First U.S. Bridge with 100% UHPC Superstructure:
Michigan's Bricker Road Bridge over Quackenbush Drain

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HIPER FIBER

MichiganEngineering

University of Michigan College of Engineering

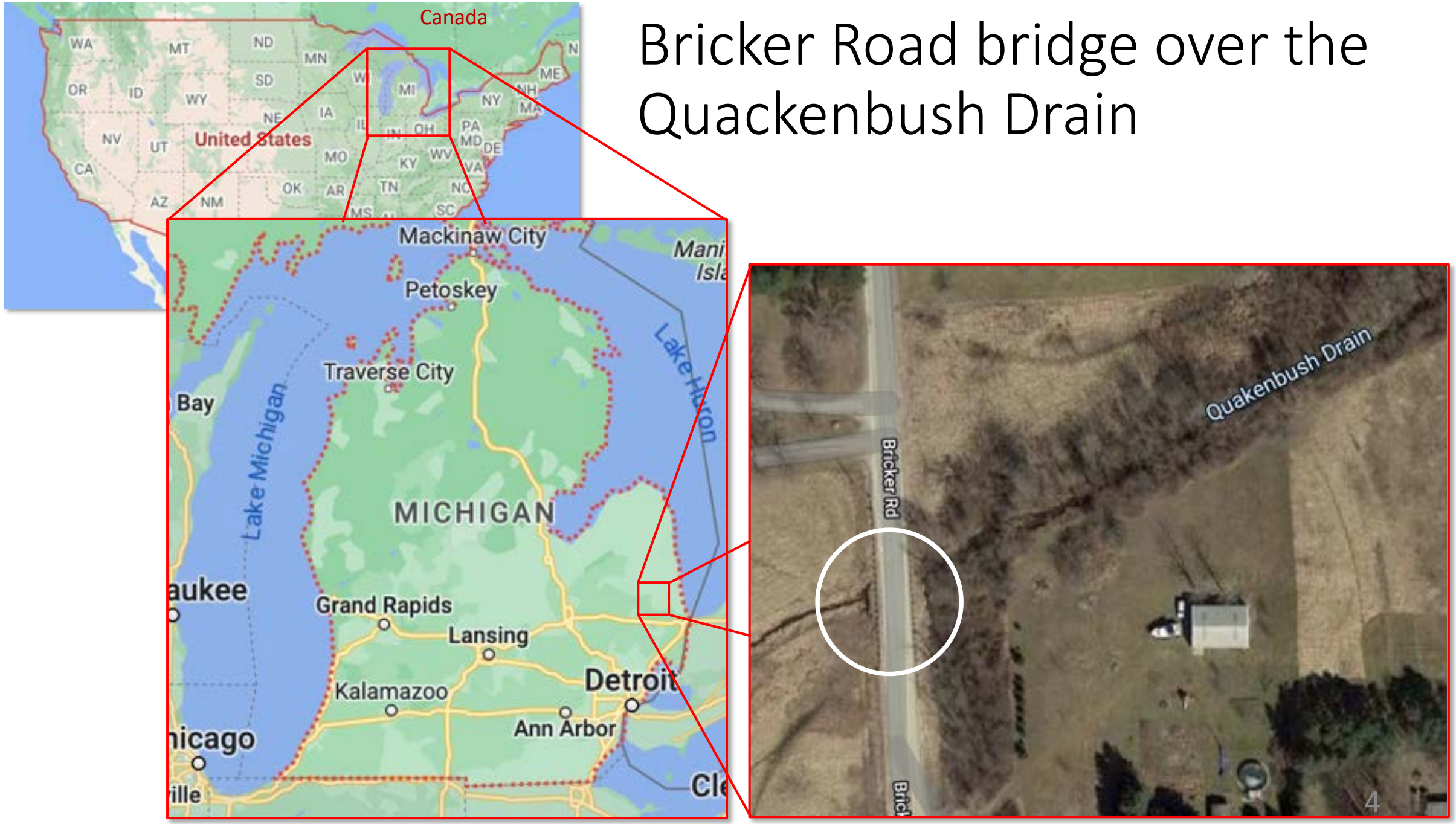
The History

- UHPC usage in St. Clair County, MI, since at least 2017
- Bricker Road Bridge project was Funded in Part by NCHRP through a grant to HiPer Fiber, LLC

Bricker Road bridge over the Quackenbush Drain

- Existing Bridge: Dual 120”x80” steel arch pipes
- Detour Route: 3 Miles
- 100-Year Flow: 290 CFS
- ADT: 300 vehicles per day with 8% commercial
- Design: Road Commission Staff with consultant assistance (TEG Engineering)
- Guardrail: 25’ Long Span, Type B Rail, with Standard Approach Terminal Endings
- Abutments: Pre-cast Redi-Rock with Strip Footing
- Approaches: Concrete
- Site Construction: 4 weeks, starting mid-August
- Deck: Finished with Epoxy Overlay

