Ultra-High Performance Concrete and New Opportunities for Prefabrication

Sri Sritharan

Anson Marston Distinguished Professor

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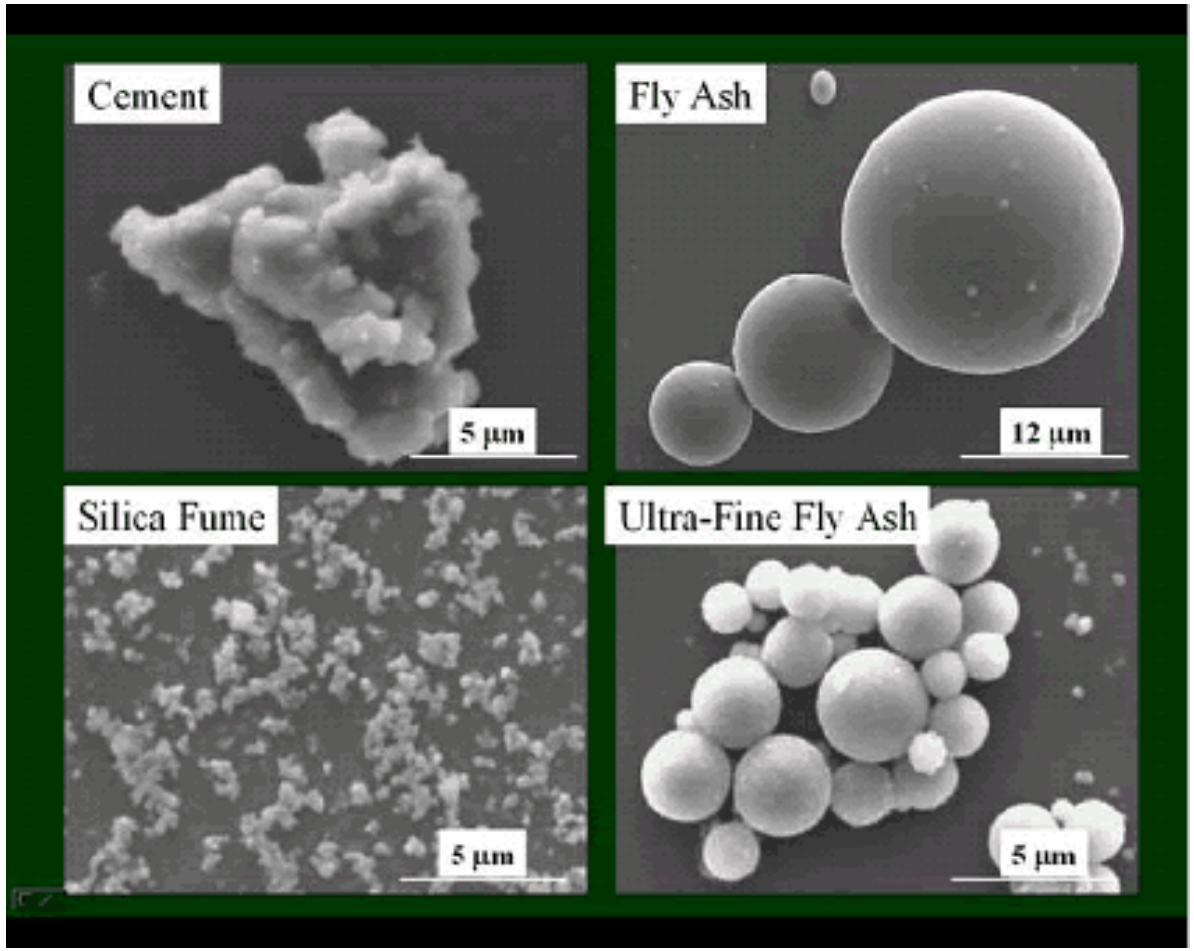
UHPC Definition

Concrete that has a minimum specified compressive strength of 150 MPa with specified durability, tensile ductility and toughness requirements; fibers are generally included to achieve specified requirements.

