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Incorporating Steel Fibers in Your Concrete Slab

Alabama Concrete Industries Association

October 15, 2013 Birmingham, AL

October 16, 2013 Huntsville, AL

PRESENTATION BY

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Bekaert Corporation

Steel Fibers

- General Steel Fiber Information
- Performance Information
- Steel vs Synthetic Fibers
- Design
- Dosing Mixing and Placing
- Applications
- Better Together

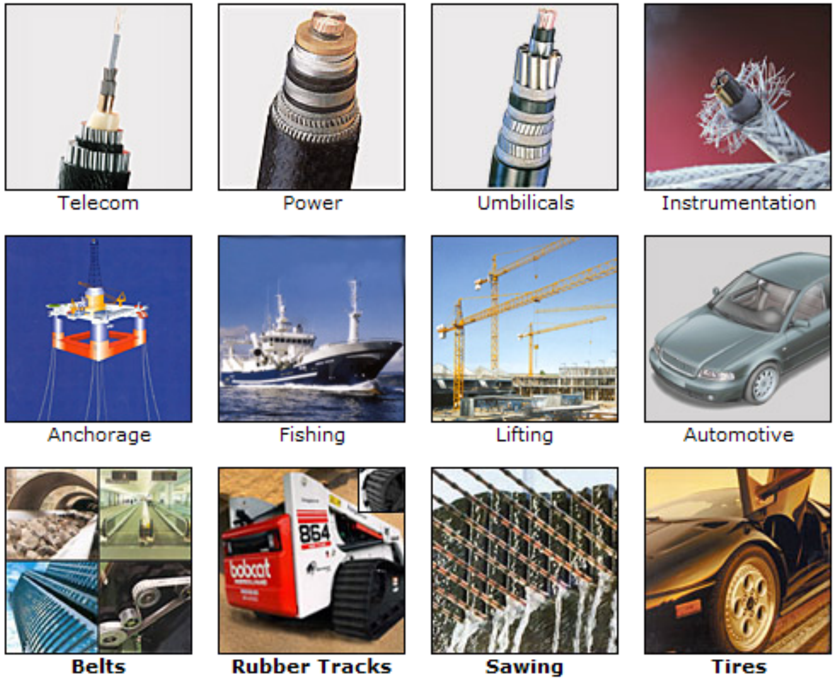
VARIOUS APPLICATIONS

- Other applications:
  - Toppings and overlays
  - Shotcrete,
  - Tunnels linings,
  - Precast
  - Housing, footings
  - Paving
  - Replacement of stirrups/hoop shear reinforcing in beams to 2' x 2' max. 2008 IBC
  - New structural applications being researched

General Information

Who is Bekaert?

- Founded in **1880**
- Based In Belgium With Factories And Offices Throughout The World
- **25,000** employees Worldwide
- Customers in **120** countries
- Combines sales of € 3.3 billion
- Worlds **Largest** Independent manufacturer of steel wire and wire products



→ Metal Transformation

→ Advanced Materials & Coatings

INFORMATION

STEEL

FIBER

REINFORCED

CONCRETE

Is made from hydraulic cement, water, coarse and fine aggregates, admixture and discontinuous discrete steel fibers

Why Steel Fibers?

What Are The Benefits of Using Steel Fibers?

Technical Considerations

Full Depth Reinforcement

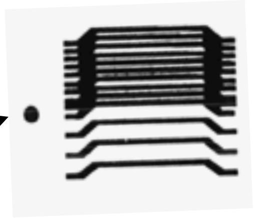
Excellent Crack Control

No Corrosion Or Spalling Of Concrete

Supplying Reinforced Concrete

PERFORMANCE

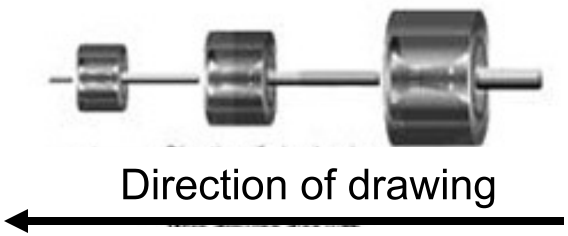
Typically highest Tensile strength



ASTM A820-04

- Five types
  - Type I - Cold drawn wire
  - Type II - Cut or Slit sheet (Loose)
  - Type III - Melt extracted (Typically alloys)
  - Type IV - Mill cut
  - Type V - Modified Cold Drawn Wire

- Minimum tensile strength (50,000 psi)
- Tolerances
- Physical properties

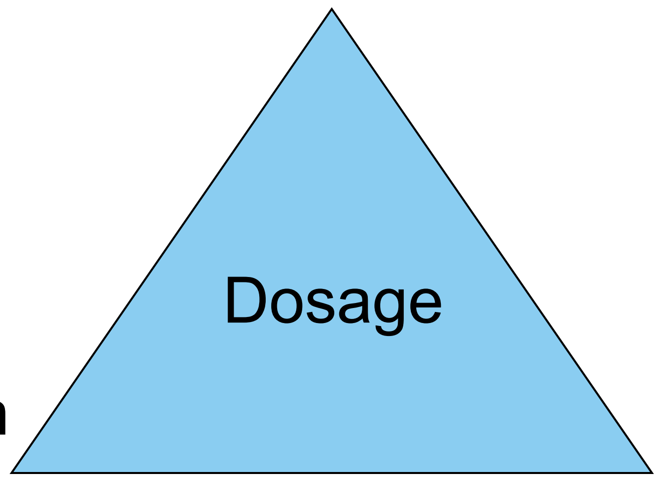


PERFORMANCE

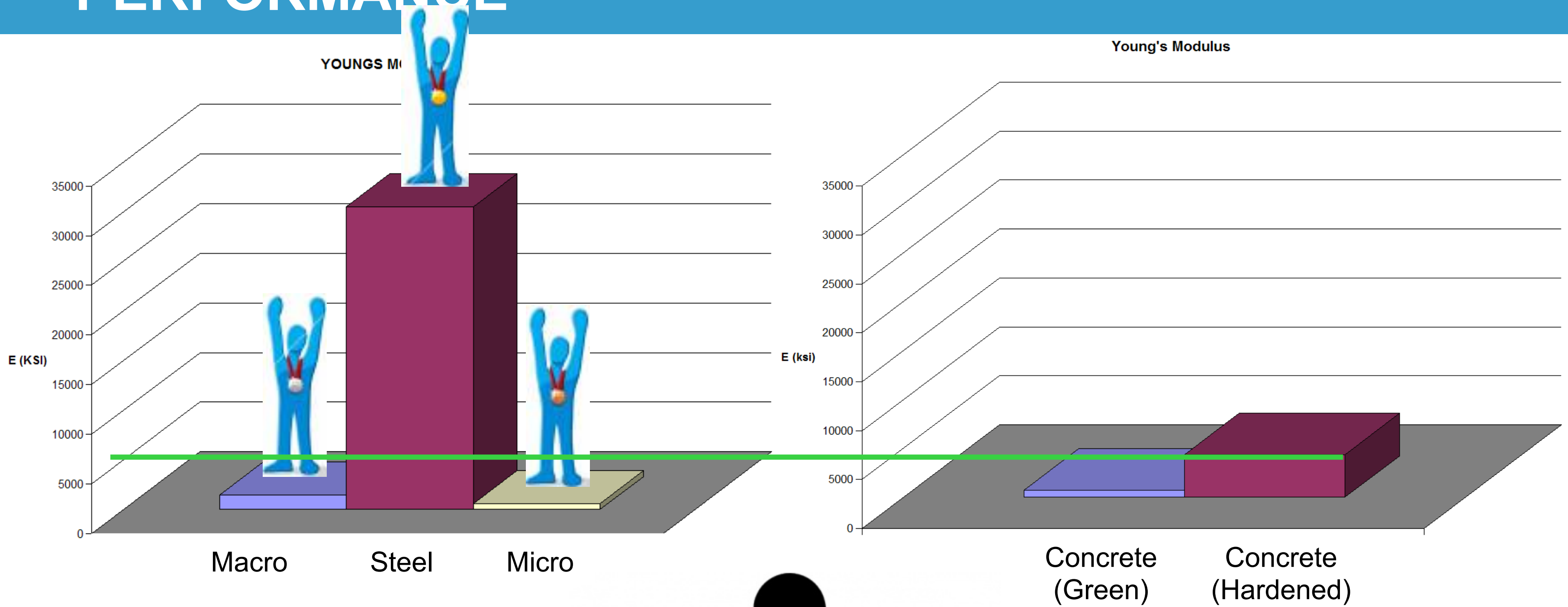
- Is there a difference in performance?

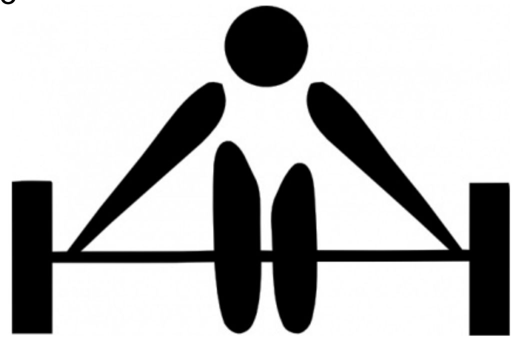
Aren’t they all the same?

The Performance Of Steel Fibers Depends On :



PERFORMANCE

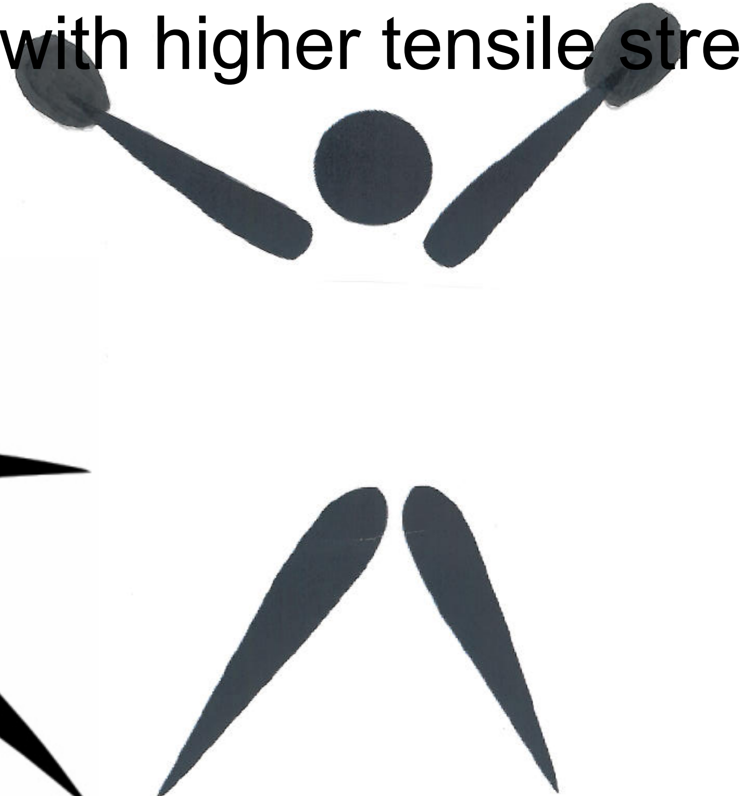




YOUNG' S MODULUS

Reinforcing needs to be stronger then concrete

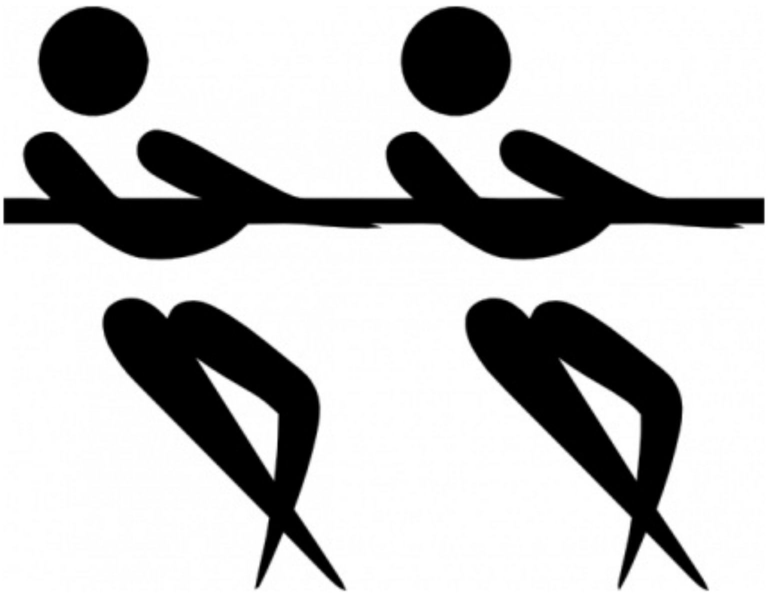
Score a knock out with higher tensile strength