Bricker Road bridge over the Quackenbush Drain



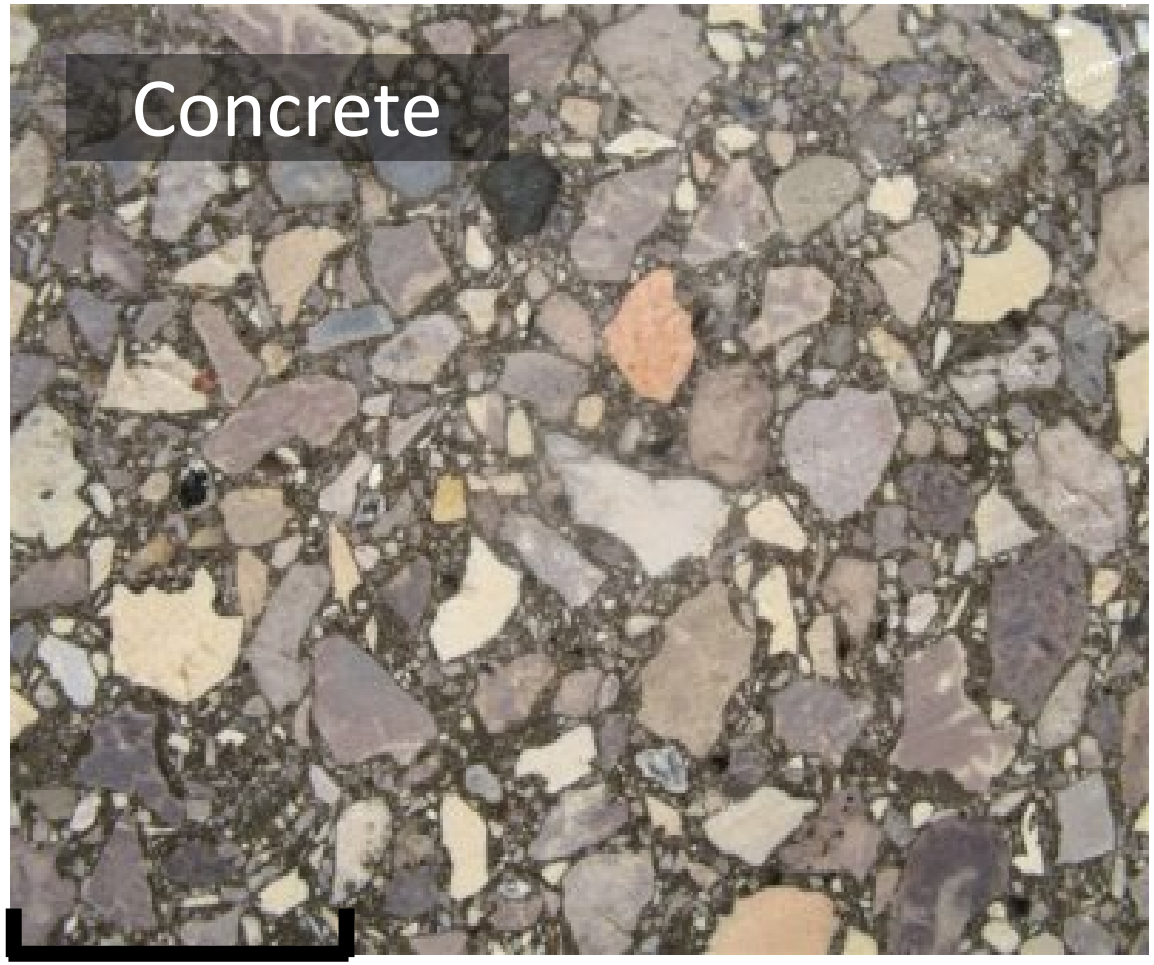
Bricker Road bridge over the Quackenbush Drain

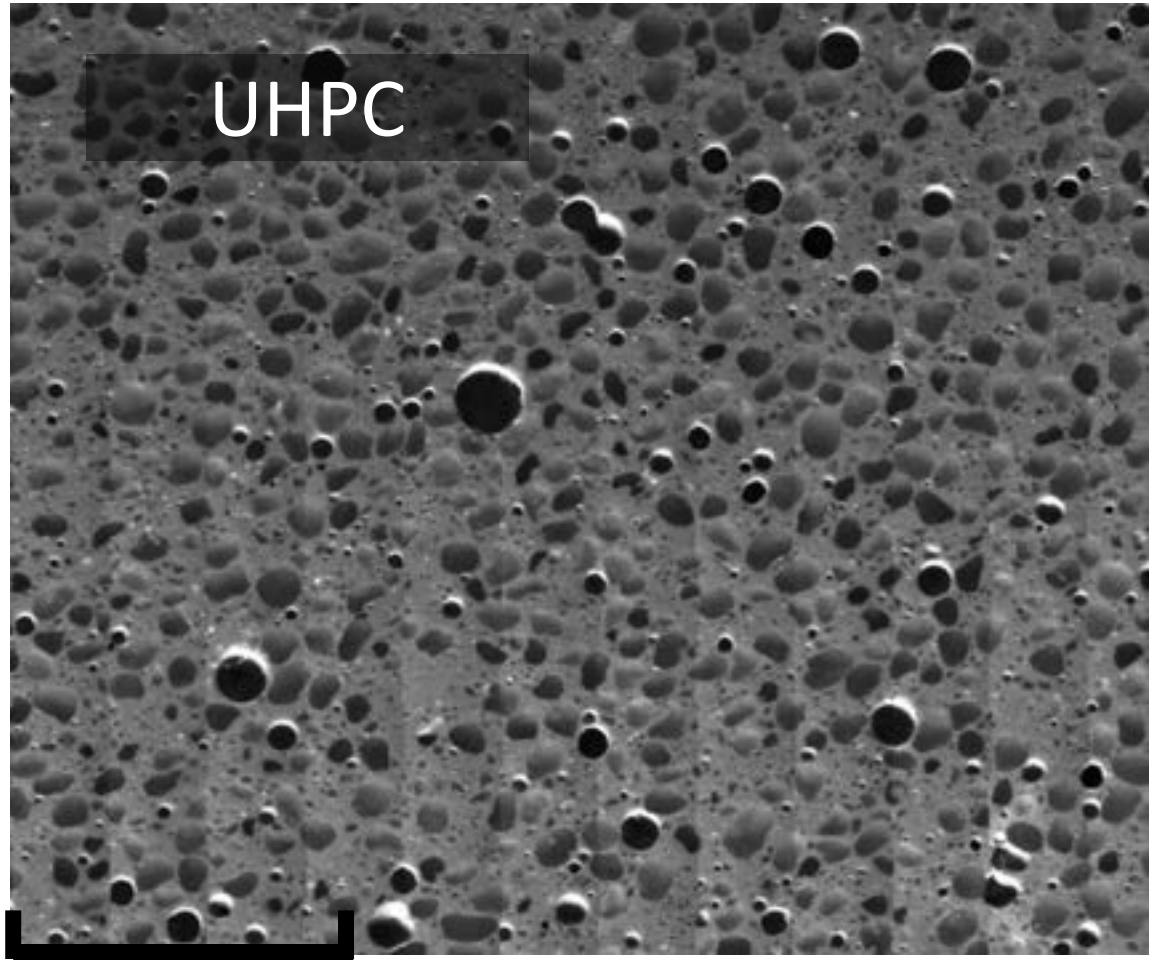
First Place Award Winner in the Short Span Bridge Category: Third International Interactive Symposium on Ultra High Performance Concrete (3IISUHPC)