ACI Committee 239

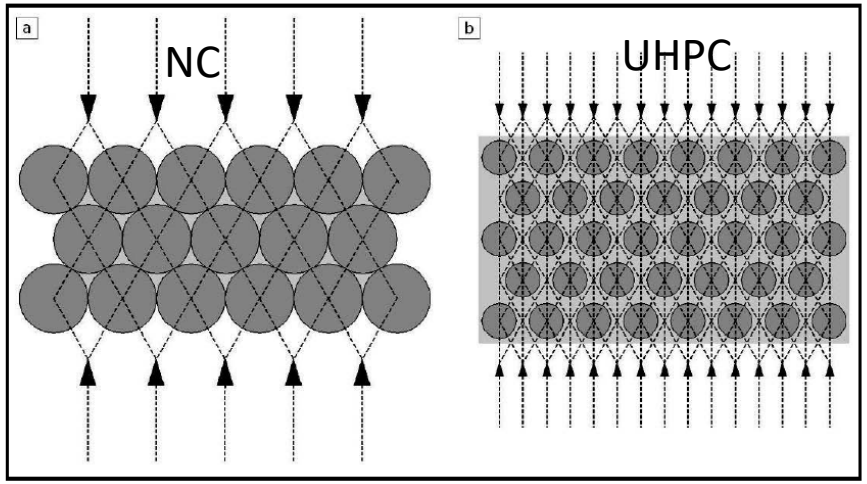
Components

Mineral Admixtures

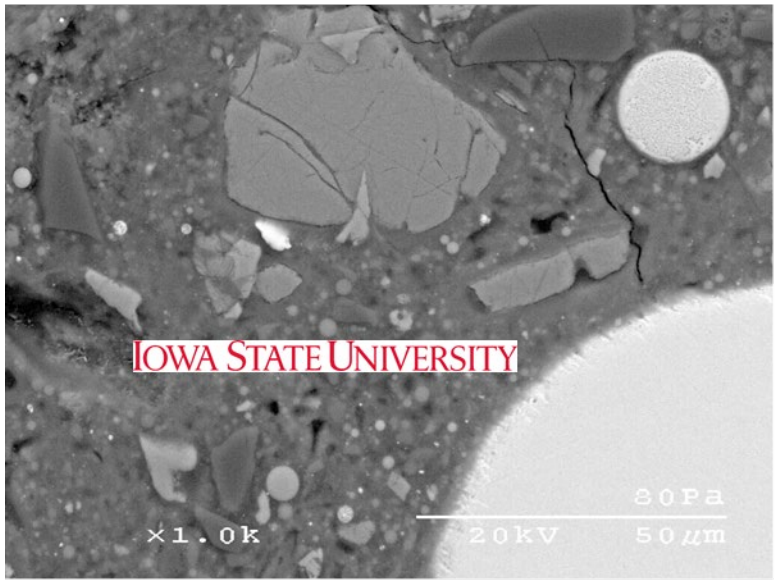


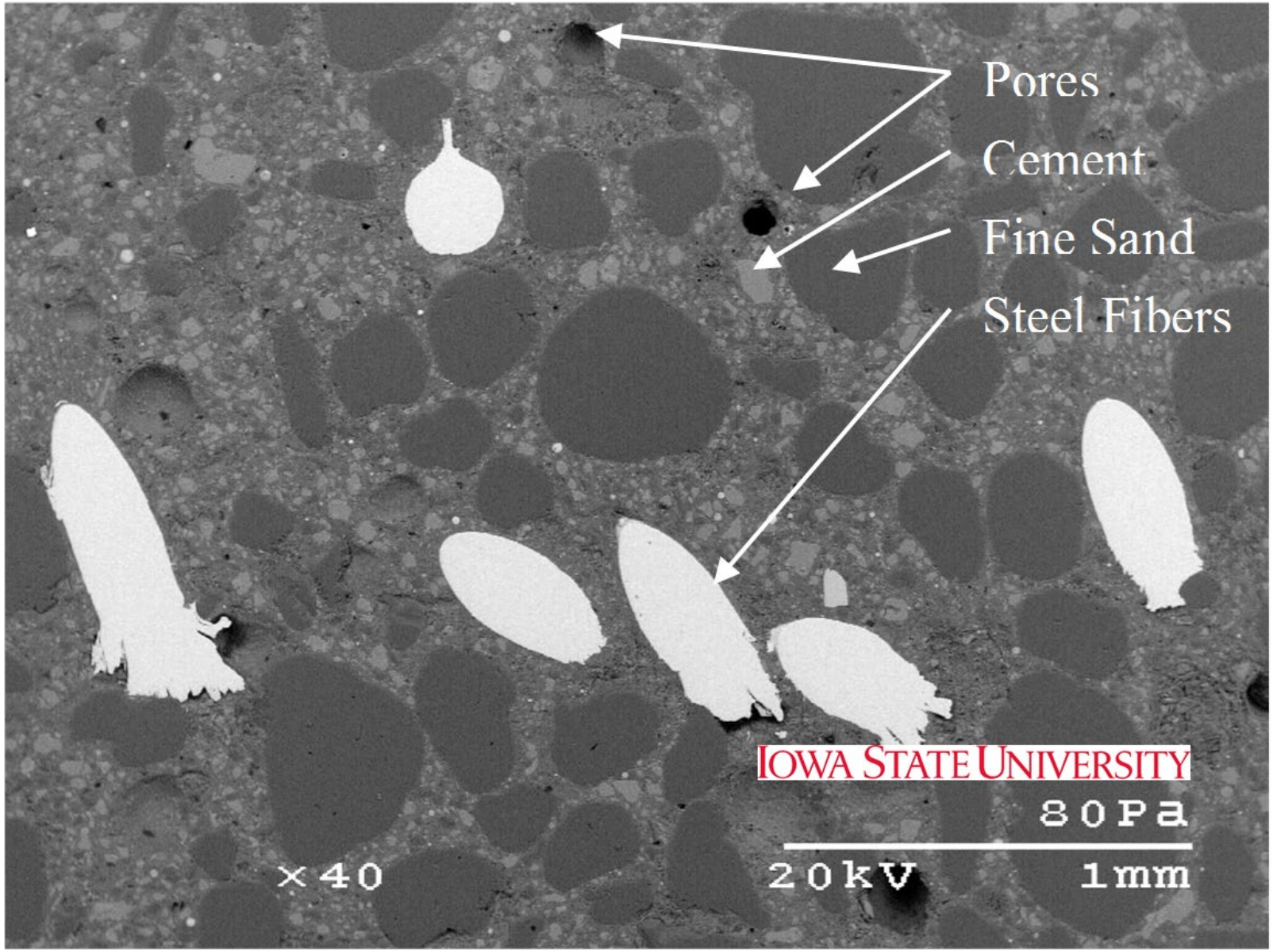
Chemical Admixtures

Proprietary vs. non-proprietary

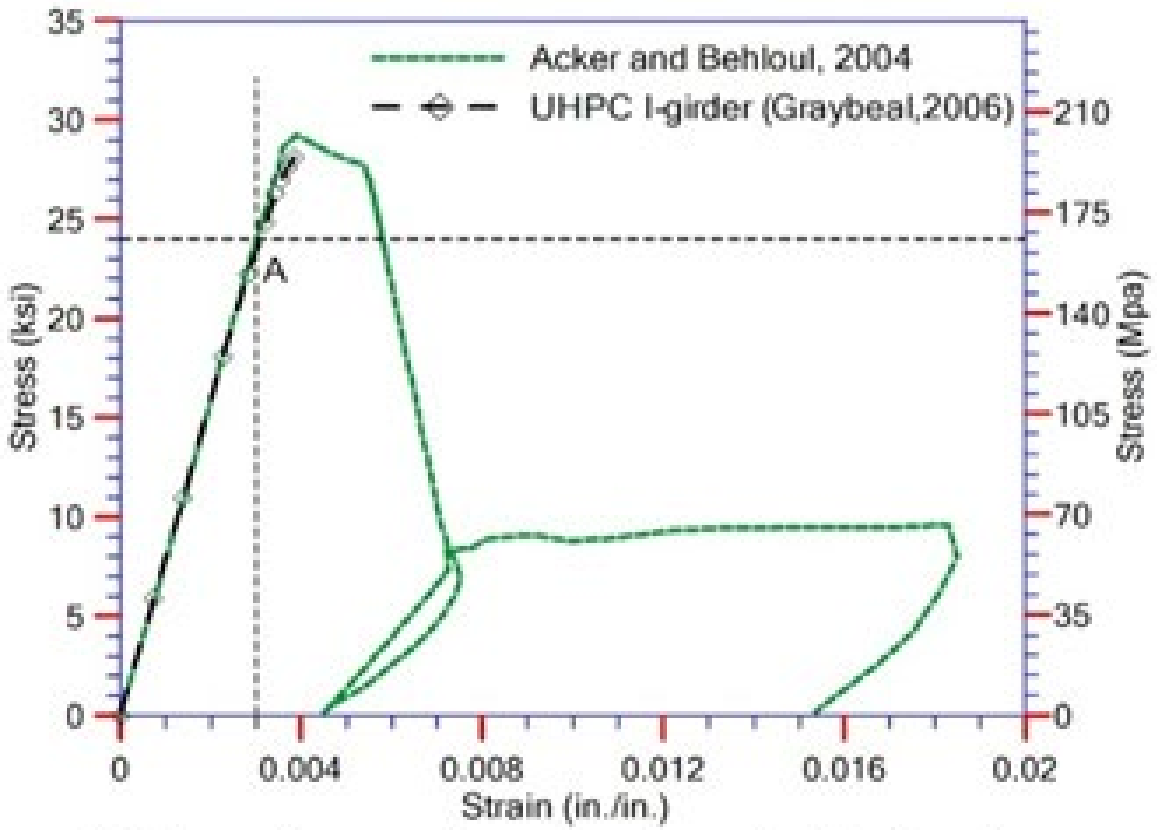


Waraven 2002

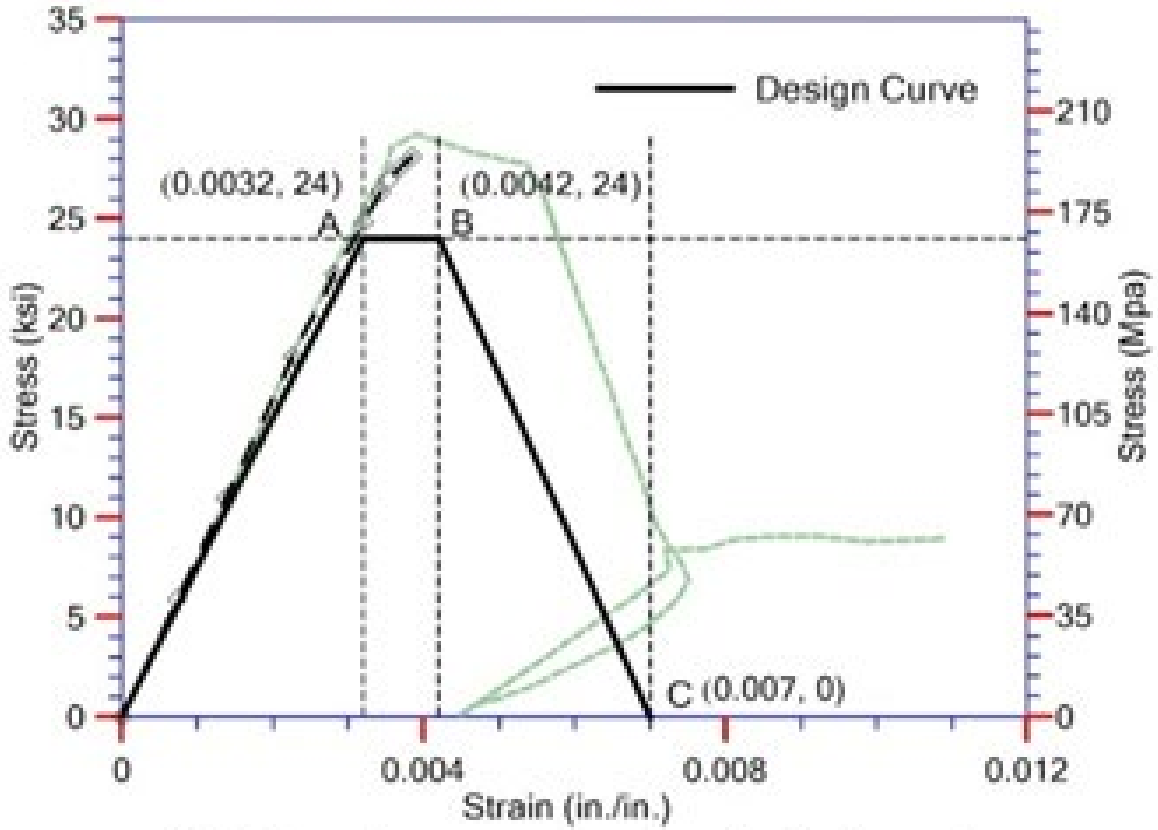




Compression Behavior

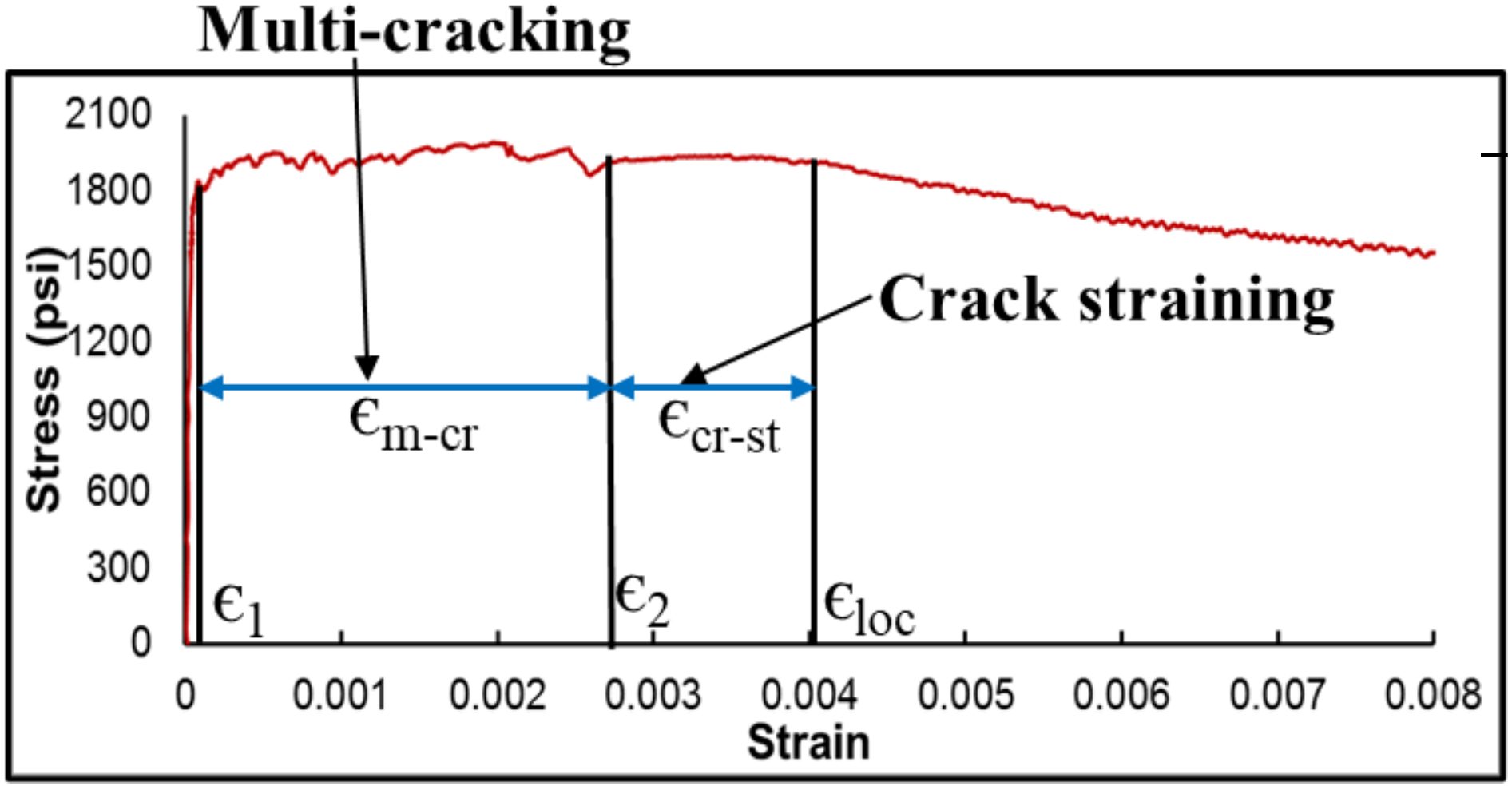


a) Experimental stress-strain behavior



b) Design stress-strain behavior

Tension Behavior



13.4 MPa