Steel Fiber
Macro
WWF
Type 2
87,000 psi
72,000 psi
50,000 psi

Steel Fiber
Type 1
177,000 psi

PERFORMANCE

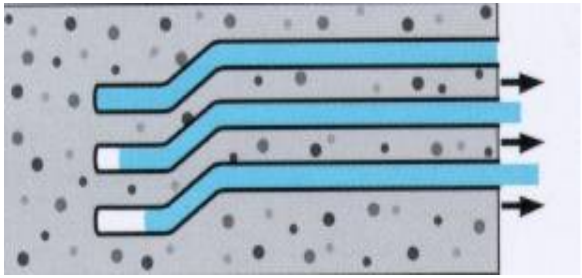


Anchorage

-Hooked ends

-Controlled Pull-Out

- Due to deformation of the crack
- **DUCTILITY!**



PERFORMANCE

GOLD METAL COUNT:

	Type 1 (Steel)	Type II (Steel)	Macro (Synthetic)
Tensile strength			
Anchorage		?	?
Aspect Ratio			
	3	**0**	**1**

PERFORMANCE

Aspect Ratio

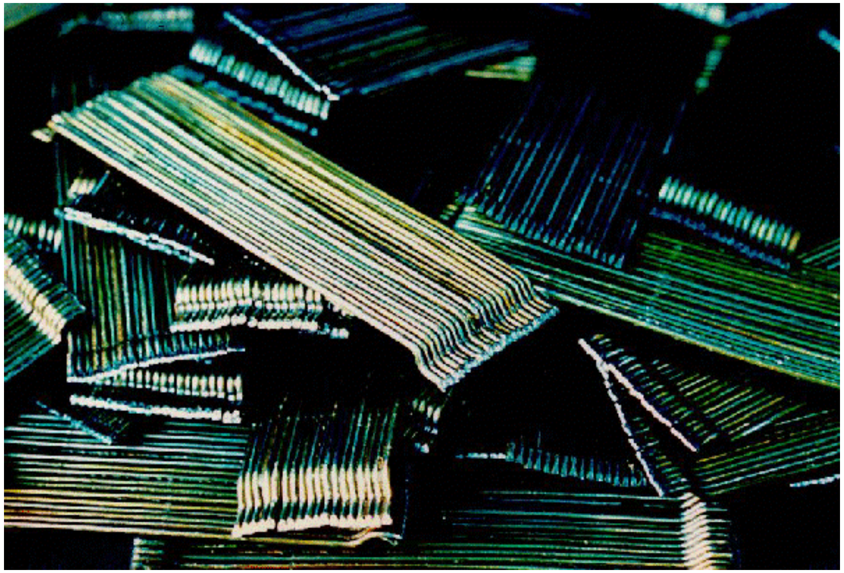
Performance Concrete

Dosage Rates

Low L/D (<60) are usually loose.

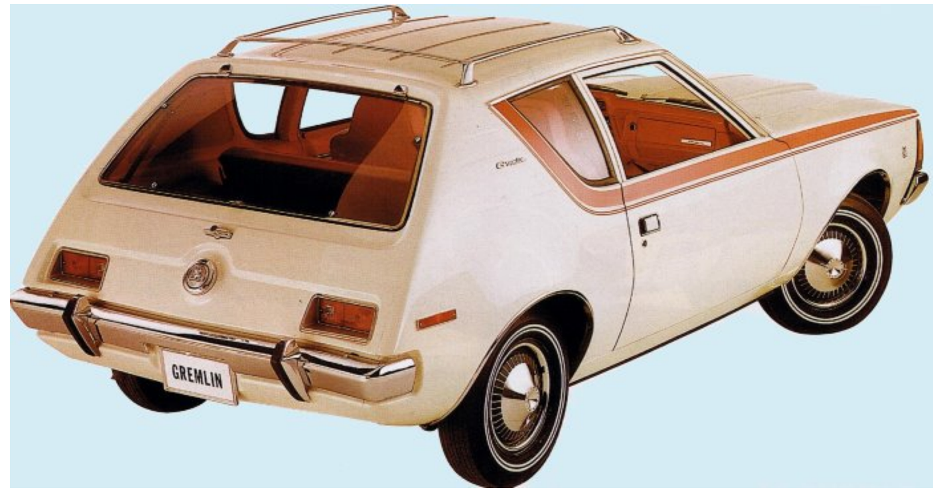
Loose hook ended fibers

Collated (glued) fibers with L/D > 60



SYNTHETIC OR STEEL

STEEL VS SYNTHETIC

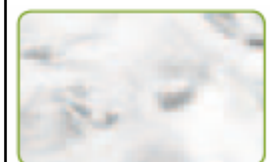


Aren't they all fibers the same?

STEEL AND SYNTHETIC FIBRE REINFORCED CONCRETE
Which fiber to use? & for which application and why?

STEEL VS SYNTHETIC

What can we learn from material properties?

	Steel Mesh / Steel Fibers  	Micro / Macro Synthetic Fiber  
Young's Modulus (E)	30,450 ksi	1,450 ksi
Tensile Strength	72 – 290+ ksi	100 ksi

Young's Modulus (E)

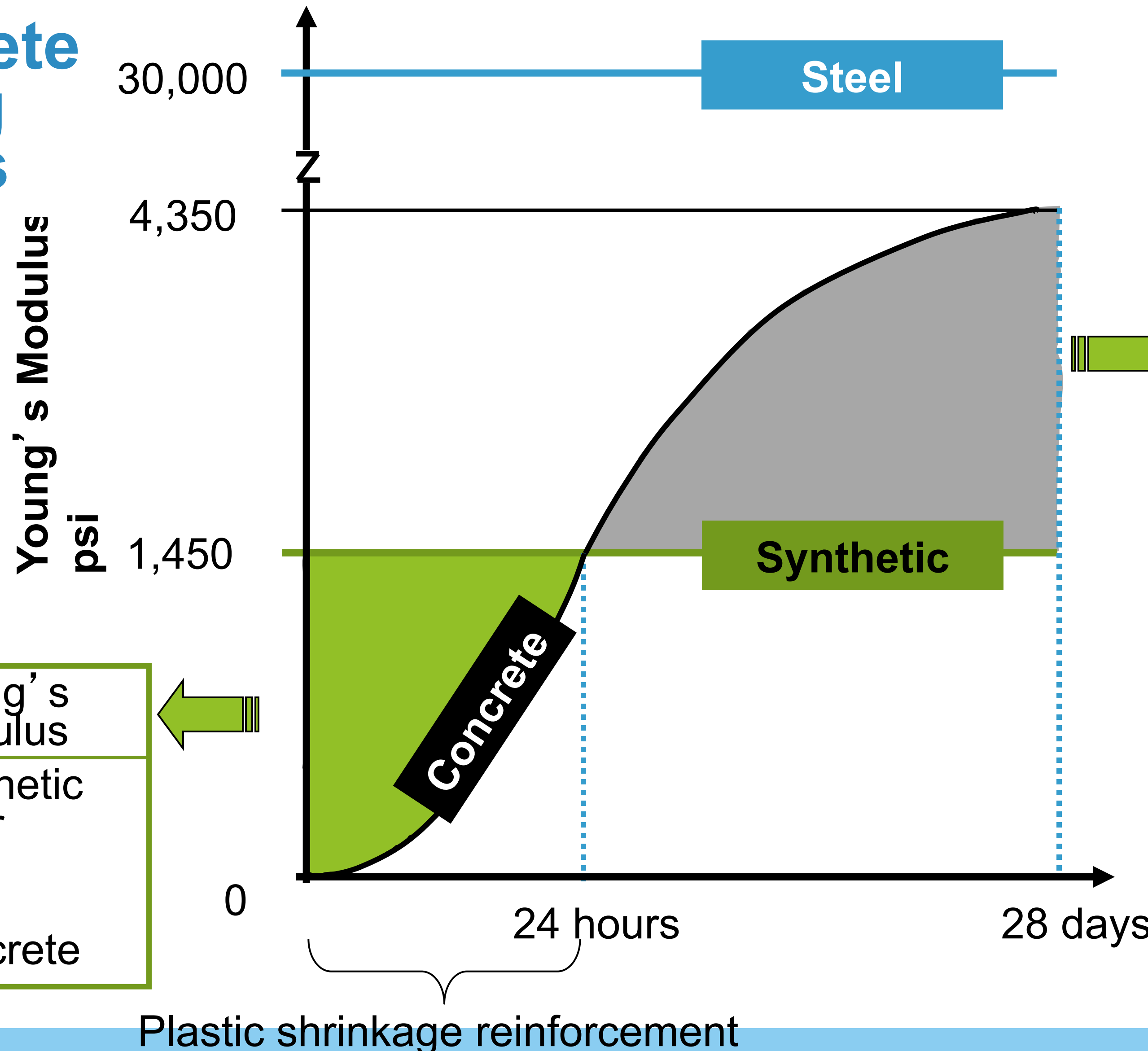
- The mathematical description of an object tendency to be deformed elastically (i.e., non-permanently) when a force is applied to it.