'A Small Bridge with Big Implications': Bricker Road bridge over the Quackenbush Drain, St. Clair County, Michigan, USA

What is UHPC?

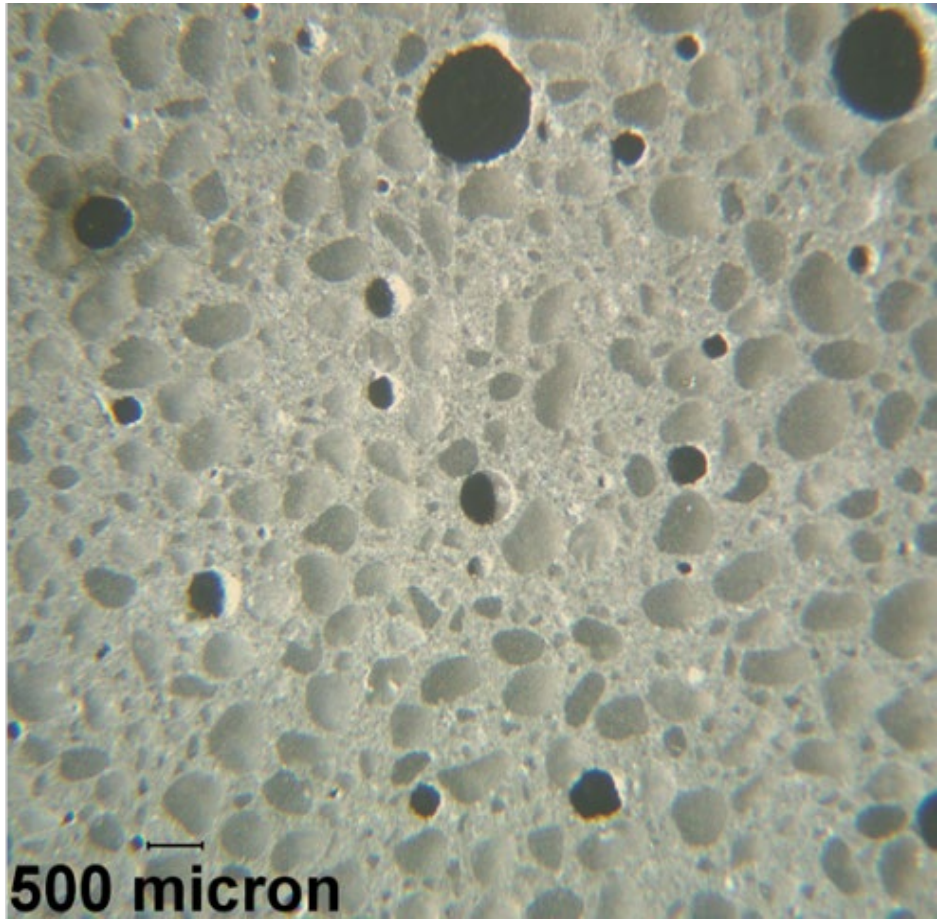
- It is a class of steel fiber reinforced cementitious materials with a suite of enhanced properties:
  - Fresh mix characteristics
  - Mechanical properties
  - Durability properties
- There is no agreed upon definition for UHPC
- Cementitious material with compressive strength > 150 MPa (21.7 ksi)