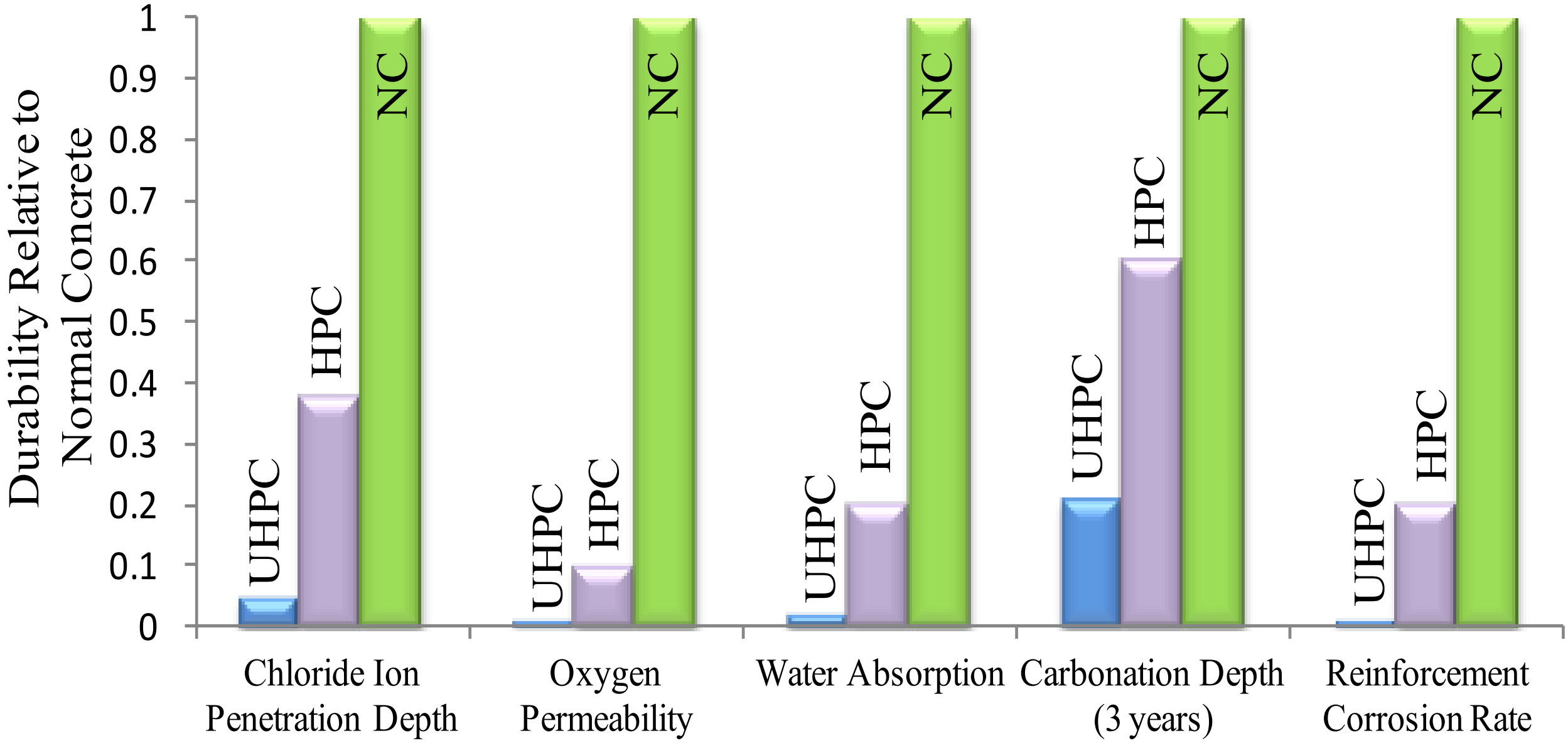
Typical UHPC Properties

- High compressive strength : 124 MPa to 240 MPa
- Sustained Tensile Capacity: 6 to 10 MPa
- Modulus of Elasticity: 40 to 55 GPa
- Rebar Bond: $8d_b$ embedment can ensure yield
- Interface Bond: surpass substrate tensile strength
- Low permeability: 100x less than conventional
  - $2 \times 10^{-11} m^2/s$ for conventional concrete
  - $2 \times 10^{-12} m^2/s$ for HPC
  - $2 \times 10^{-13} m^2/s$ for UHPC
- Freeze/Thaw Resistance: RDM > 95%
- Minimal creep and shrinkage