$$E = \frac{STESS}{STRAIN} = \frac{FORCE}{AREA} \Big/ \Delta ELONGATION$$

HIGH **LOW**

STEEL VS SYNTHETIC

Concrete Curing Stages



Young’s Modulus

Synthetic Fiber **>** Concrete

Young’s Modulus

Synthetic Fiber **<** Concrete

STEEL VS SYNTHETIC

CREEP

STEEL VS SYNTHETIC

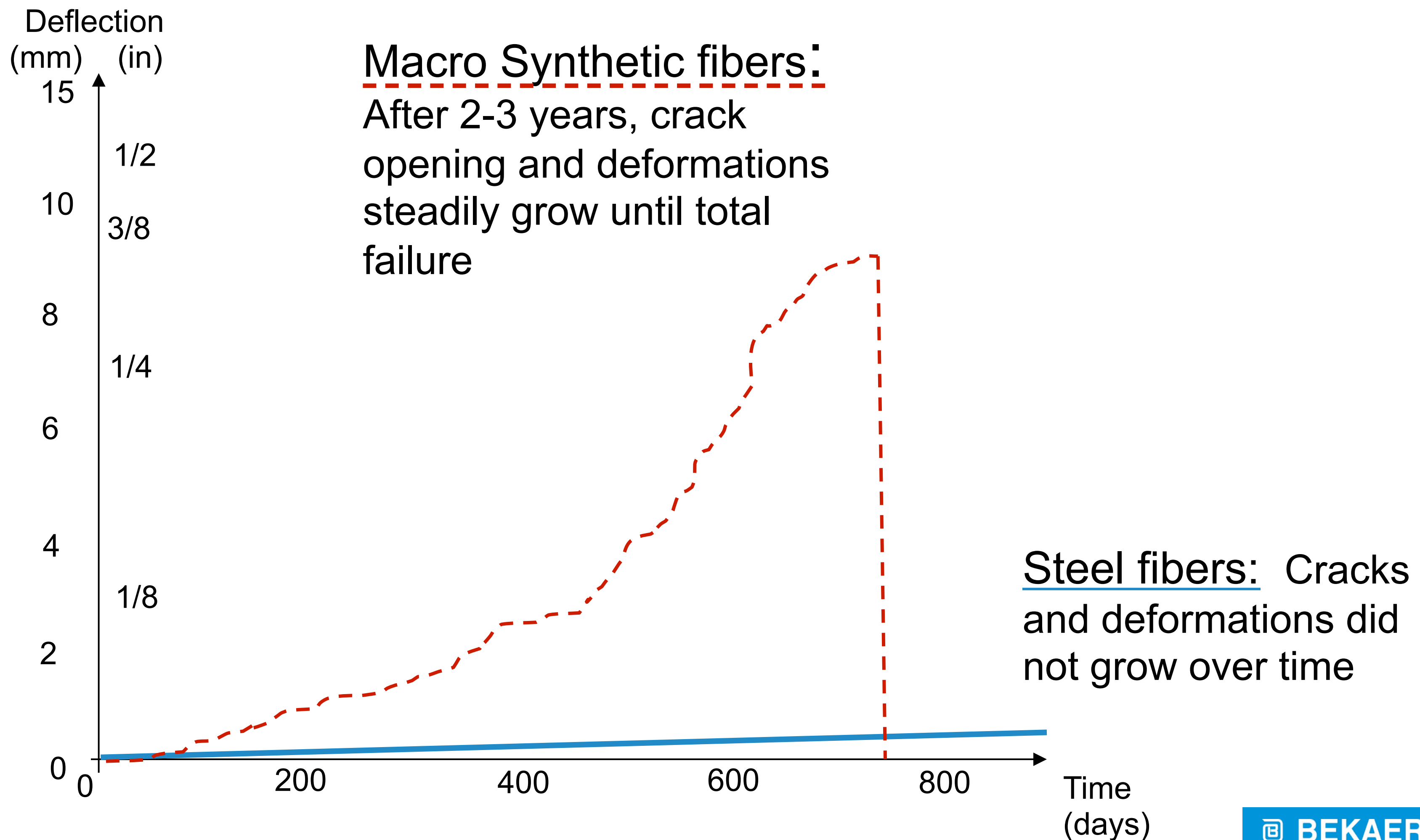
Polymer fibers creep

- 2004 to Currrent - different concrete labs have tested and evaluated the creep behavior of different fiber materials.

Creep test set-up

STEEL VS SYNTHETIC

Cracks associated with loads and shrinkage



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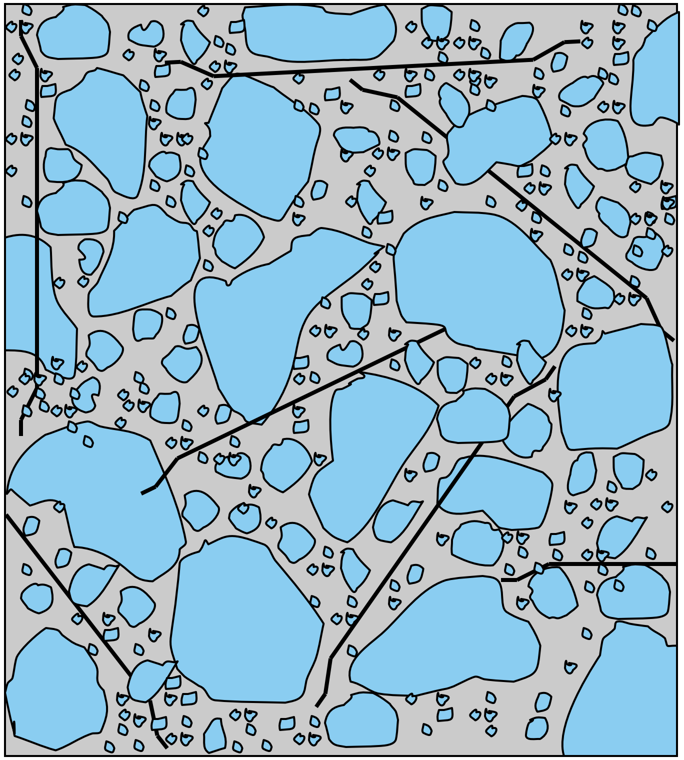
STEEL VS SYNTHETIC

	Specific Gravity
Macro Synthetic fiber	0.91
Water	1.00
Pozzolan	2.35
Fine Aggregates	2.61
Coarse Aggregates	2.73
Cement	3.15
Steel fiber	7.85



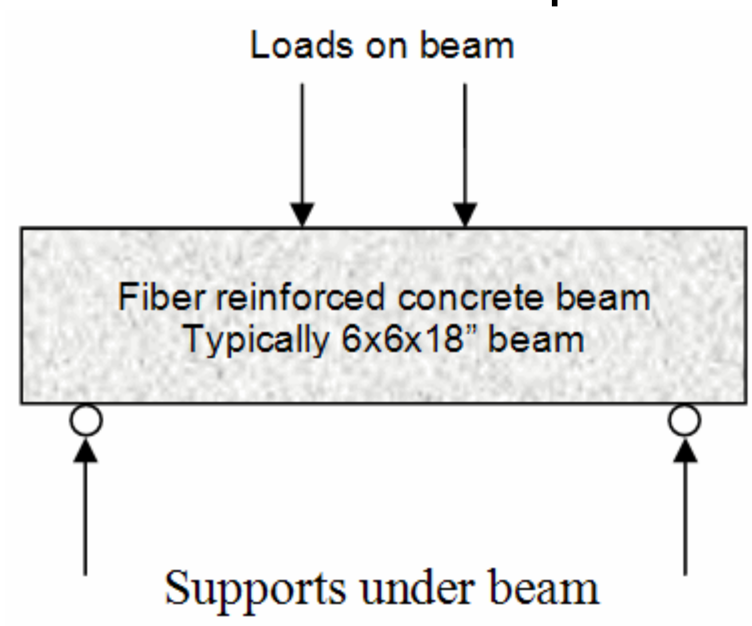
DESIGN

DESIGN

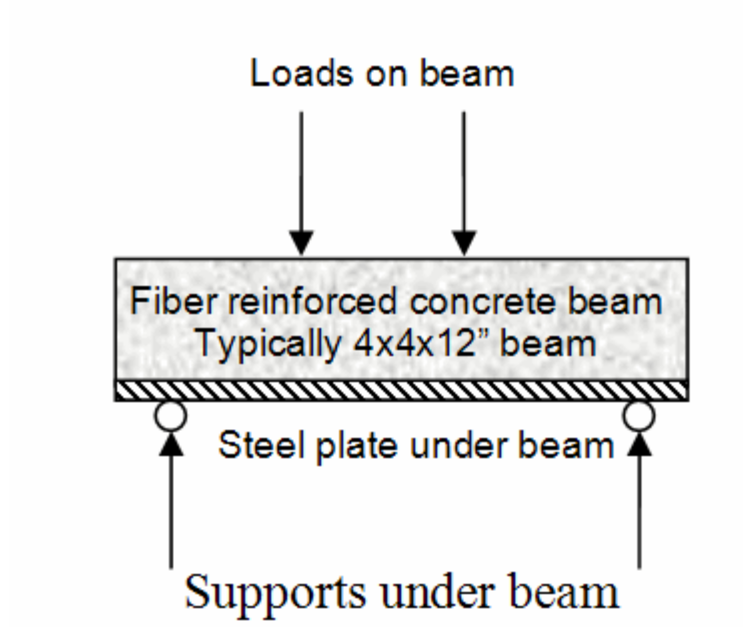
- Beam tests characterize engineering properties of the composite
  - ASTM C 1609 - Performance (Replaced ASTM C 1018 Jan 2006)
  - ASTM C 1399 - Comparative
  - JSCE SF-4
- Panel tests are used for quality control (primarily shotcrete Tunneling/Ground support projects)
  - EN 14488-5 (Efnarc)
  - ASTM C 1550