Concrete
50 mm


UHPC
10 mm

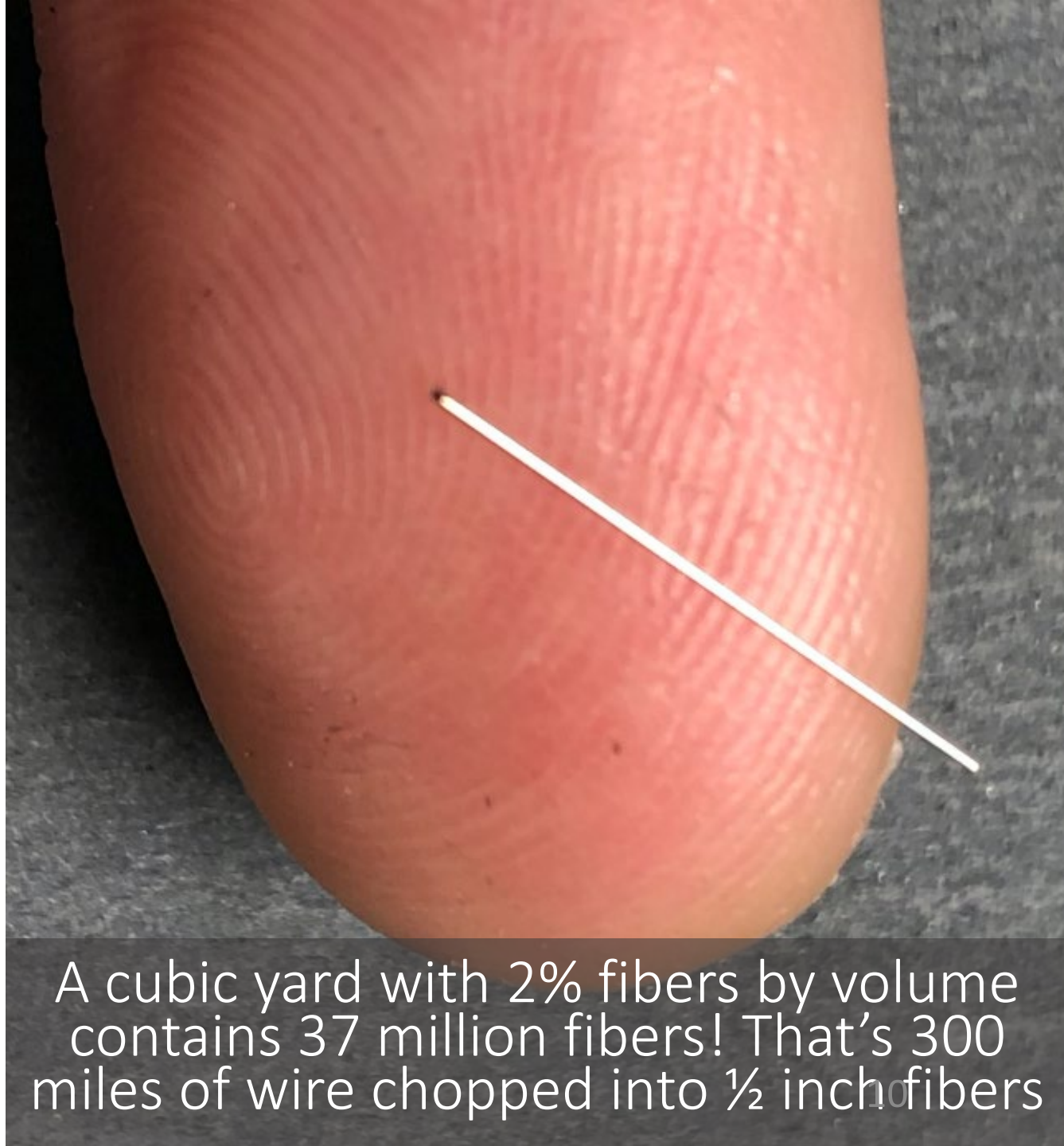
What gives UHPC its Unique Properties?

- High packing density
  - Achieved by carefully controlling the size and distribution of the constituent particles
- Discontinuous pore structure
  - Results from the uniformity of the matrix
  - Prevents water from entering the material, leading to its exceptional durability properties.
- Presence of steel fibers