UHPC vs. HPC vs. NC

- Optimized, fiber-reinforced , heat-treated UHPC
- High Performance Concrete
- Normal Concrete

Property	UHPC	HPC	Normal Concrete
Compressive Strength	26-30 ksi (179-207 MPa)	12-18 ksi (82-124 MPa)	4-8 ksi (28-55 MPa)
Tensile Strength	1.7 ksi (12 MPa)	0.8-0.9 ksi (5-6 MPa)	0.3-0.7 ksi (2-5 MPa)
Elastic Modulus	8000 ksi (55 GPa)	4800-6400 ksi (33-44 GPa)	3600-5100 ksi (25-35 GPa)


Durability Relative to Normal Concrete
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
UHPC
HPC
NC
Chloride Ion Penetration Depth
Oxygen Permeability
Water Absorption
Carbonation Depth (3 years)
Reinforcement Corrosion Rate

Why use UHPC?

- Enhanced durability properties – the primary motivation
  - Increased strength is treated as a bonus
- Extend the service life of structures and reduce maintenance costs
- Optimize structural members and systems
- Reduce reinforcing steel congestion and improve constructability
- Cost competitiveness

UHPC for Prefabrication

- Opportunity to create and own UHPC mix design
- Effective use of pre-tensioning and enhanced UHPC products
- Gain full strength through heat treatment
- Potential to increase production
  - Reduction in member sizes
  - Reduced use of labor
- Promote a new generation of accelerated construction
  - Reduced impact on the traveling public
- Contributes to sustainable solutions

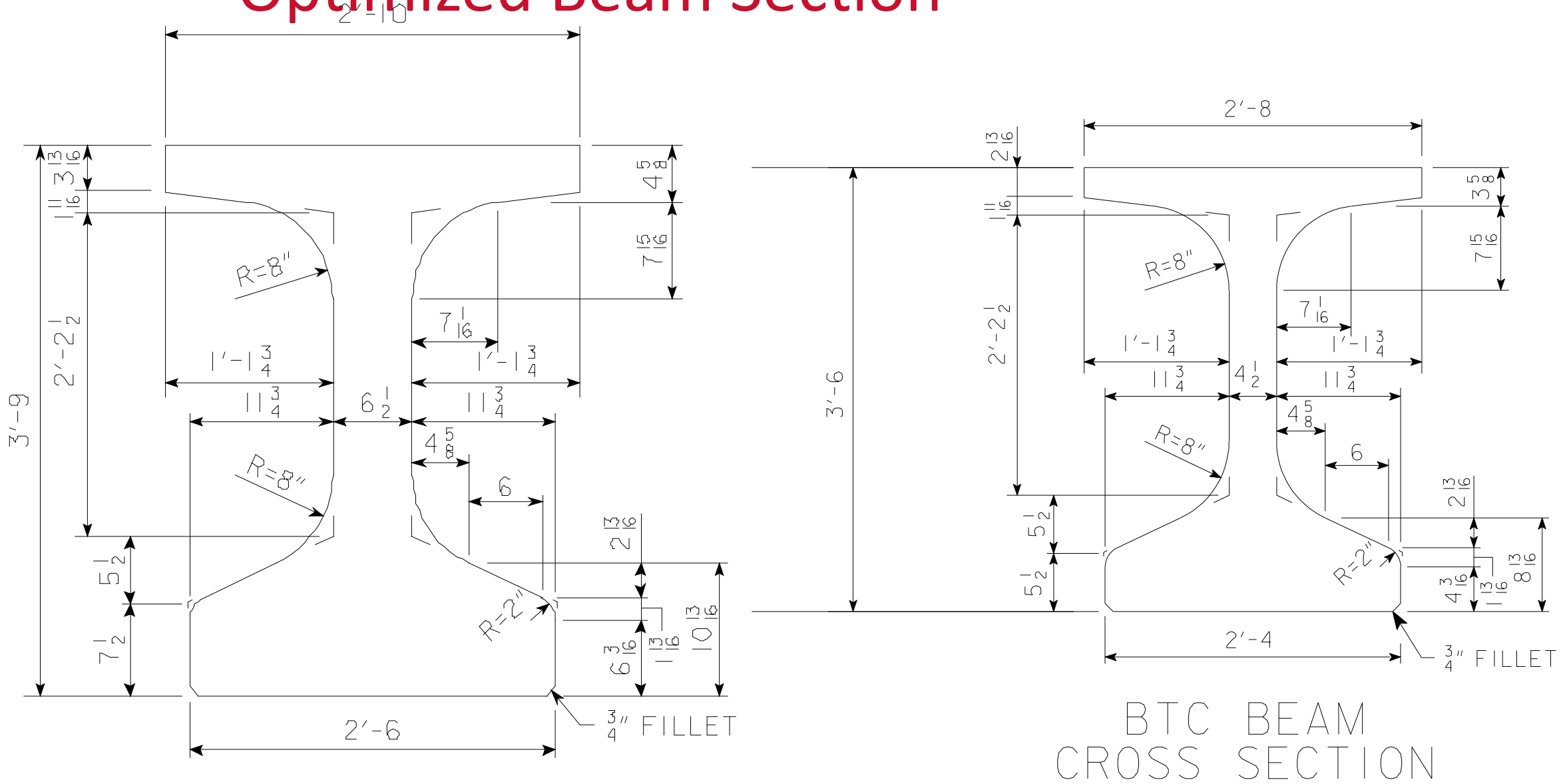
Precast UHPC towards Sustainable Solutions

- Slender, shallower members
- Increased lifespan, and reduced maintenance costs
- Reduced transportation impact
- Promote a new generation of accelerated construction
  - Reduced impact on the traveling public
- Facilitate innovation for both architectural and structural elements
- Increase the precast market share