DESIGN

- More Conservative
- Modulus of Rupture



ASTM C1609



ASTM C1399

Beam Tests

ASTM C1609

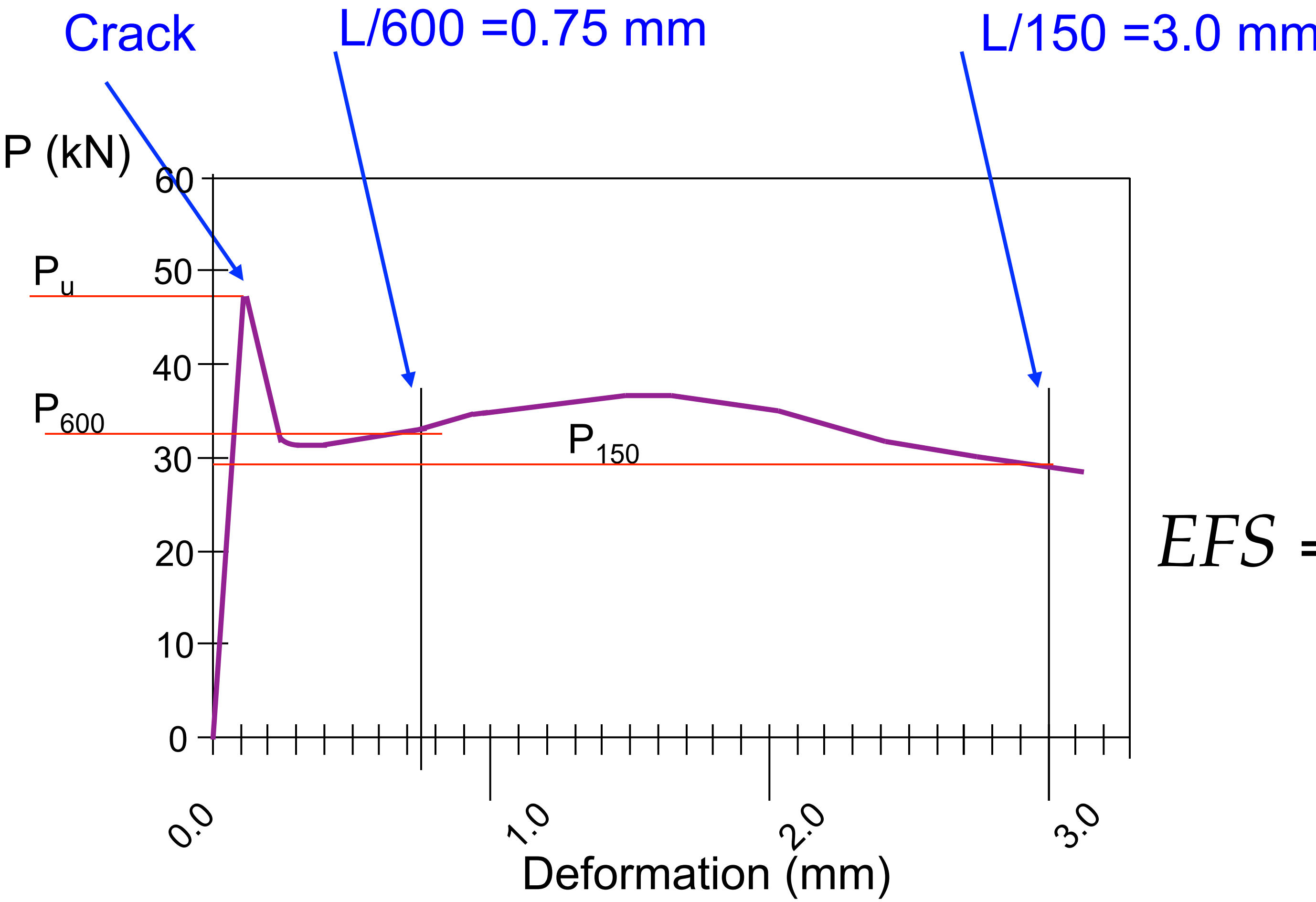
Closed loop controlled platen

LVDT deflection monitors

Rotating supports

Stiff table

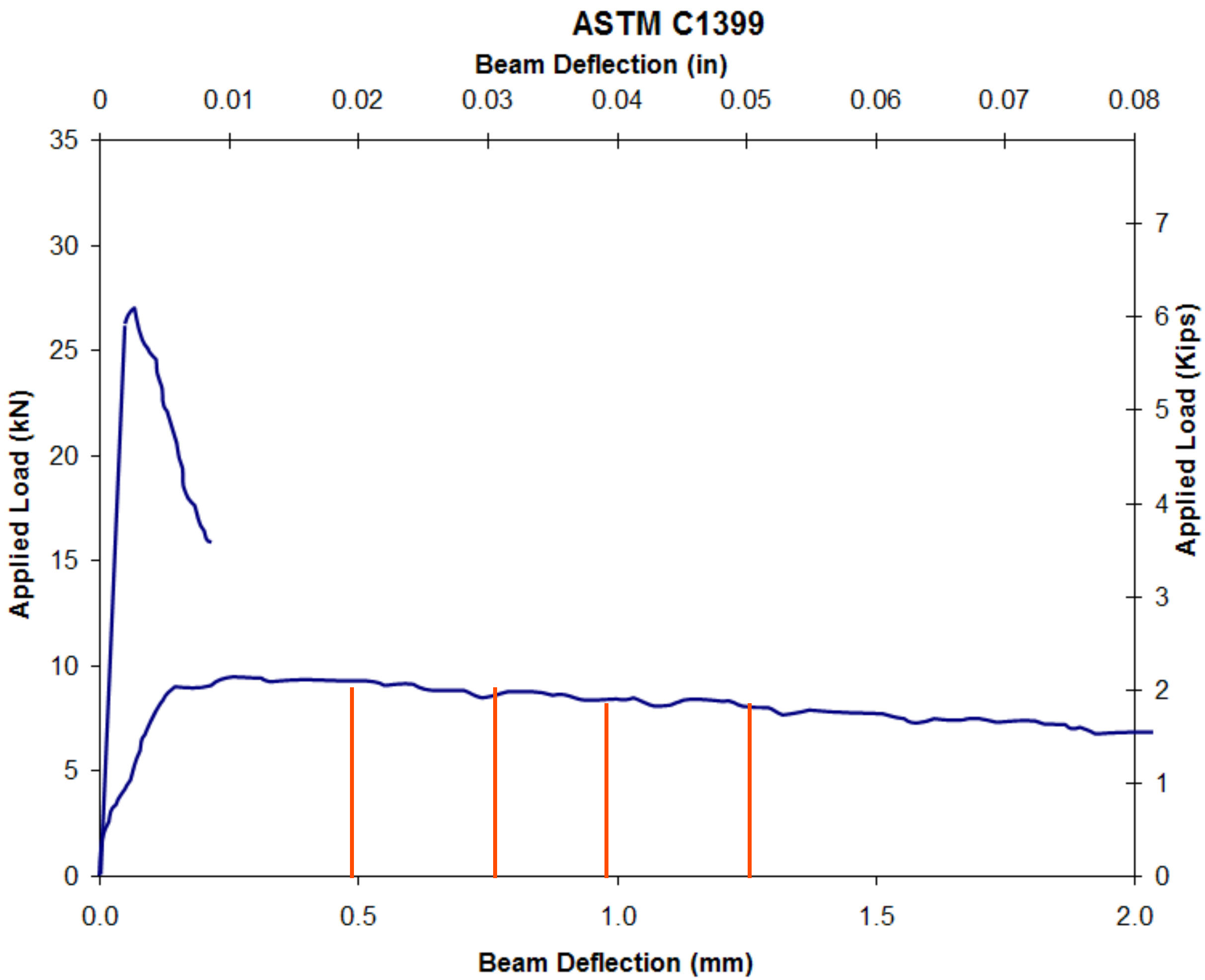
Beam Tests – ASTM C1609



$$f_e = \frac{P_e \times L}{b \times h^2}$$

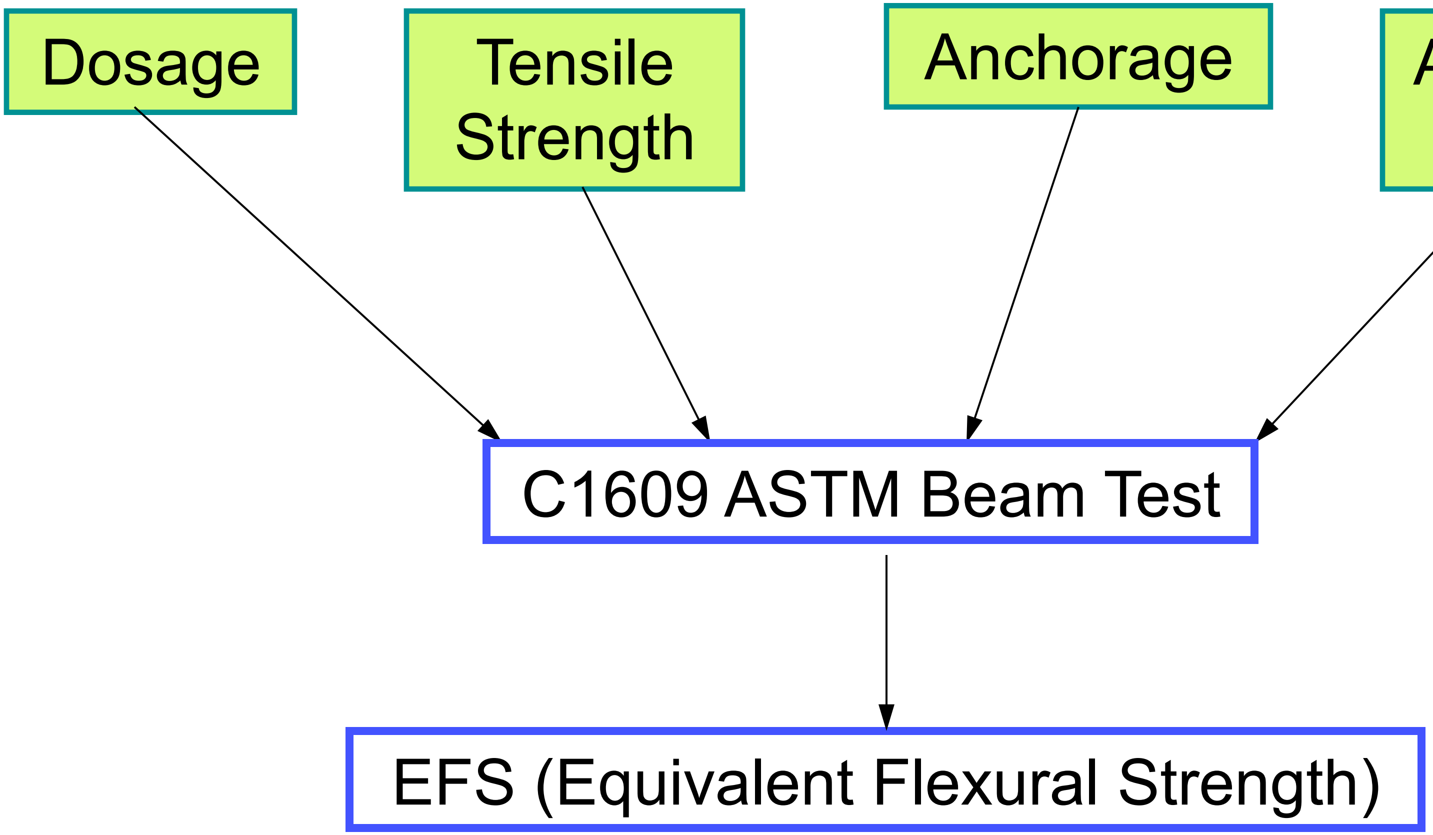
$$EFS = (fe_{600} + fe_{150}) / 2$$

DESIGN

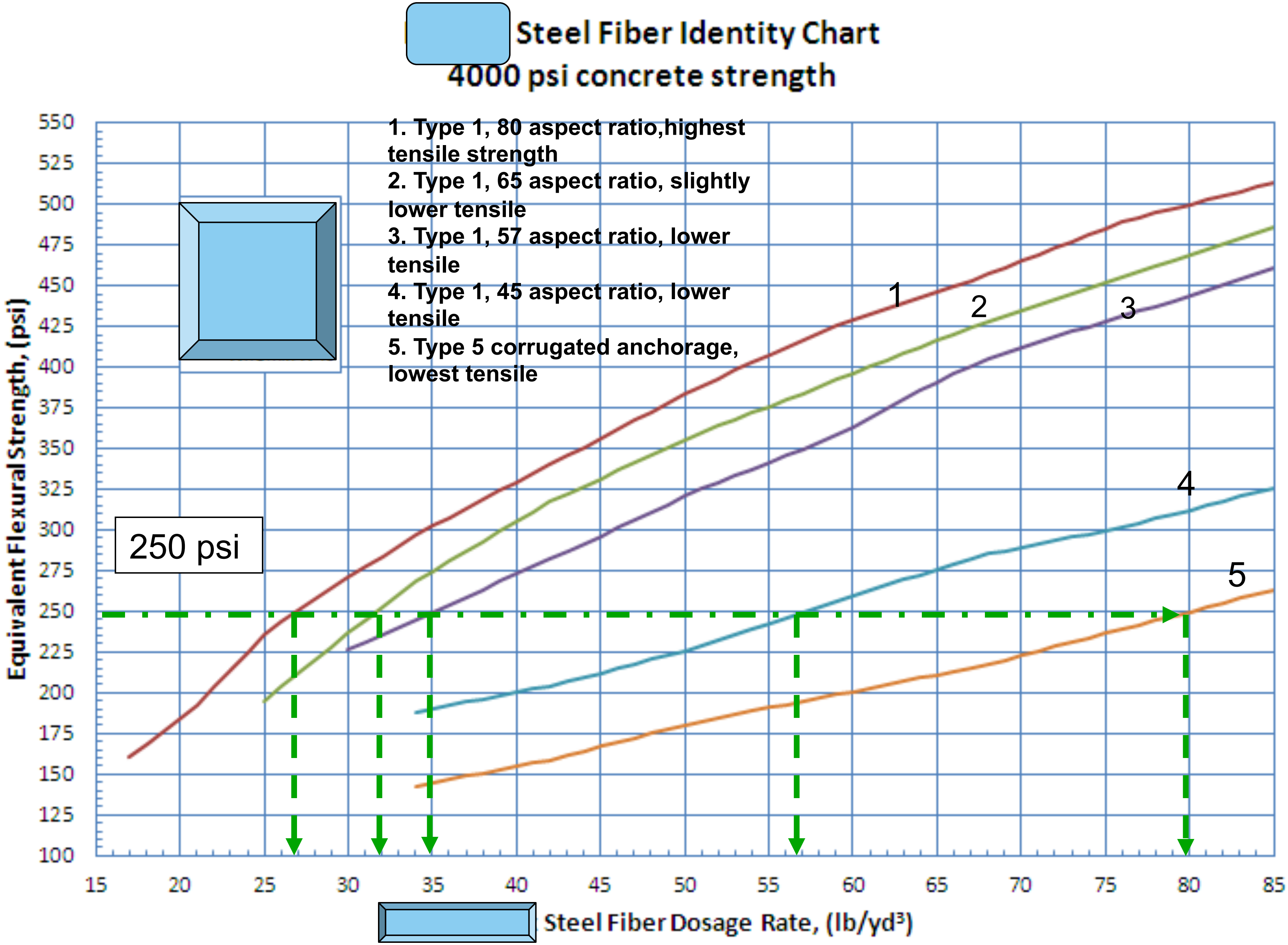


$$ARS = \frac{P_{avg} L}{bxh^2}$$

DESIGN

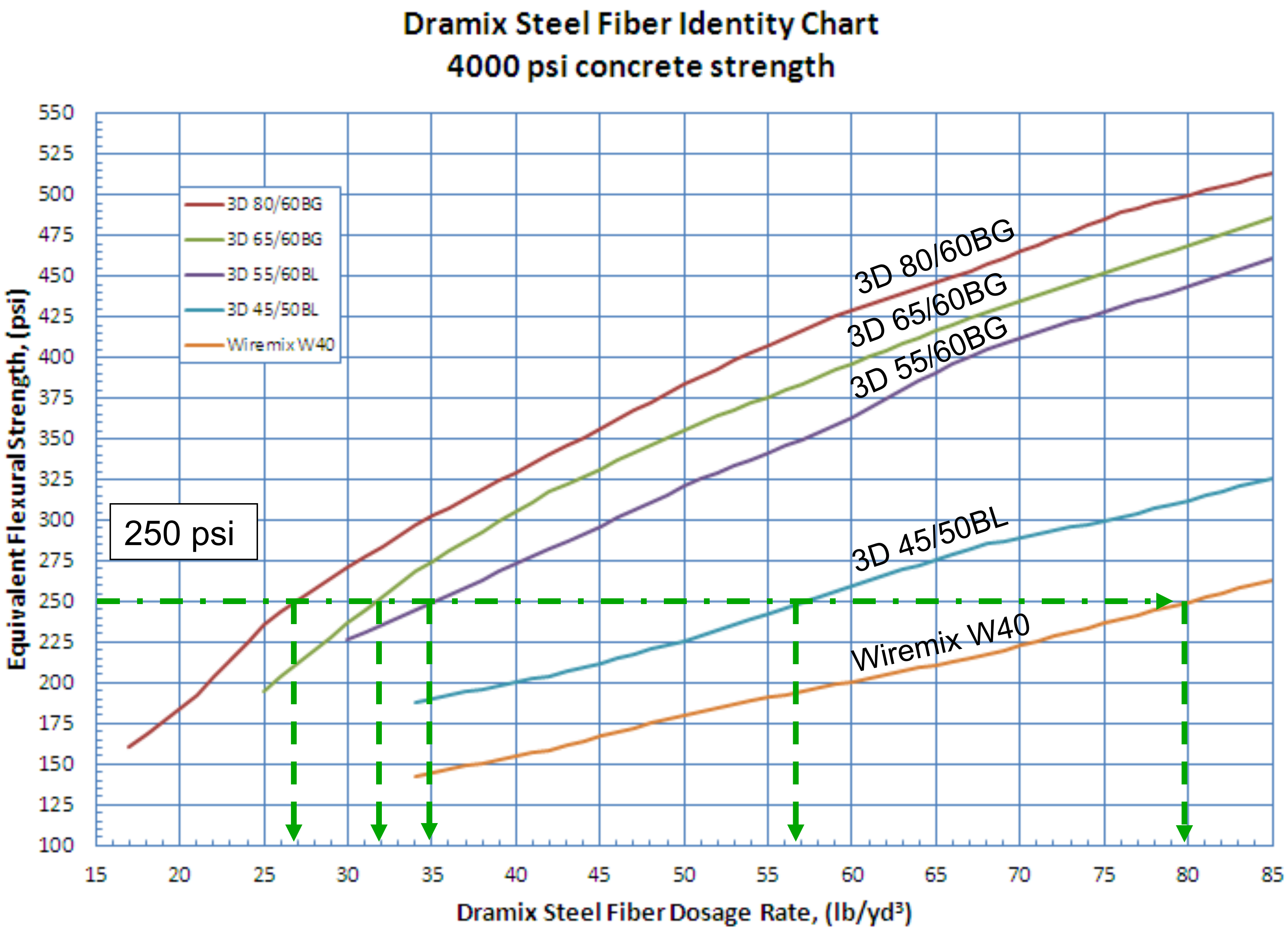

Dosage
Tensile Strength
Anchorage
Aspect Ratio
C1609 ASTM Beam Test
EFS (Equivalent Flexural Strength)

DESIGN



Steel Fiber Identity Chart
4000 psi concrete strength
1. Type 1, 80 aspect ratio,highest tensile strength
2. Type 1, 65 aspect ratio, slightly lower tensile
3. Type 1, 57 aspect ratio, lower tensile
4. Type 1, 45 aspect ratio, lower tensile
5. Type 5 corrugated anchorage, lowest tensile
250 psi
Equivalent Flexural Strength, (psi)
Steel Fiber Dosage Rate, (lb/yd³)
550
525
500
475
450
425
400
375
350
325
300
275
250
225
200
175
150
125
100
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
1
2
3
4
5

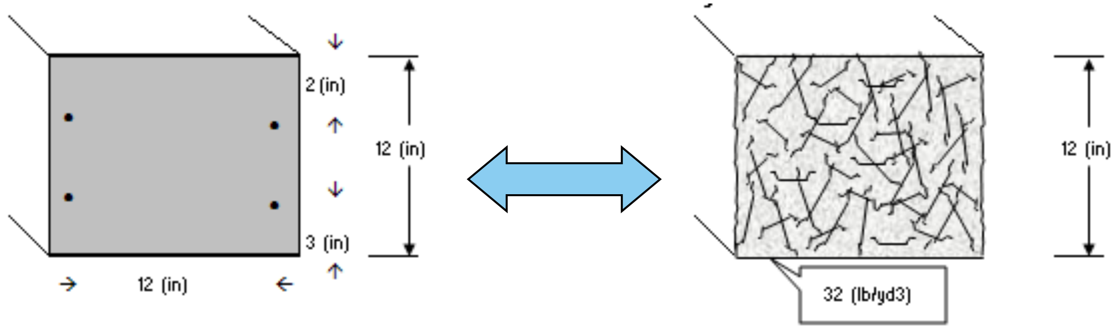
DESIGN



Dramix Steel Fiber Identity Chart
4000 psi concrete strength
Equivalent Flexural Strength, (psi)
Dramix Steel Fiber Dosage Rate, (lb/yd³)
550
525
500
475
450
425
400
375
350
325
300
275
250
225
200
175
150
125
100
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
3D 80/60BG
3D 65/60BG
3D 55/60BL
3D 45/50BL
Wiremix W40
250 psi
3D 80/60BG
3D 65/60BG
3D 55/60BG
3D 45/50BL
Wiremix W40

Equivalent Moment Capacity

- Equates capacity of conventional steel reinforcement to SFRC section



Note: The 3 items needed

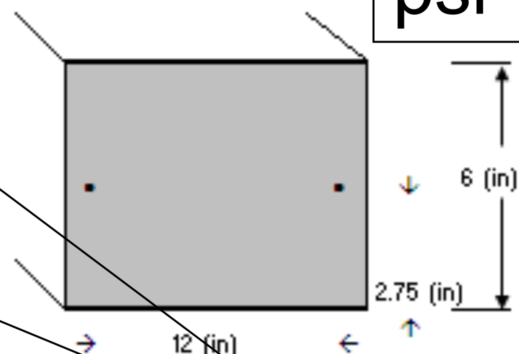
1. **slab thickness,**
2. **concrete psi**
3. **size/spacing of the steel to include the number of layers**

DESIGN

		Plain Concrete (Note 1)	Rebar Reinforcing (Note 2)	SFRC (Note 2)
Thickness	(in)	6.0	6.0	6.0
Concrete Strength	(psi)	4000	4000	4000
Modulus of Rupture	(psi)	569.0		569.0
Moment Capacity	**(ft-lb/ft)**	**1,707.0**	**4,307.7**	**4,431.0**

Deformed Rebar Reinforcement ____________ **#4 bars at 12 in O.C.**