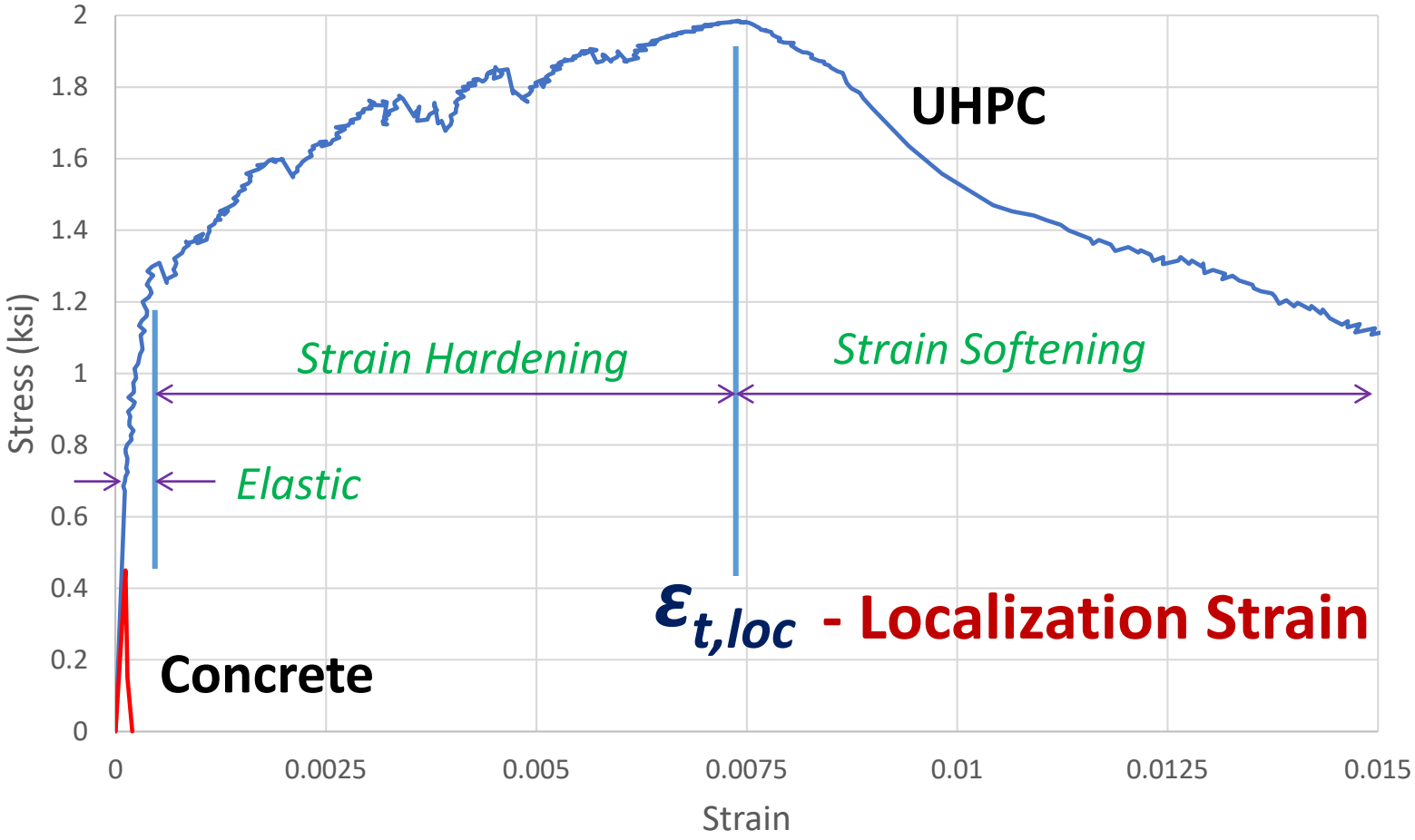
Fibers are Critical for UHPC

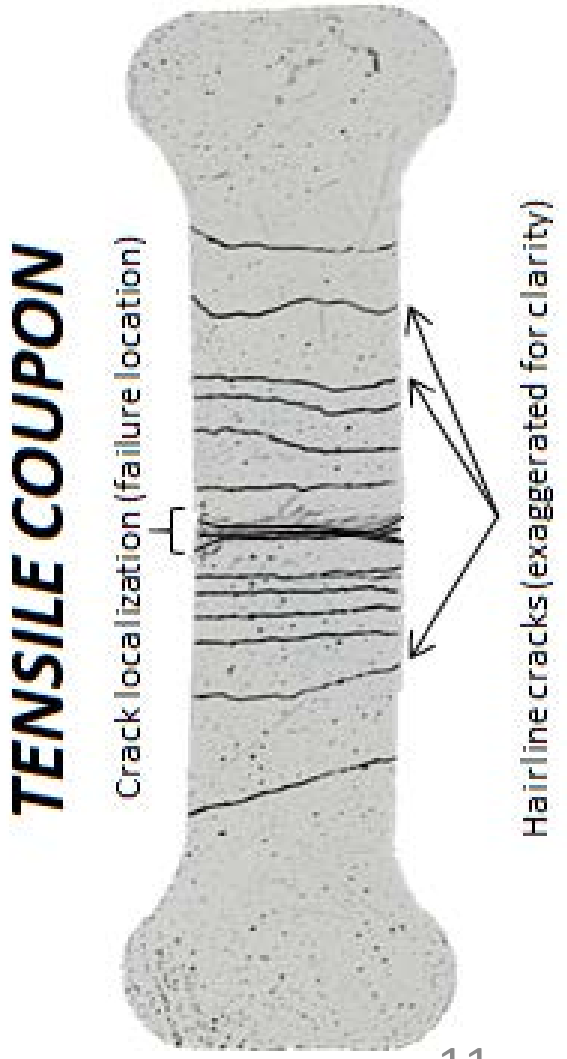
- Fibers ‘hold’ the material together
- Fibers promote strain hardening tensile behavior
- Optimal UHPC response is achieved by carefully tailoring the fiber-matrix bond characteristics
  - Too high: promotes early fiber breakage - brittle behavior
  - Too low: allows fibers to pull out easily - limited contribution
  - Must be just right!



A cubic yard with 2% fibers by volume contains 37 million fibers! That’s 300 miles of wire chopped into ½ inch fibers