UHPC in Precast Applications

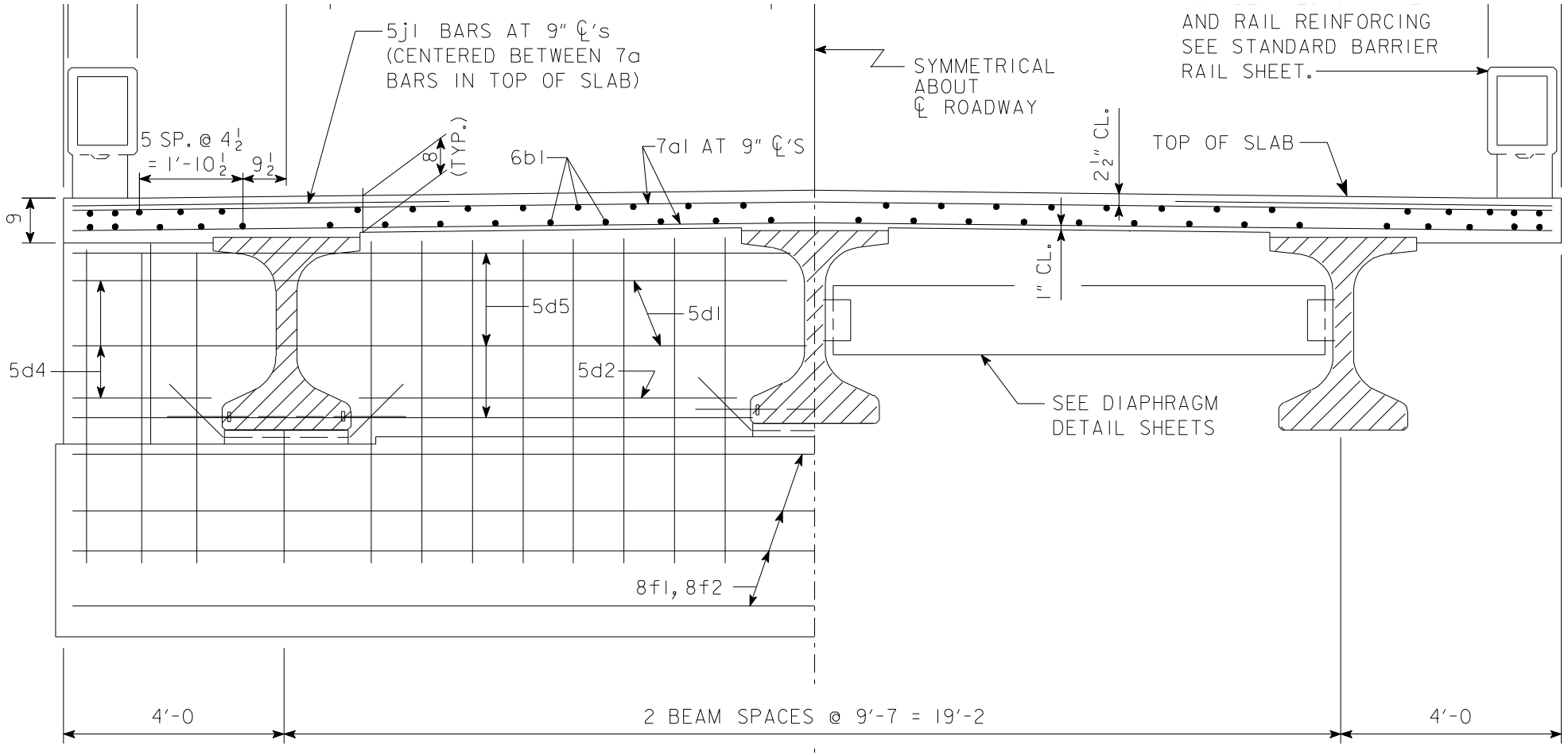
- Bridge Girders (traditional I-shape)
- Bridge Superstructure (optimized π-shape)
- Bridge Deck System (waffle panels)
  - Connections
- Deck overlay
- Piles
- Shell structures
- Wind tubine towers