Number of Layers	1	1 layer
Rebar spacing		12 (in)
Rebar diameter	#4	0.5 (in)
Rebar area		0.2 (in2)
Rebar area per unit of width (As)		0.2 (sq.in./ft)
Steel yield strength (Fy) =		60,000 (psi)
Bottom layer cover =		center (in)



1. Slab Thickness

2. Concrete psi

3. Reinforcing

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Determine Equivalency

2) Rebar reinforced slab:

Bar Reinforcement =	#4 bars at 12 in O.C.	
Strength reduction factor for reinforced section (Φ) =	0.90	
Strength reduction factor for plain section (Φ) =	0.55	
Moment Capacity Φ Mn =	ΦMn = Φ *As*Fy (0.9*d)/12	(Ref 1, p 39)
Moment Capacity Φ Mn+ =	2,430 (ft-lb/ft)	(capacity of reinforced concrete, bottom)
	1,878 (ft-lb/ft)	(capacity of plain concrete, top)
Combined moment capacity, Φ Mn = Φ(Mn+) +Φ(Mn-) =	**4307.7 (ft-lb/ft)**	

3) Dramix Steel Fiber Reinforced Slab

Steel fiber type and dose =		32 pounds per cubic yard of Dramix 3D 65/60BG
Section Thickness (t) =		6.0 (in)
Concrete Strength (f'c) =		4,000 (psi)
Section Modulus (s) =	$w \cdot t^2 / 6$ =	72.0 (in3)
Modulus of rupture, (fr) = 9*√f'c =		569 (psi)
Strength reduction factor for reinforced section (Φ) =		0.90
Equivalent flexural ratio, Re3 =		44 %
Moment Capacity		ΦMn = Φ * [1+Re3/100] fr * S /12
Moment Capacity Φ Mn =		**4431 (ft-lb/ft)**

DESIGN

- Design based on **actual loading** conditions of the slab

- The Floor Design Sheet Captures the information

- Loading parameters of the slab and is usually **more** cost effective

DESIGN

Yield Line Theory

- Ultimate limit state (ULS) thickness design
  - Check on structural integrity of the slab using yield line model.
  - Safety factors for overload, performance and material resistance

- Serviceability limit state (SLS) check
  - Check on crack widths for durability.
  - Check on deformation for usability
  - External loads and material resistance are unfactored.

\- Follows movement toward LRFD and away from ASD in slab-on-ground design (Westergaard Theory 1926)

Yield Line Theory

- Yield line analysis accounts for the redistribution of moments and formation of plastic hinges in the slab.

- Plastic hinge regions develop at points of maximum moment and cause a shift in the elastic moment diagram.

