practice for Probability Sampling of Materials

3. Terminology

3.1 *Definitions*—For definitions of terms relating to concrete pipe not defined in this specification, see Terminology C822.

3.2 $D_{Service}$—the D_{Test} test load divided by a factor of safety of 1.5.

3.3 D_{Test}—the load the pipe is required to support in the three-edge bearing test expressed as a D-load.

4. Classification

4.1 Pipe furnished under this specification shall be designated as Class I, II, III, IV, or V. The corresponding strength requirements are prescribed in Table 1. Special designs for pipe strengths not designated in Table 1 are permitted, provided all other requirements of this specification are met.

5. Basis of Acceptance

5.1 The acceptability of the pipe design shall be in accordance with Section 9.

5.2 Unless designated by the owner at the time of, or before placing an order, the pipe shall be accepted on the basis of Sections 10 and 11, and such material tests as are required in 7.2, 7.3, and 7.5.

5.3 *Age for Acceptance*—Pipe shall be considered ready for acceptance when they conform to the requirements of this specification.

6. Design and Manufacturing

6.1 The manufacturer shall provide the following information regarding the pipe unless waived by the owner:

6.1.1 Pipe design strength ($D_{Service}$).

6.1.2 *Physical Characteristics*—Diameter, wall thickness, laying length, and joint details.

6.1.3 *Steel Fiber Concrete Compressive Strength*—Minimum steel fiber concrete compressive strength equal to 4000 psi.

[1] This test method is under the jurisdiction of ASTM Committee C13 on Concrete Pipe and is the direct responsibility of Subcommittee C13.02 on Reinforced Sewer and Culvert Pipe.
Current edition approved Sept. 15, 2013. Published October 2013. DOI: 10.1520/C1765–13.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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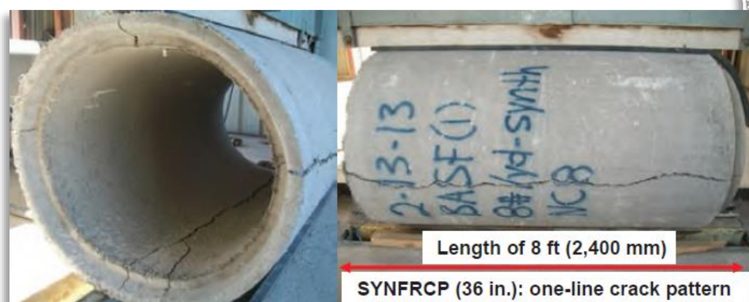
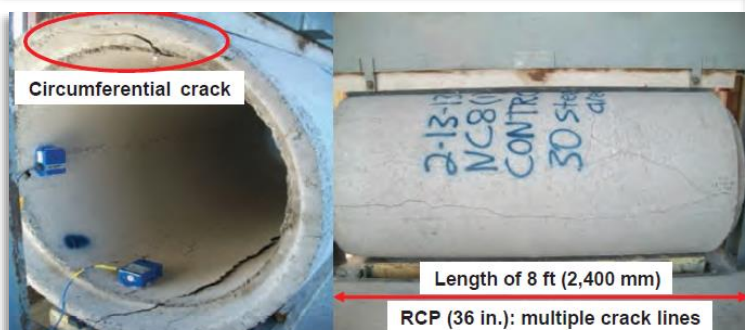
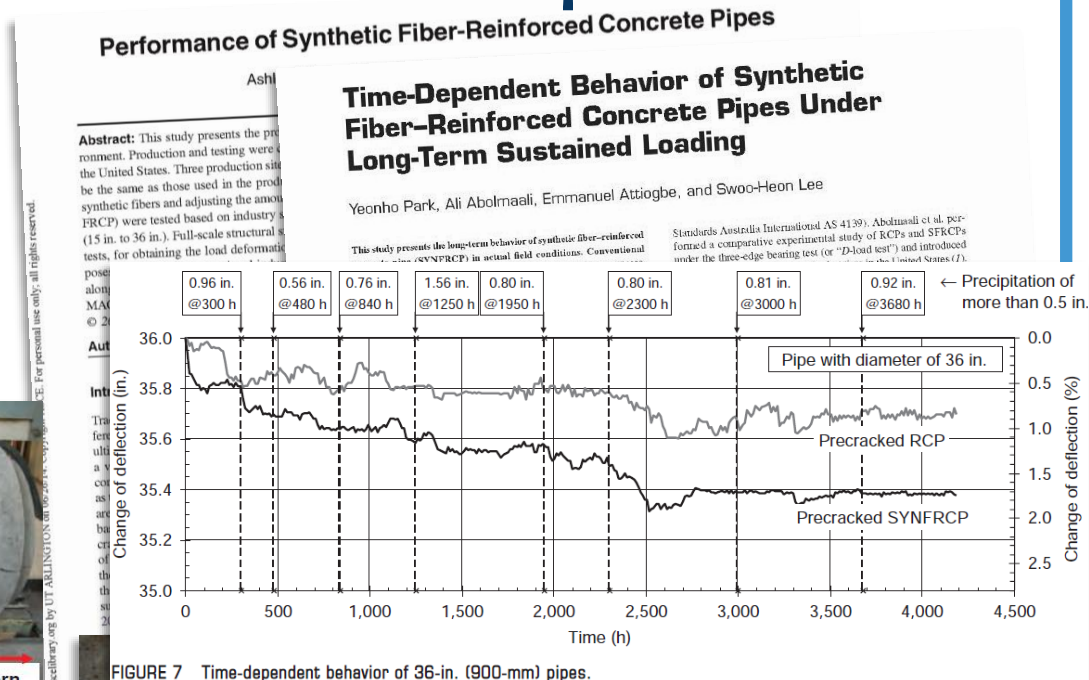
HSR & FRC Design: Example Applications