Optimized Beam Section

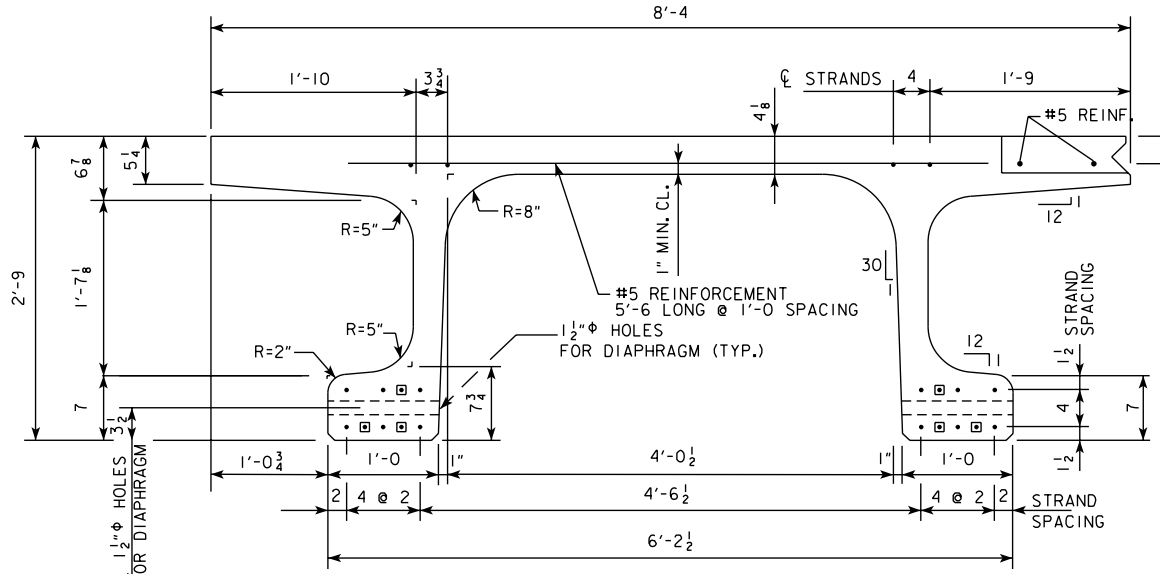


2005

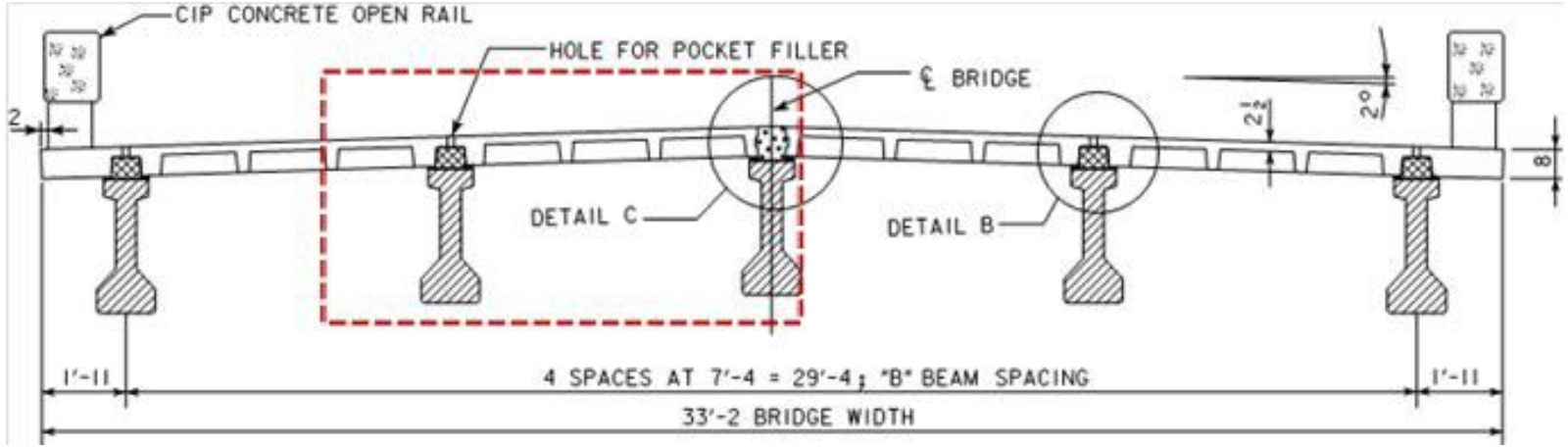
Optimized Cross Section



Optimized Superstructure



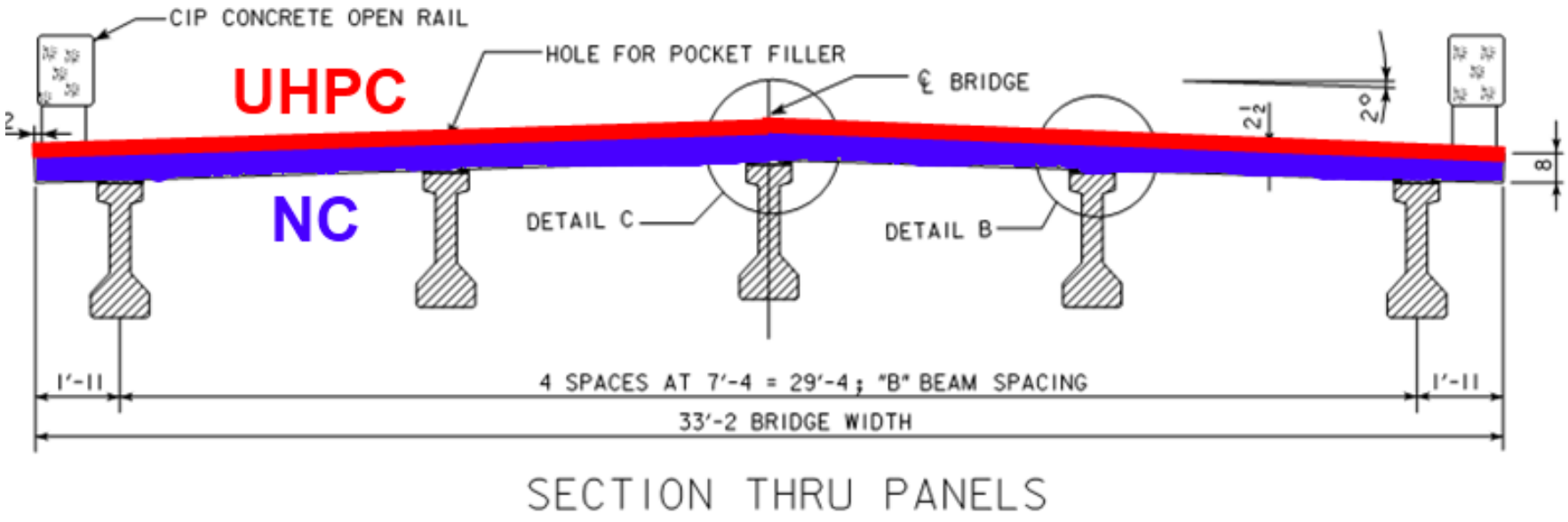
Waffle Deck


CIP CONCRETE OPEN RAIL
HOLE FOR POCKET FILLER
℄ BRIDGE
2
2½
2°
8
DETAIL C
DETAIL B
1'-11
4 SPACES AT 7'-4 = 29'-4; "B" BEAM SPACING
1'-11
33'-2 BRIDGE WIDTH


11/21/2011 14:20


45-2
45-1

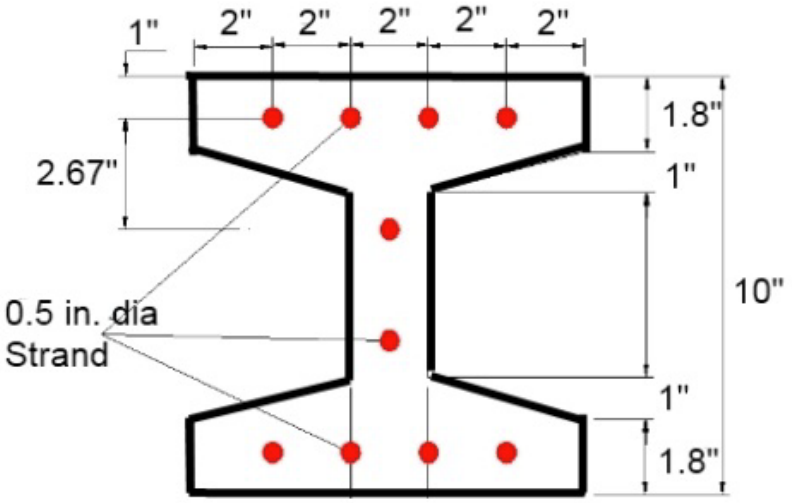
The Overlay Concept



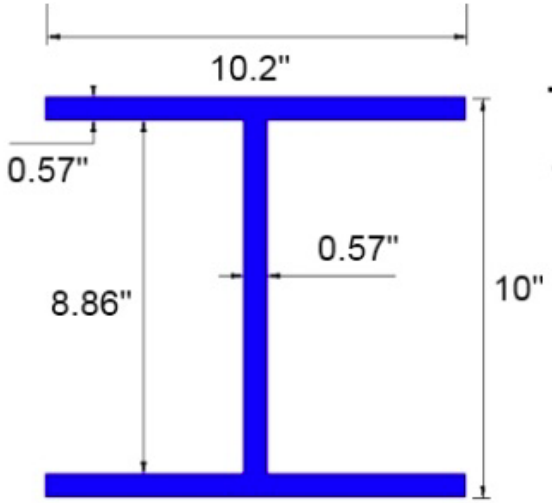
SECTION THRU PANELS

No mechanical connection!

Optimized Pile Section



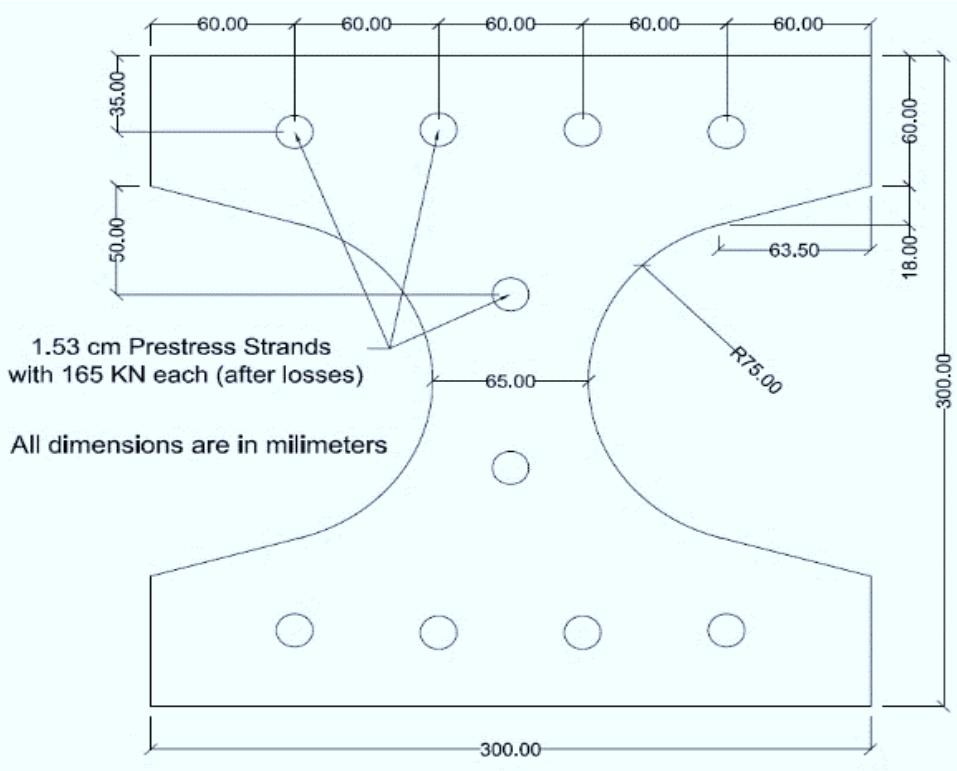
i) UHPC Pile



ii) HP 250 x 85

Parameter	Steel HP 10 x 57	UHPC Tapered H-Shape
Area	16.8 in^2 (108 cm^2)	56.8 in^2 (366 cm^2)
Weight	57.2 lb/ft (85.1 kg/m)	61.1 lb/ft (90.9 kg/m)
Stiffness Term (E·I)	8.53×10^6 kip·in^2 (2.25×10^{13} N·mm^2)	6.36×10^6 kip·in^2 (1.83×10^{13} N·mm^2)