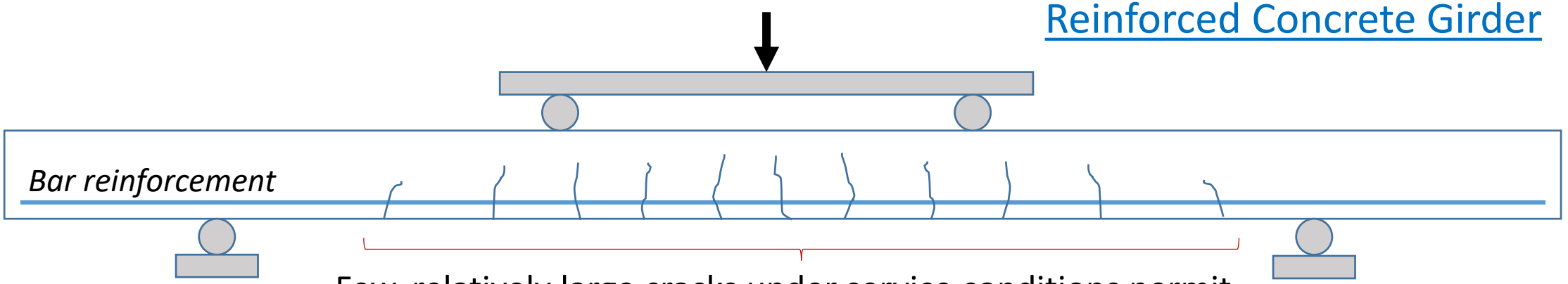
Strain Hardening Response in Tension





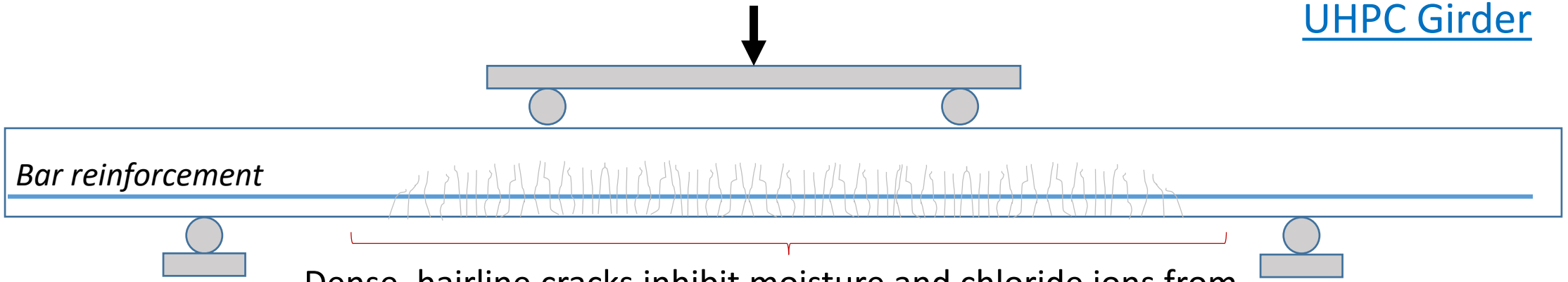
Service Conditions

Reinforced Concrete Girder

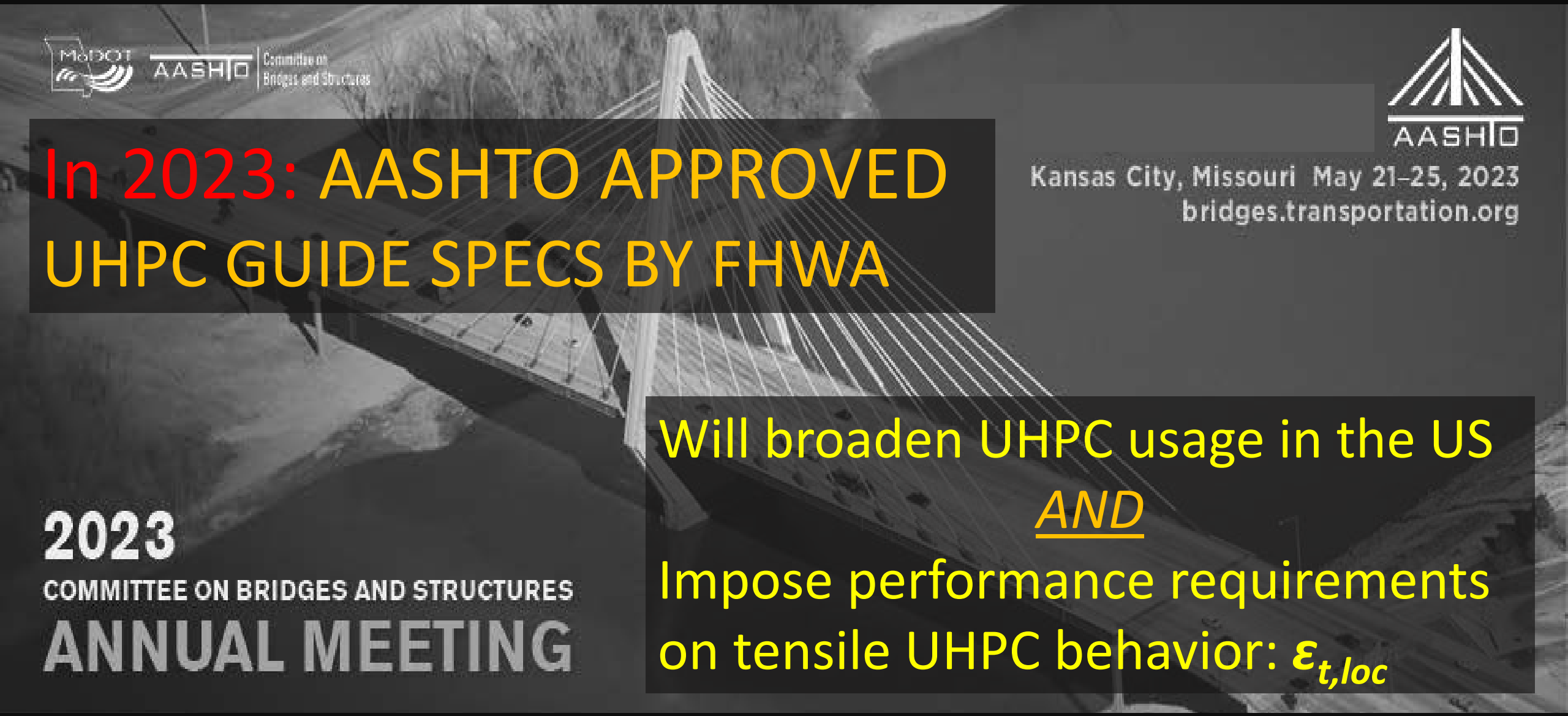


Few, relatively large cracks under service conditions permit the ingress of moisture and chloride ions over time

UHPC Girder



Dense, hairline cracks inhibit moisture and chloride ions from reaching the reinforcement