ACI 360R-06

Design of Slabs-on-Ground

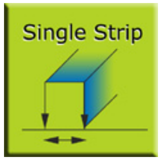
Reported by ACI Committee 360

APPENDIX 6—DESIGN EXAMPLES FOR STEEL FRC SLABS-ON-GROUND USING YIELD LINE METHOD

Step 1 Load cases

The first step is to enter the loads on the slab. The options are:

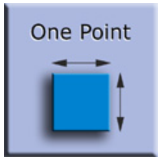
Uniform Distributed Loads:

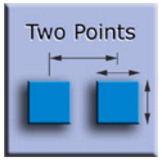


Wheel loads from fork trucks:

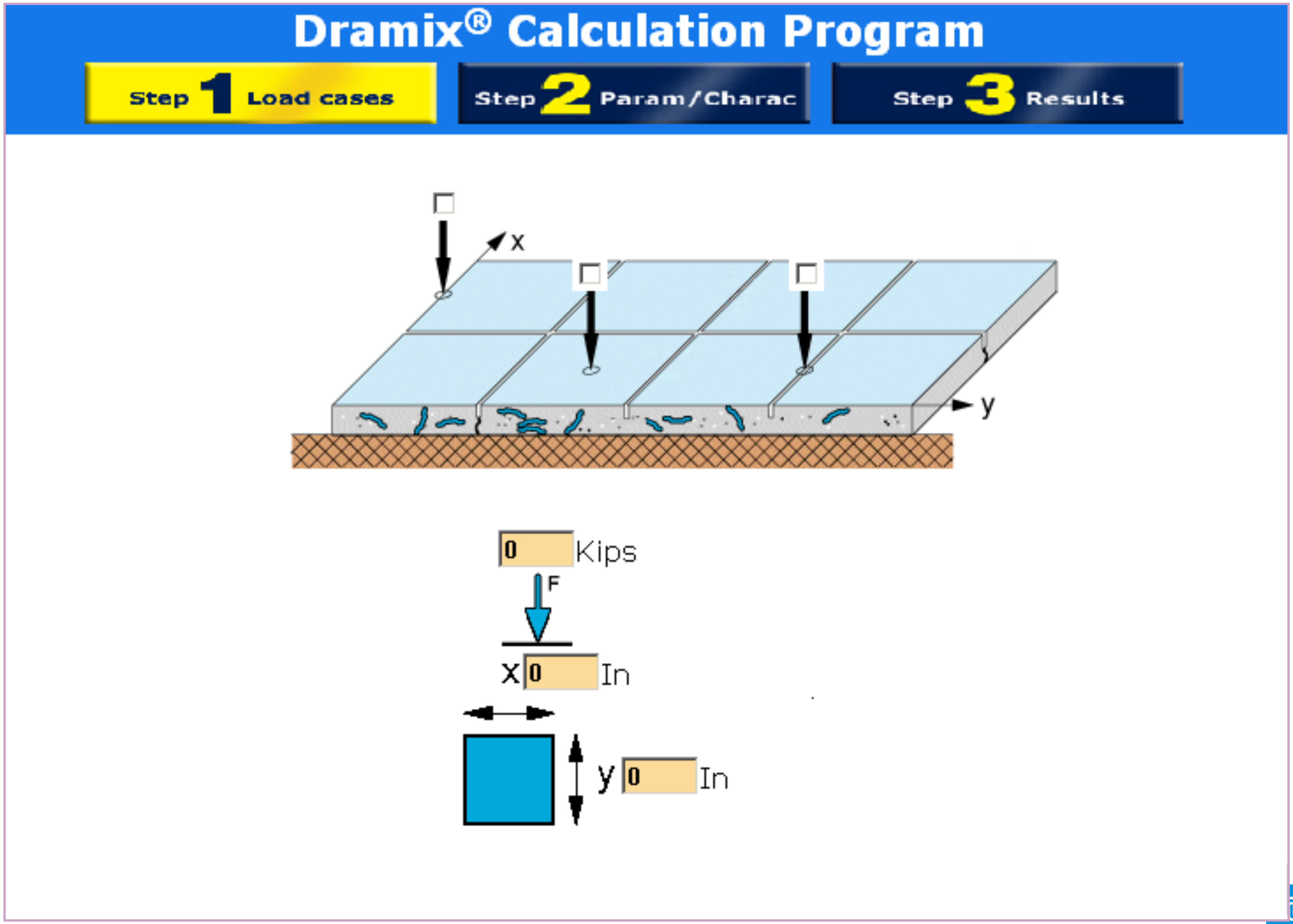
Wheel loads from trucks:

Point loads:

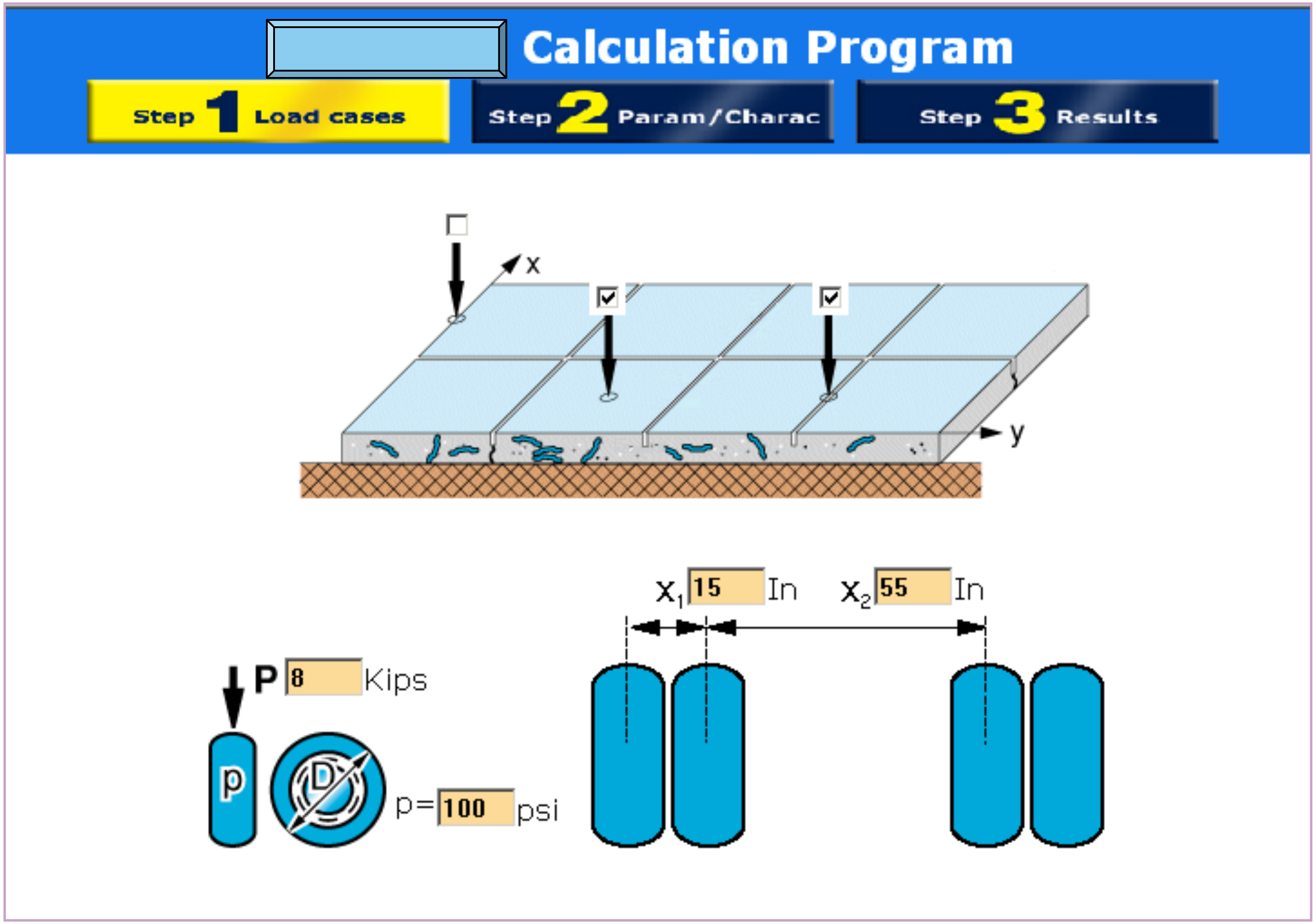




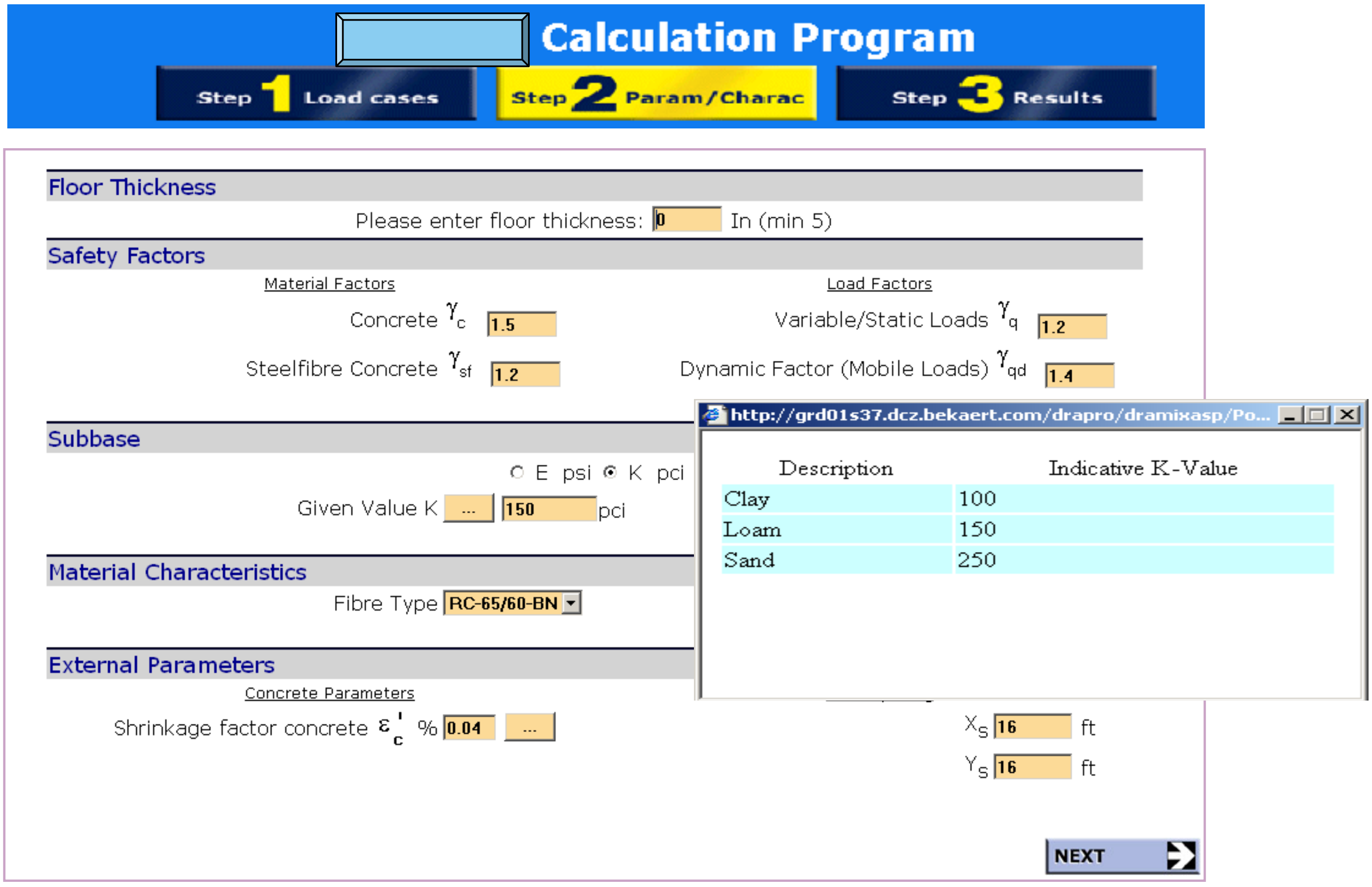
If you click on a button you see this



Or this:


Calculation Program
Step 1 Load cases
Step 2 Param/Charac
Step 3 Results
x
y
P 8 Kips
p
D
p= 100 psi
X1 15 In
X2 55 In