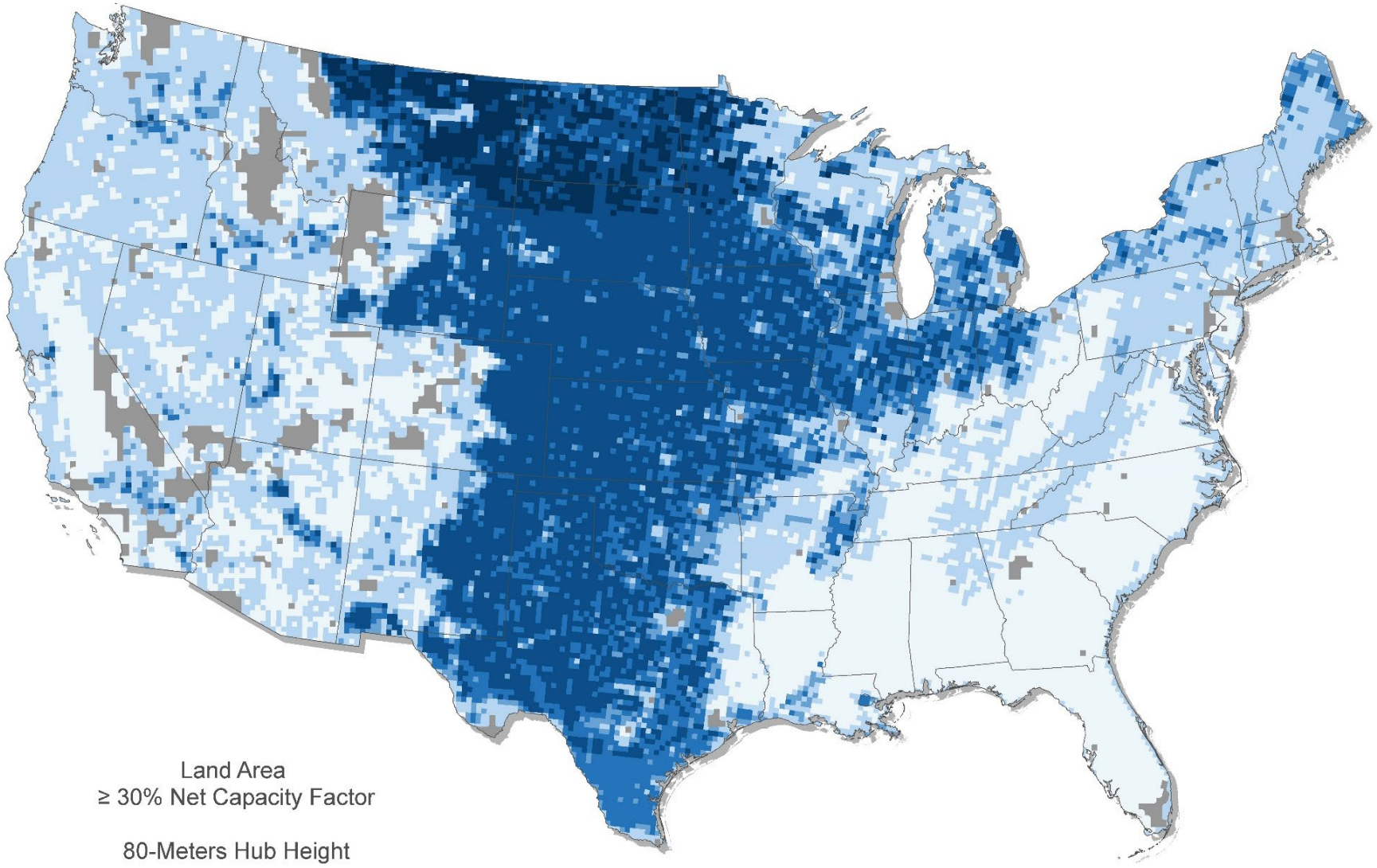
Larger Pile Section



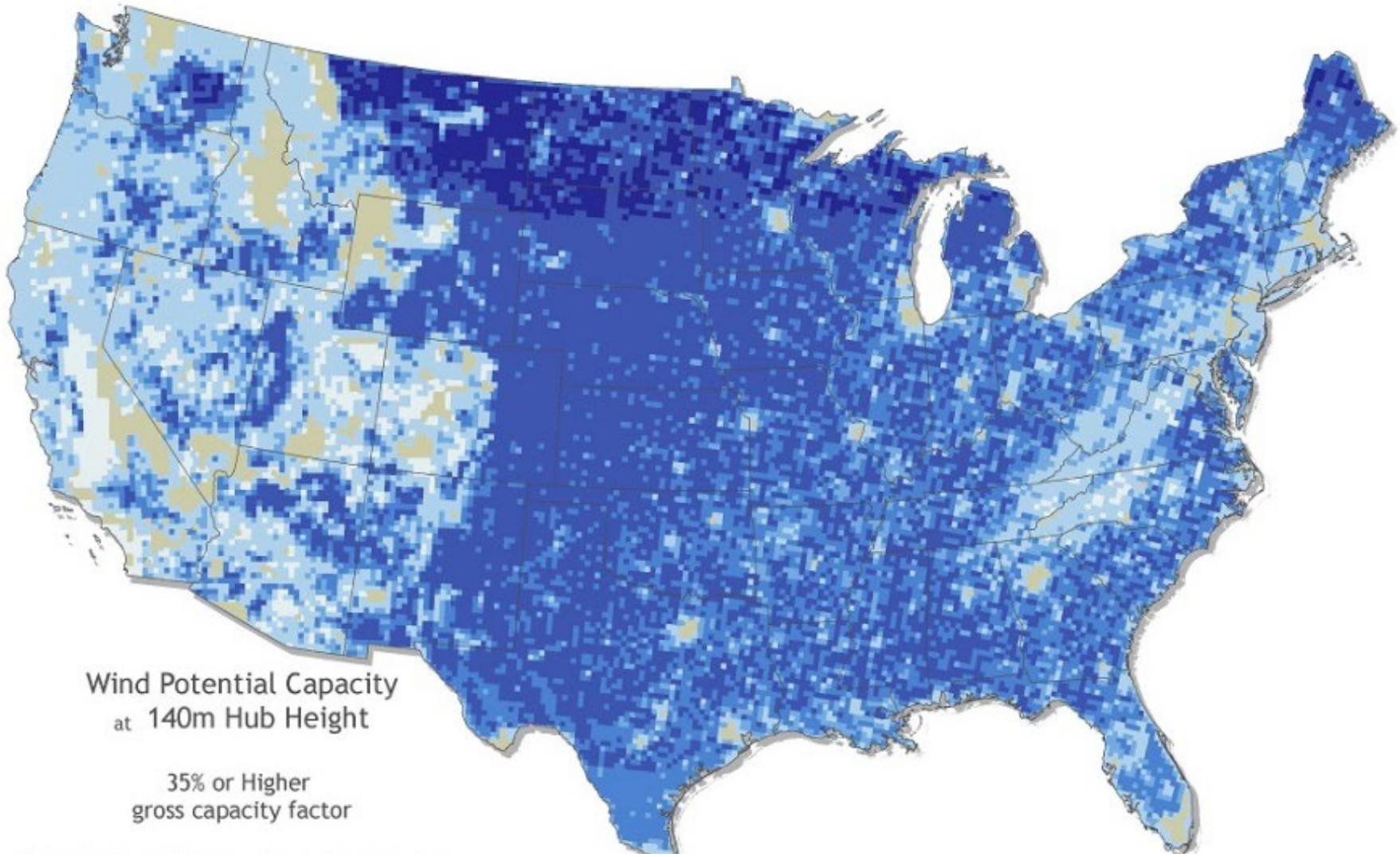
Completed Unit

Max. Diameter
≤ 14 ft (4.3 m)