In 2023: AASHTO APPROVED UHPC GUIDE SPECS BY FHWA

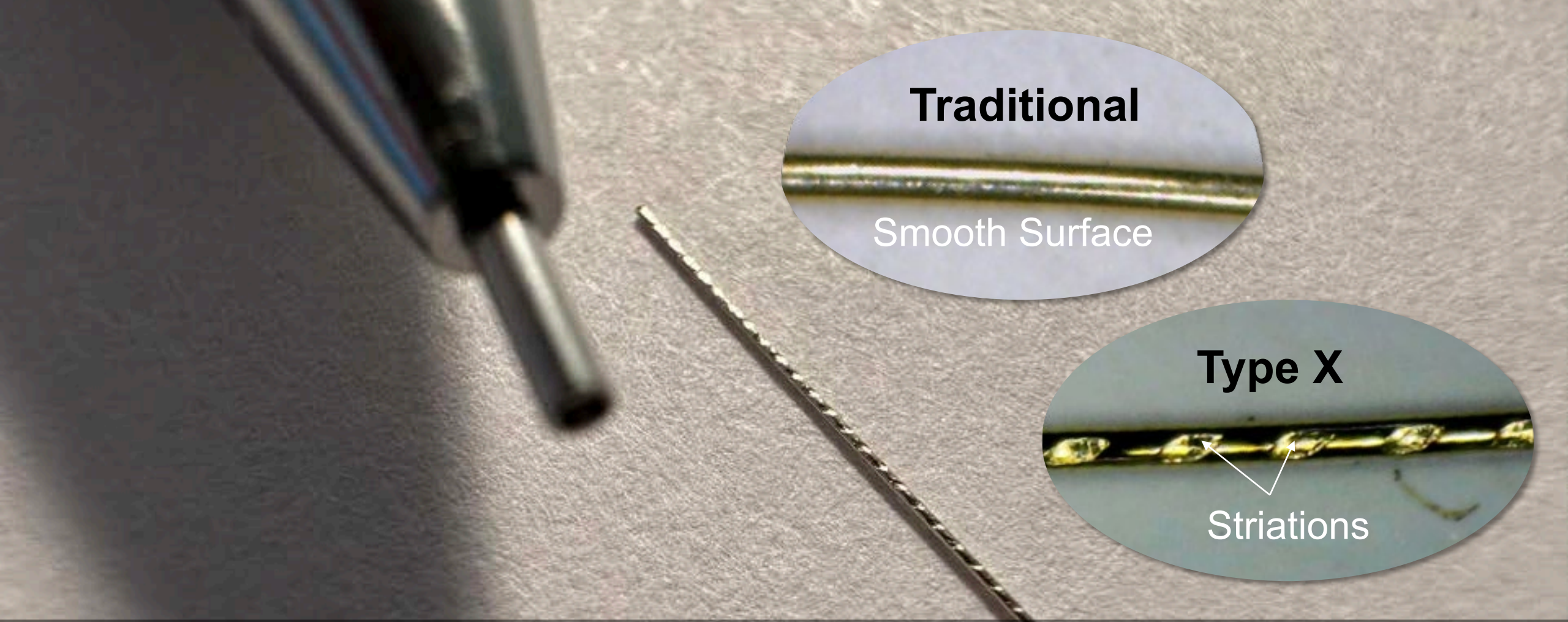
Will broaden UHPC usage in the US

AND

Impose performance requirements on tensile UHPC behavior: $\varepsilon_{t,loc}$

NCHRP 20-30/IDEA 235 : High Bond Steel Fibers for Ultra High Performance Concrete (UHPC)

- Project awarded to HiPer Fiber, LLC
- Objectives:
  1. Investigate a new type of steel fiber that is highly effective in reinforcing UHPC
  2. Assess the effect of the new fibers on composite UHPC properties through material testing
  3. Conduct a demonstration project on an actual bridge to showcase the potential of the new technology – Bricker Road Bridge



Type X - HiPer Steel Fibers

Compliant with the Buy America Act (BAA)
Made in the USA by HiPer Fiber, LLC, in Michigan
Commercially available in the US