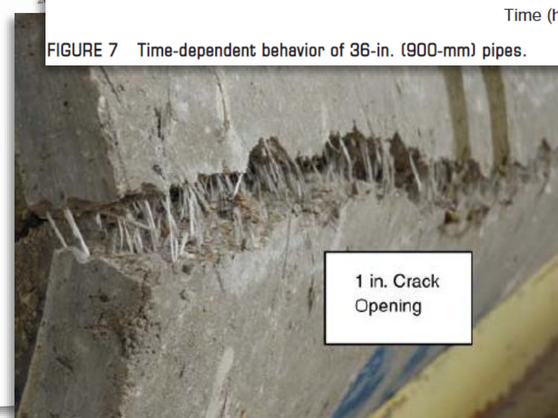
Structural Synthetic Fibers in Precast Pipe (*ASTM C1818*)

- FDOT will be adding new ***ASTM C1818*** to Specification Section 449 once design life curves are established.





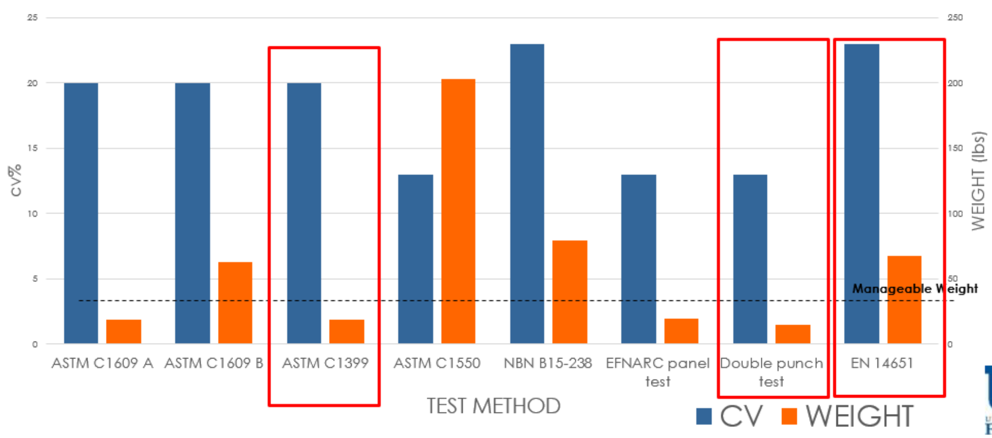




HSR & FRC Design: Challenges

1. Expensive Qualification Testing process using ***EN14651*** for characterizing design properties;
2. Large test samples (flexural beams 6"x 6"x 22");
3. ARS not reliable for design, but still relatively wide result scatter with ***EN14651;***
4. New design methods and inconsistent application;
5. Visual verification not effective, need controlled process and/or plastic sample testing for fiber content verification and distribution (see ***Materials Manual*** **– 6.3.7.4.11 Volume II**)

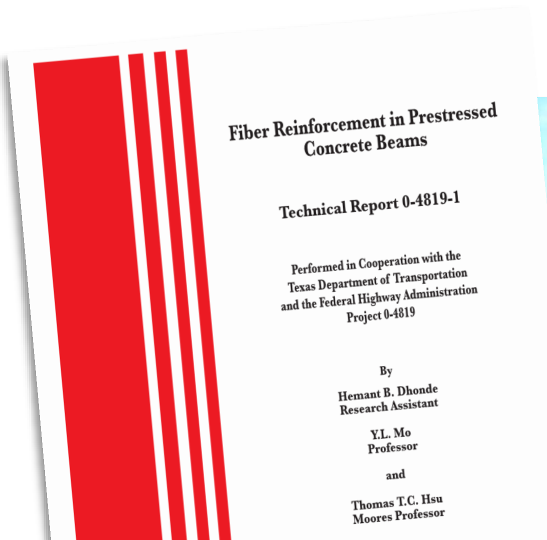
Comparison: Testing Methods



HSR & FRC Design: Challenges

TxDOT Research:

- FHWA/TX-06/ 0-4819-1
  Fiber Reinforcement in Prestressed Concrete Beams (2005)


Fiber Reinforcement in Prestressed Concrete Beams

Technical Report 0-4819-1

Performed in Cooperation with the Texas Department of Transportation and the Federal Highway Administration
Project 0-4819

By

Hemant B. Dhonde
Research Assistant

Y.L. Mo
Professor

and

Thomas T.C. Hsu
Moores Professor

FDOT Research:

- BDV31 977-41 *Macro Synthetic Fiber Reinforcement for Improved Structural Performance of Concrete Bridge Girders (2017);*
- BD545-09 *Crack Control in Toppings For Precast Flat Slab Bridge Deck Construction (2006);*
- BD545-41 *Durability of FRC in Florida Environments (2009);*
- BDK80 977-27 *Use of FRC for Concrete Pavement Slab Replacement (2014);*
- BC386 *Application of FRC in the End Zones of Precast Prestressed Bridge Girders (2002).*

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Questions?

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