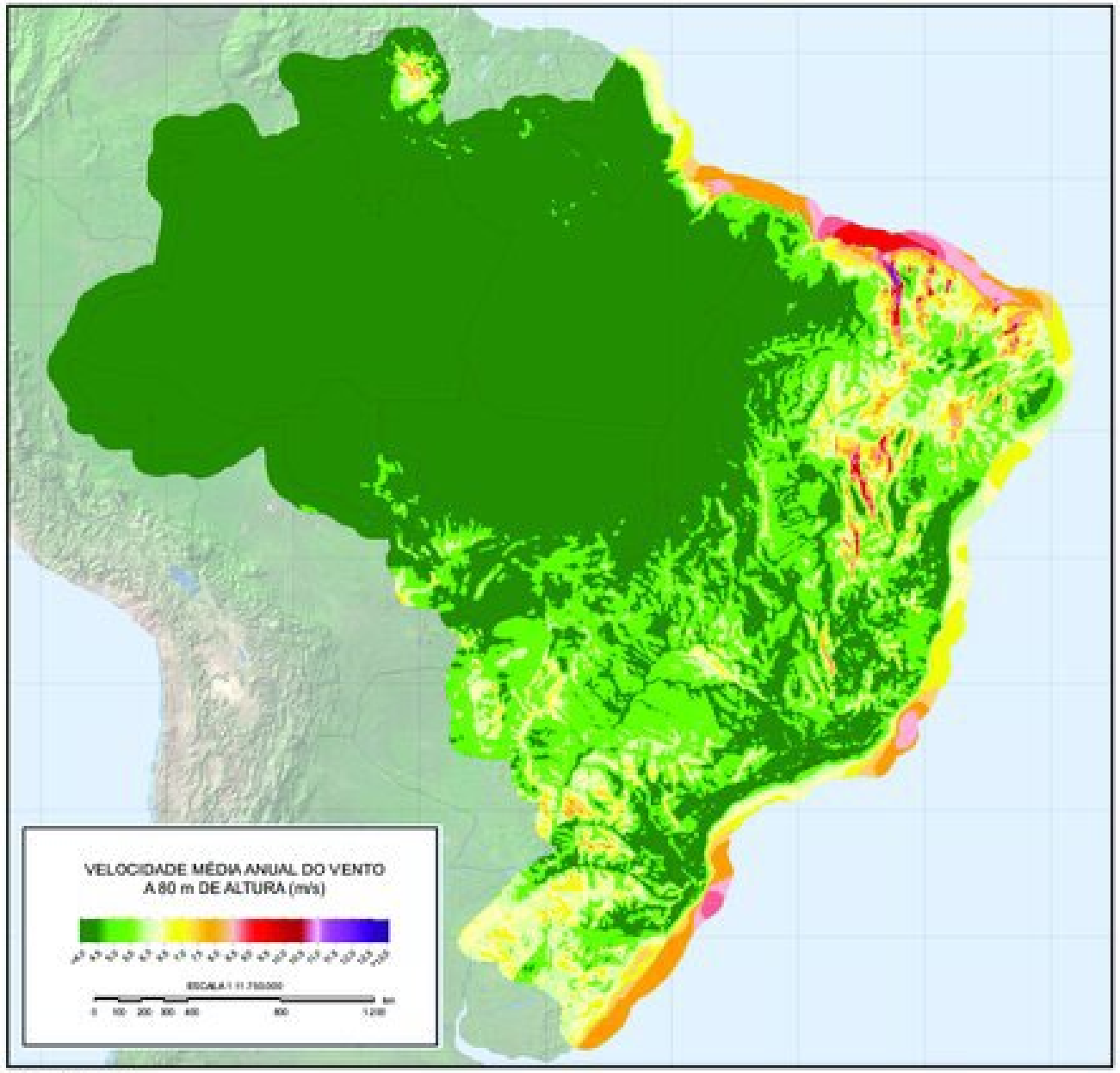
Market Penetration - 80m Hub Height



Wind Potential at a 140 m Hub Height

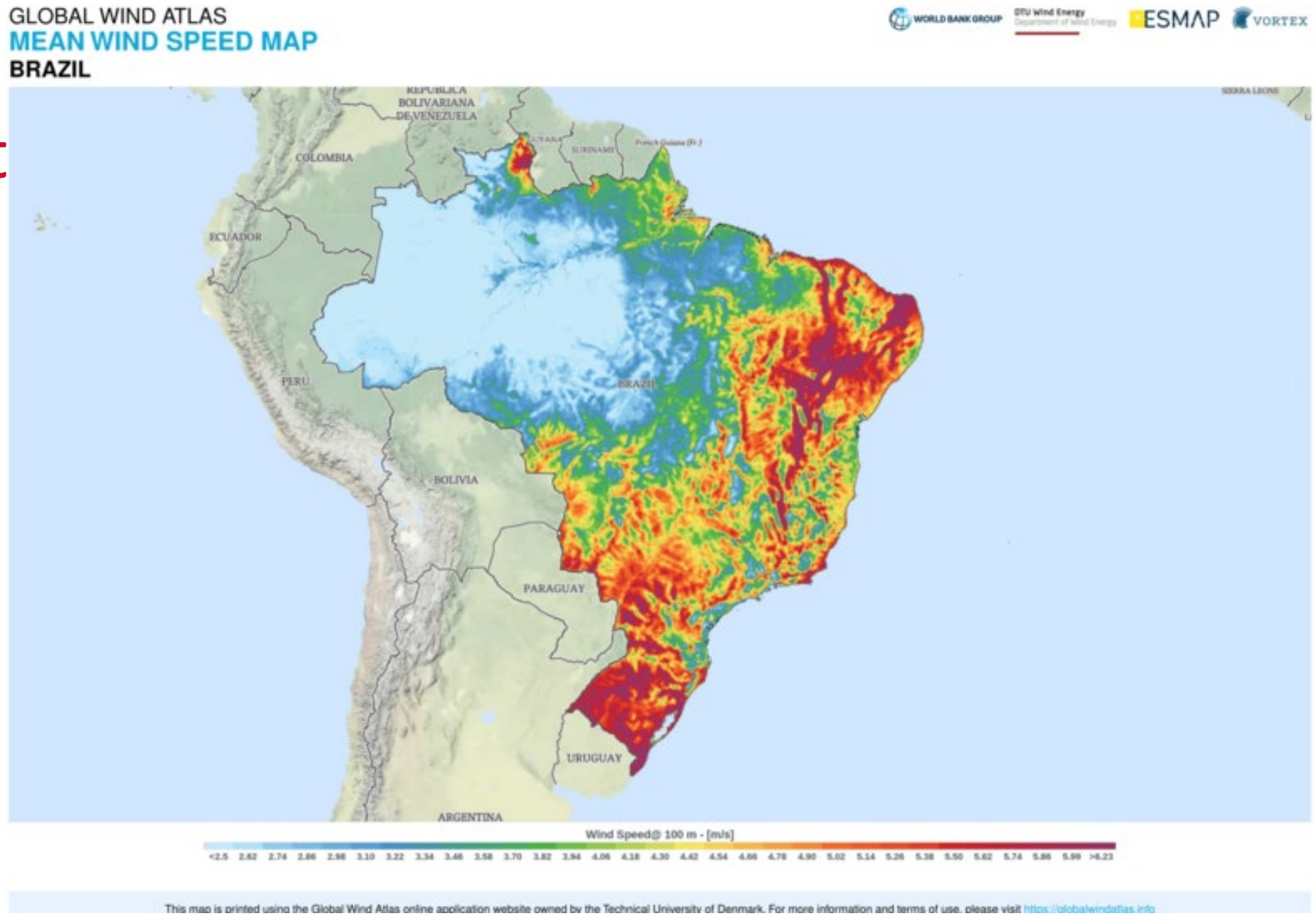


Wind speed at 80 m



Source: CEPEL, 2016

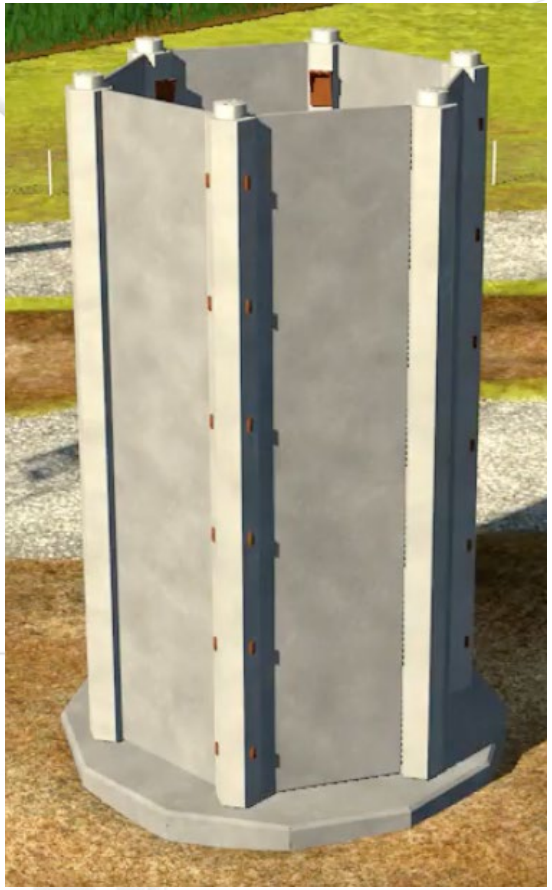
Wind speed at 100 m



Benefits of Tall Wind Turbine Towers

- Increased wind speed
- Increased production time
- Use of bigger rotors
- Reduced number of towers
- Reduced LCOE or electricity cost
- Increased areas for wind power production
- More cost-effective than offshore wind power

Hexcrete Technology



- Modularized construction
- Eliminate transportation constraint
- Grow local economy
- Increase service life

Partnership

Countries with UHPC Applications

Malaysia

Canada

Denmark

South Korea

China

Germany

France

Japan

USA

Conclusions

- UHPC can provide unique and cost-competitive solutions when
  - their material properties are taken advantage of in the member/system design, and
  - nonconventional solutions are adopted.
- UHPC provides unique opportunities for precast fabrication
  - Slender members
  - Effective use of prestressing
  - Innovative architectural and structural products
- Use a holistic approach in finding UHPC solutions
- UHPC can be used to create more sustainable solutions