DESIGN


Calculation Program
Step 1 Load cases
Step 2 Param/Charac
Step 3 Results
Floor Thickness
Please enter floor thickness: 0 In (min 5)
Safety Factors
Material Factors
Load Factors
Concrete γc 1.5
Variable/Static Loads γq 1.2
Steelfibre Concrete γsf 1.2
Dynamic Factor (Mobile Loads) γqd 1.4
Subbase
E psi K pci
Given Value K ... 150 pci
Material Characteristics
Fibre Type RC-65/60-BN
External Parameters
Concrete Parameters
Shrinkage factor concrete ε'c % 0.04 ...
Xs 16 ft
Ys 16 ft
NEXT
http://grd01s37.dcz.bekaert.com/drapro/dramixasp/Po...
Description
Indicative K-Value
Clay
100
Loam
150
Sand
250

DESIGN

- OUTPUT

Type of load	: Pointload
Number of loads	: 4
Positioning of the loads	: In a rectangle
Location on the floor	: Center

Assumptions /Design Criteria	
K value:	150.000 pci
Concrete compressive strength, f_{ck} :	4000 psi
For ultimate limit state, the governing load case is : One pointload - Next to the intersection	5230.71 lb-ft/ft
For serviceability limit state, the governing load case is : One pointload - Saw Cut	5015.60 lb-ft/ft
Temperature differential between top and Bottom of the slab	9.00 °F
Coefficient of friction (μ) between slab and subbase :	0.50
Solution	
Floor thickness :	7.30 in
Dosage :	32.00 lb/yd^3
Fiber type :	3D 65/60BG
$R_{e,3}$ value :	44.51%
Equivalent flexural strength ($F_{fct,eq,150}$) :	253.04 psi
Max joint spacing :	15.00 ft * 15.00 ft

							-m SLS
							6.8 ft.lbs
							6.8 ft.lbs
	3.00 in	6.00 in	0.1277	3.098	0.9133	2672.1 ft.lbs	2226.8 ft.lbs
	3.00 in	6.00 in	0.1277	3.098	0.9133	2672.1 ft.lbs	2226.8 ft.lbs
	3.00 in	72.00 in	0.0853	2.651	1.2569	3048.0 ft.lbs	2540.0 ft.lbs

DESIGN

- SFRC shall provide an EFS- equivalent flexural strength **250 psi,** minimum when tested in accordance with ASTM C1609, which represents the numerical average of $f_{150,3.0}$ and $f_{150,\,0.75}$

- XYZ steel fibers

- Concentration Rate: 32 pcy to meet required equivalent flexural strength.

- Submittals: Certified test reports showing compliance with specified performance characteristics and physical properties.

Temperature differential between top and bottom of the slab	[illegible]
Coefficient of friction (μ) between slab and subbase :	0.50
Solution	
Floor thickness :	7.30 in
Dosage :	32.00 lb/yd^3
Fiber type :	3D 65/60BG
$R_{e,3}$ value :	44.51%
Equivalent flexural strength ($F_{fct,eq,150}$) :	253.04 psi
Max joint spacing :	15.00 ft * 15.00 ft

DOSING, MIXING & PLACING

DOSING MIXING AND PLACING

- Automatic dosing and dispensing equipment

DOSING MIXING AND PLACING

DOSING MIXING AND PLACING

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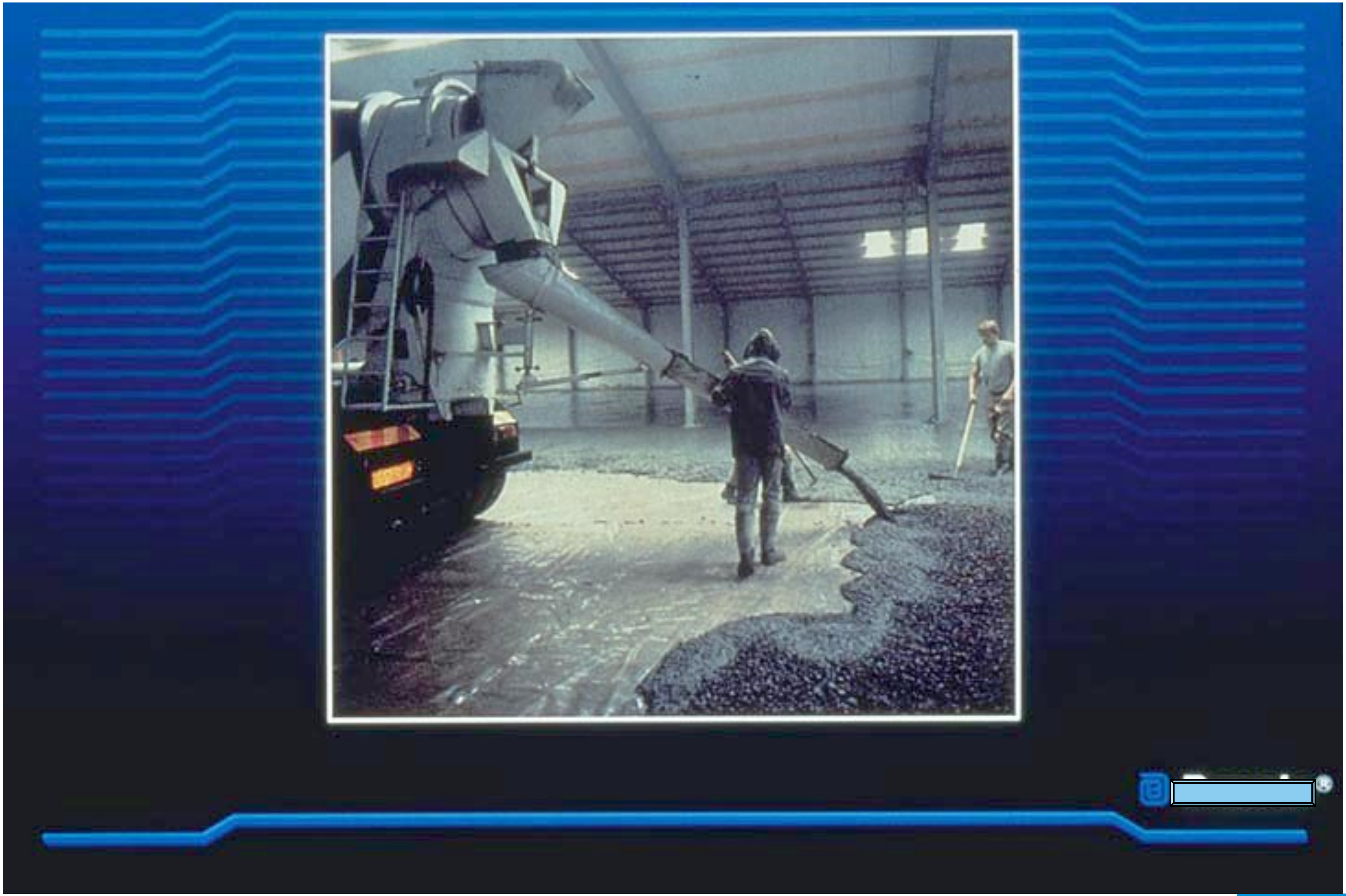


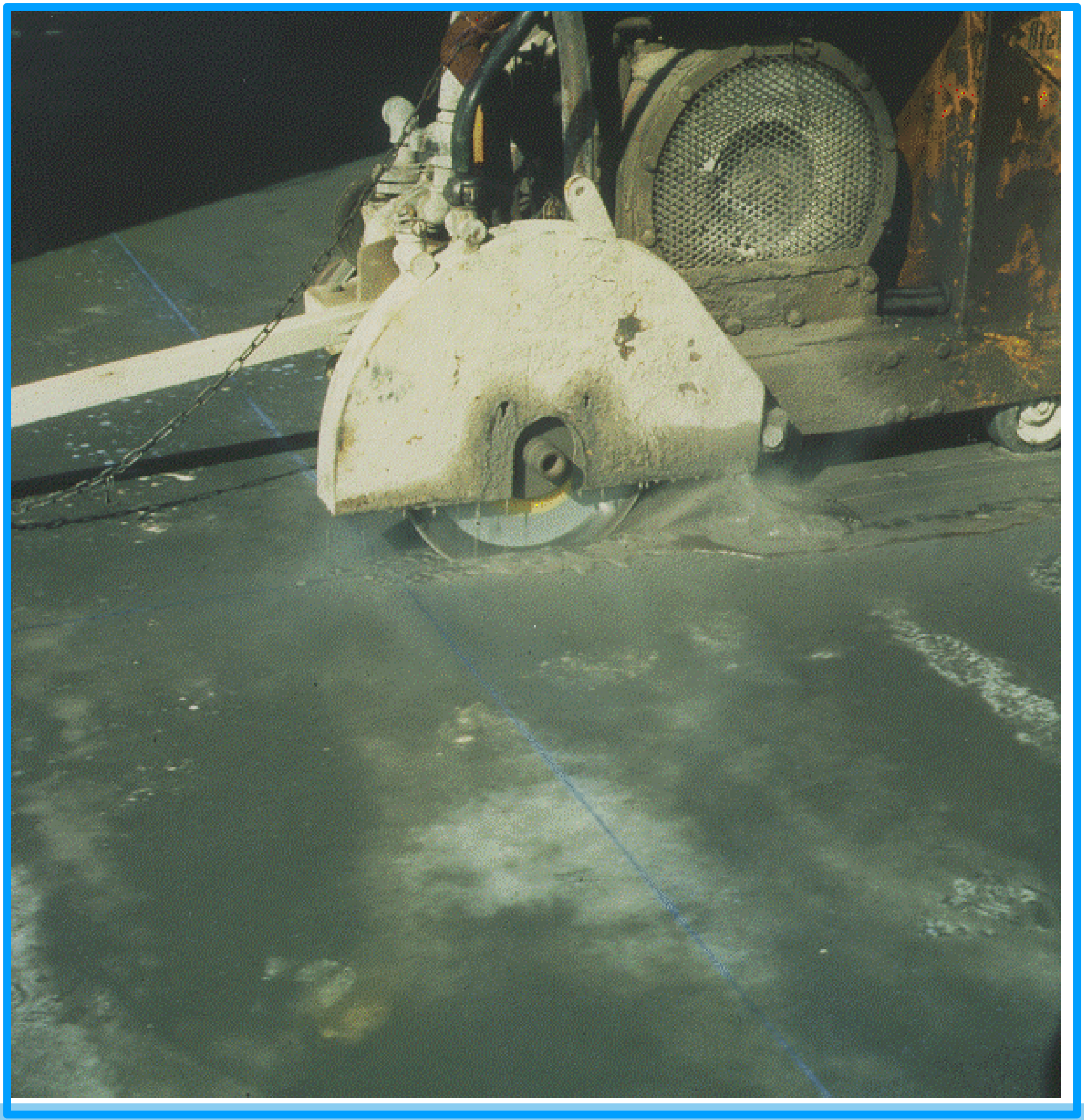
DOSING MIXING AND PLACING

DOSING MIXING AND PLACING

DOSING MIXING AND PLACING

Finishing must be timed correctly to avoid disturbing the fresh concrete surface and uncovering fibers

DOSING MIXING AND PLACING



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BETTER TOGETHER

How Can Steel Fibers Benefit Project Construction?

- **Concrete Floor Projects Are Built Everyday!**
- **Your company can increase profit margins and enhance quality by designing steel fiber concrete reinforcement to speed placements with shorter construction schedules!**

- **Value Engineering quality floors is the key to having an edge!**
- **Your firm can be the extra service provider to your customer base!**

Some Steel Fiber Applications

Commercial

Industrial

Residential

Wiremesh – Correct Orientation is Rare and Time Consuming

Steel Fibers can replace wire mesh!

Concrete Placement Challenges with Rebar

When rebar is placed properly, <u>production is slow.</u>

Steel Fibers can replace rebar!

Have Your Reinforced Concrete Delivered to the Job

Direct discharge of SFRC is no different than plain concrete

1. No conventional reinforcment in the way = more efficient laser screed placement

2. Reduced labor

3. May eliminate pumping.

SC Industrial Floor Project Facts

Scope: 950,000 Square Feet

Conventional Design

12 inches thick, 4500 psi concrete, (2) layers of #4 rebar at 12 inches on center each way, pump required to place

VE Solution

Thinned slab to 8 inches
4000 psi concrete
34 pounds per cubic yard – replaced double mat of rebar!
No pump required

Large Cost Savings due to: decreased labor, time savings in tailgating readymix trucks.

High Quality Floor

Industrial Floor Slab in SC

Industrial Floor Slab in SC

Industrial Floor Slab in SC

Services Provided

- Equivalent moment calculation with steel fibers vs. conventional reinforcement for quick cost evaluation
- Load evaluation with steel fiber computer designs
- Quick turnaround of information to value engineer a project

Steel Fiber Cost Comparison – One Example

Equivalent Flexural Strength Requirement = 250 psi

Slab	Area	Volume Concrete	Fiber	Cost	Total Cost
7 inch	100,000 ft2	2160 yd3	Type 5 Fiber Low Performance Dosage = 80 lbs./yd3	$0.58/lb. x 80 = $46.40/yd3	$100,224
7 inch	100,000 ft2	2160 yd3	Type 1 High Performance Dosage = 32 lbs./ yd3	$0.88/lb. x 32 = $28.16/yd3	$60,825
			Project Savings		$39,399

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Teamwork

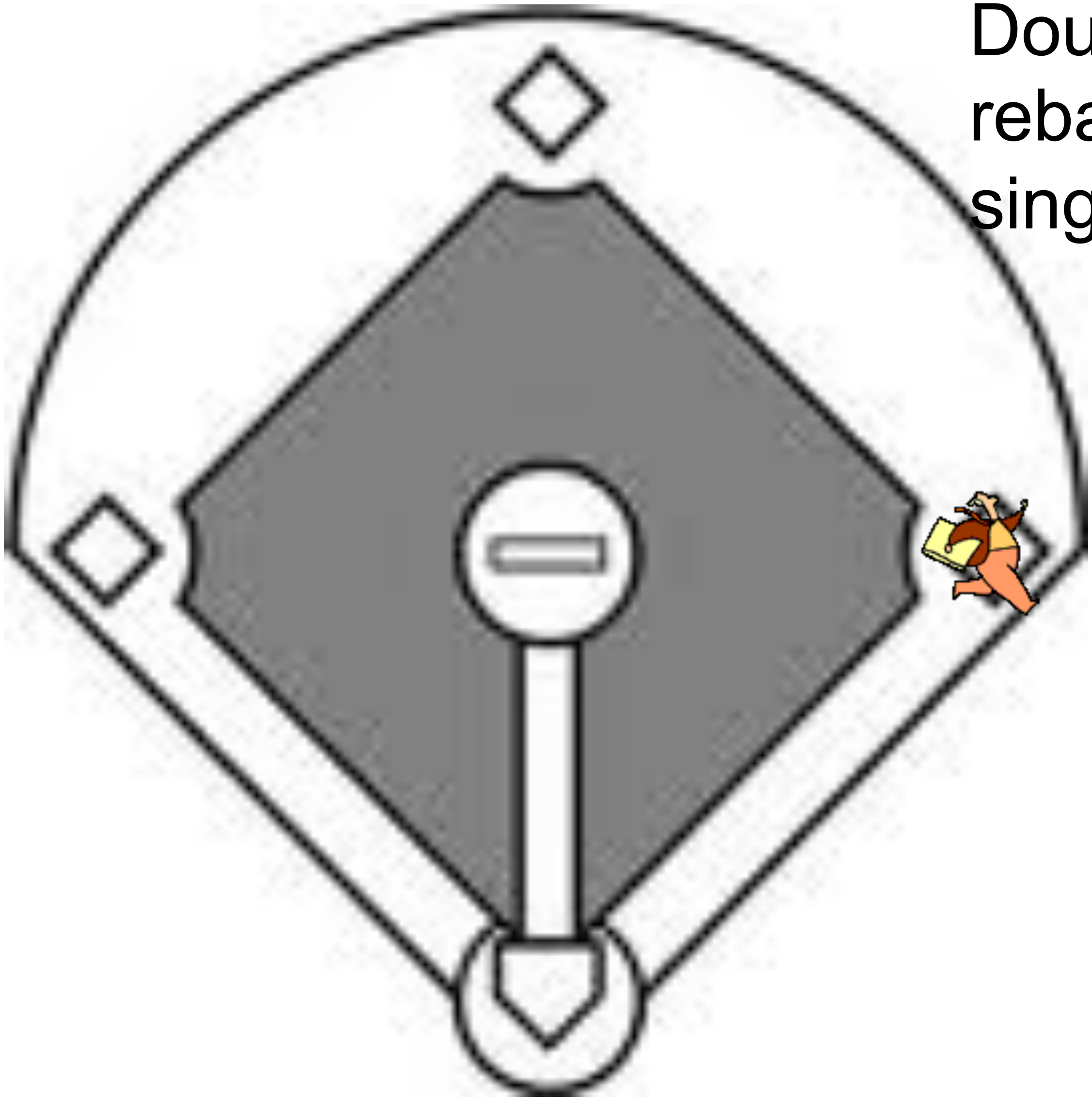
Quality Composite Concrete Floors and Design Service

Advantages– Quality & Cost

- Contractors: Shorter Construction Schedules
  Lower Maintenance Cost- Fewer Call backs; joint repair, etc.
- Engineering: Better Design Solutions
- Owners: Higher Quality Floor Slabs

Better Together

Thick slabs



Double layer of rebar or heavy single layer

Thick slabs

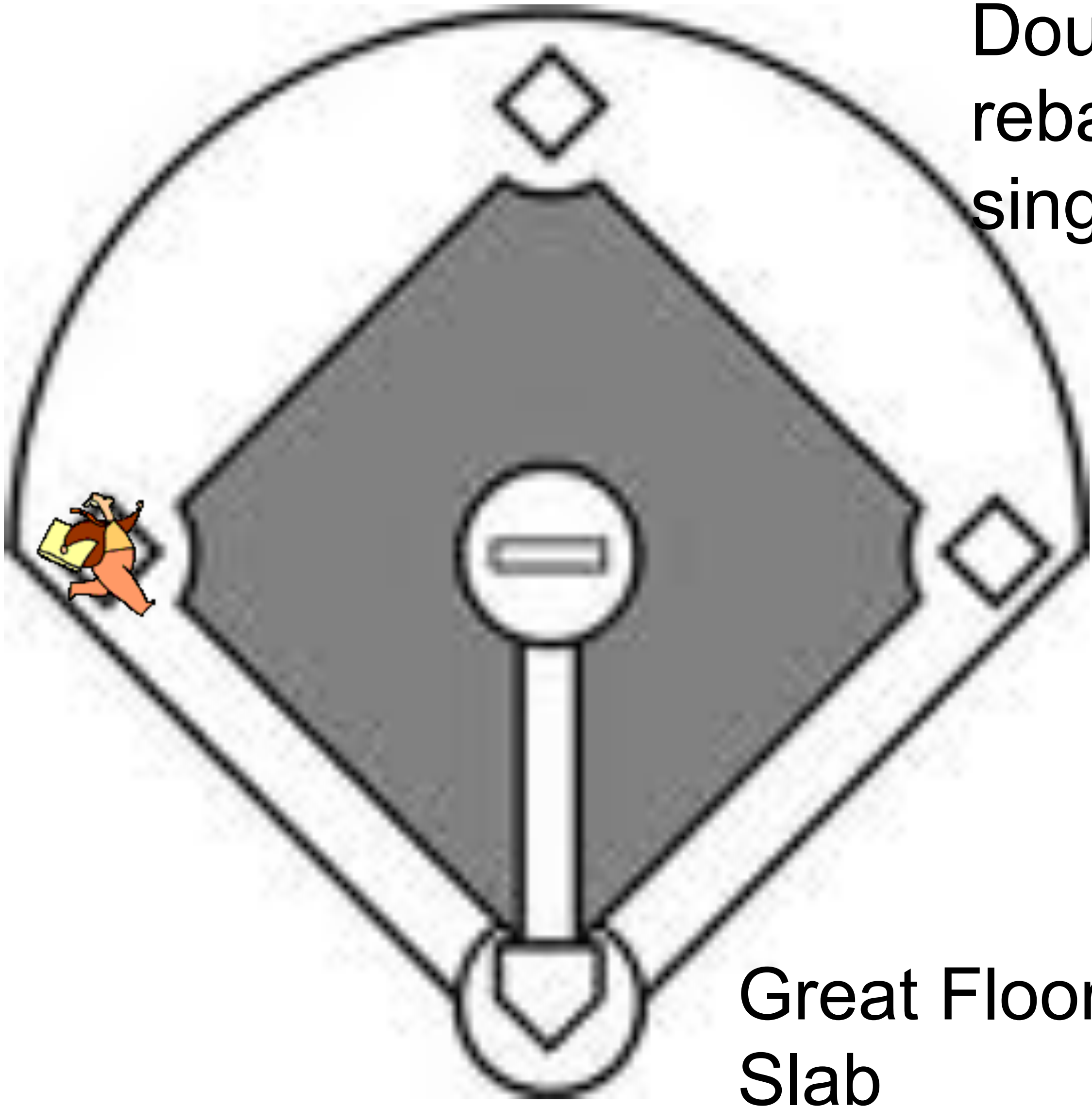
Double layer of rebar or heavy single layer

Dowels at control joints

Thick slabs

Double layer of rebar or heavy single layer

Dowels at control joints



Thick slabs

Great Floor Slab

Things to Look For

- Double Layer of Rebar – Why? – Labor intensive, pumping mandatory
  More efficient laser screed usage
- Heavy Single Layer – EX. #5 @ 12 inches on center- labor intensive
- Very thick slabs
- Dowels bars at sawn control joints – labor intensive, many type 1 steel fibers in conjunction with aggregate interlock provide good load transfer across joints.
- Steel fiber solution vs. conventional reinforcement will reduce labor cost, save time and money for shorter construction schedules.

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Thank You!

Questions?

Next Steps?

Why Dramix®?

$$ Saves Money $$

Project example: 100,000 sq ft. slab on grade, 4" thick = 1,235 cubic yards of concrete

Average mesh prices: 10 gauge mesh 17.50 per roll – 160 sq ft
Lightly Reinforced Concrete Slab Chart – Dramix 3D 80/60 BG = 10.5 pounds per cubic yard for 10 gauge wire mesh

Contractor Options

1. WWM Pricing W1.4- 10 gauge mesh is $17.50 per roll /160 = .109 per sf material + .10 labor = .209 inst. per sf

2. Ready Mix Supplier Provides Steel Fiber Reinforced Concrete

Per Lightly Reinforced Concrete Slab Chart at list price.

3D 80/60 BG truck load price = $.8024 + est .025 freight = $8.27 per yd.

4" slab $8.27 @ 25% markup = 10.33 per yd (+ 2.06 per yd RMX profit) / 81 sf = .127 Dramix sf cost to contractor

which saves .082 per sf x 100,000 sf = $ 8,200 savings for contractor vs. using W1.4 Wire Mesh

RMX makes 2.06 per yard x 1234 yds. = 2,542 profit from selling Dramix vs. only selling concrete $$