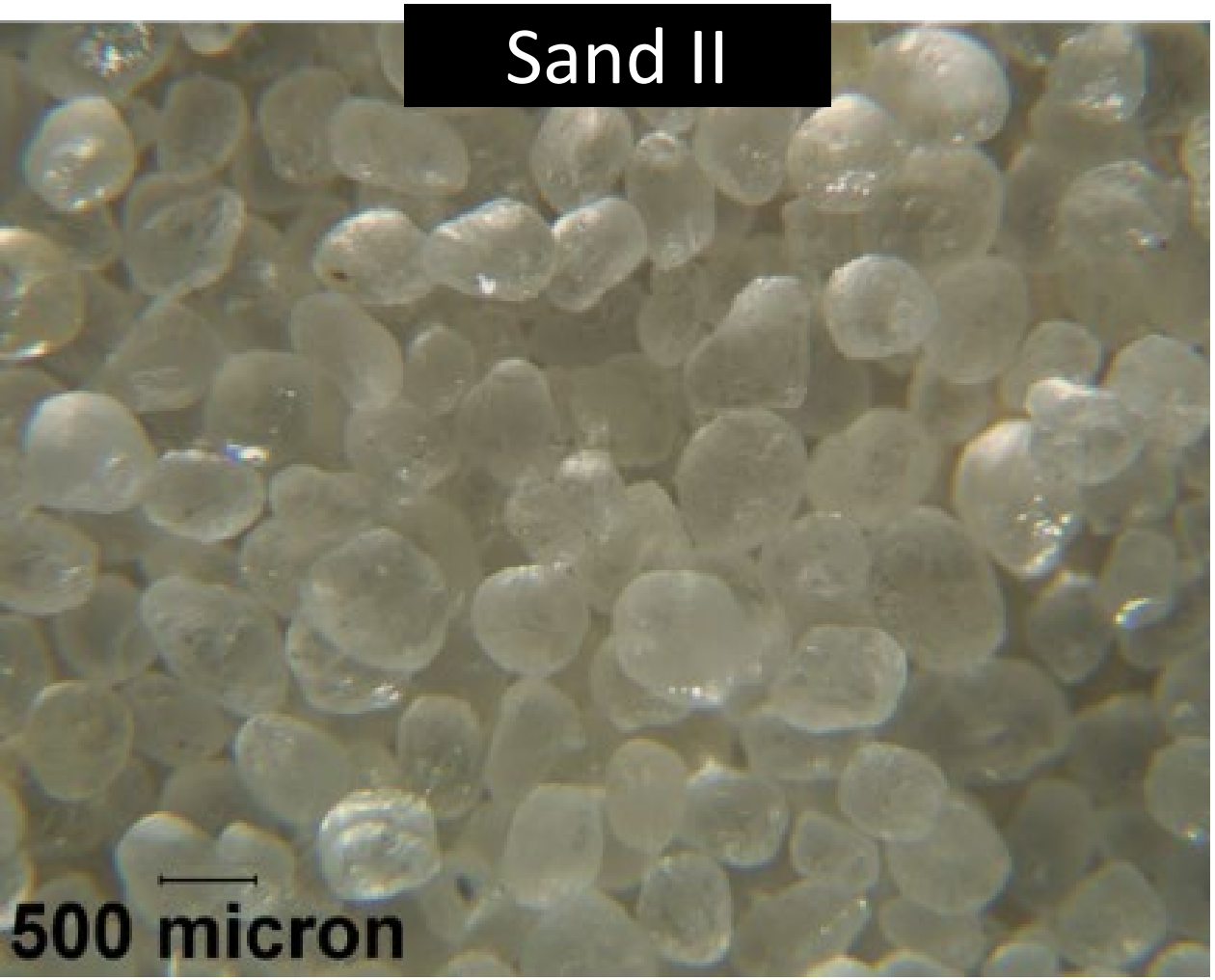
Demonstration Project Parameters

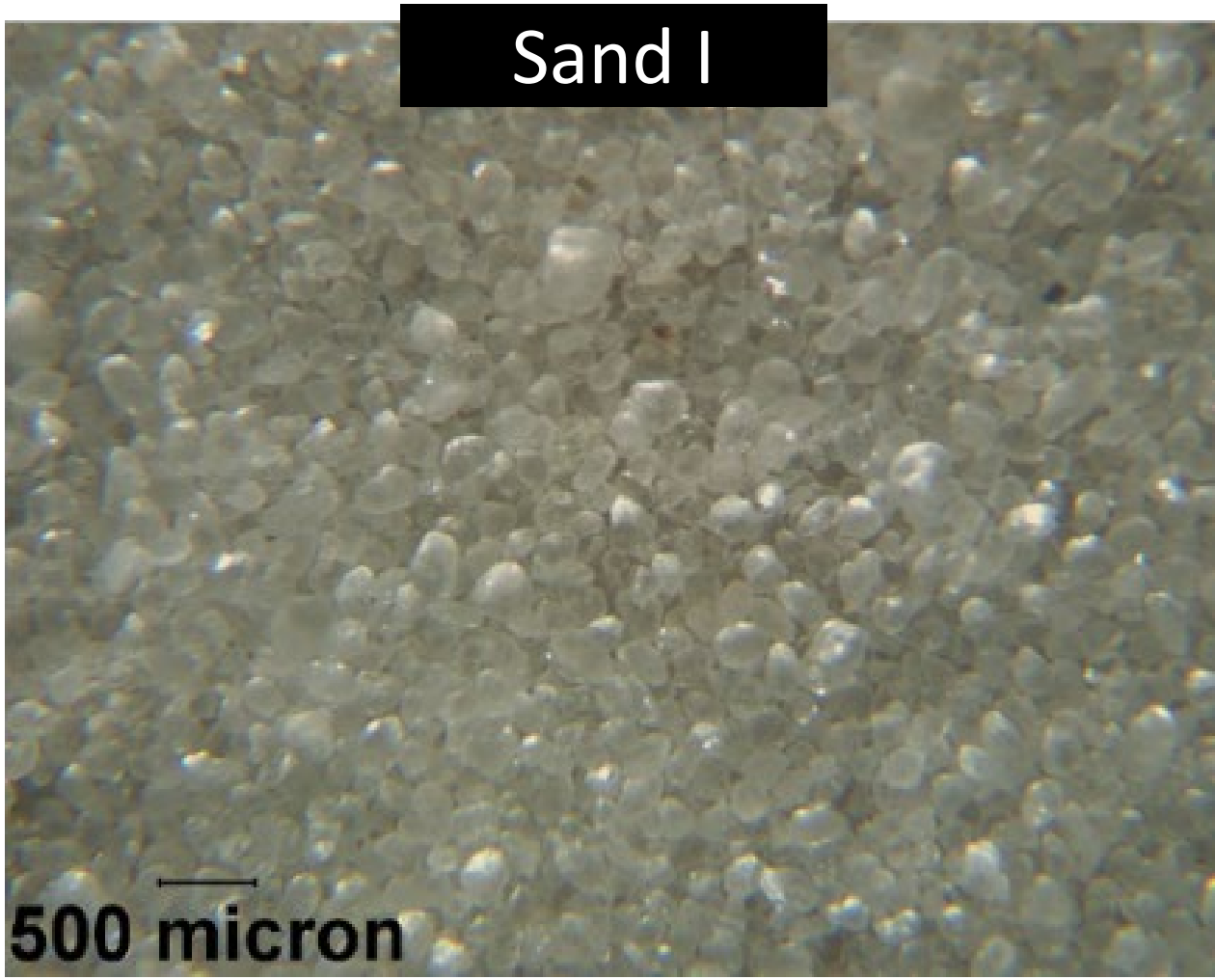
- Project was a total bridge replacement
- 23.7’ span by 36.0’ width
- New precast block abutments & wingwalls
- New road approaches
  - Concrete Paving
  - New Guardrail
- Triple Tee UHPC deck panels
  - Truck mixed open-design UHPC
  - Precast & Cured at ADL’s plant (a local precaster)
  - Bridge assembled in field by County work force
- Used Type X striated steel fibers from HiPer Fiber (as part of the NCHRP-IDEA 235 Project)
  - However, you can utilize smooth steel fibers in lieu of Type X

Open Recipe UHPC Components

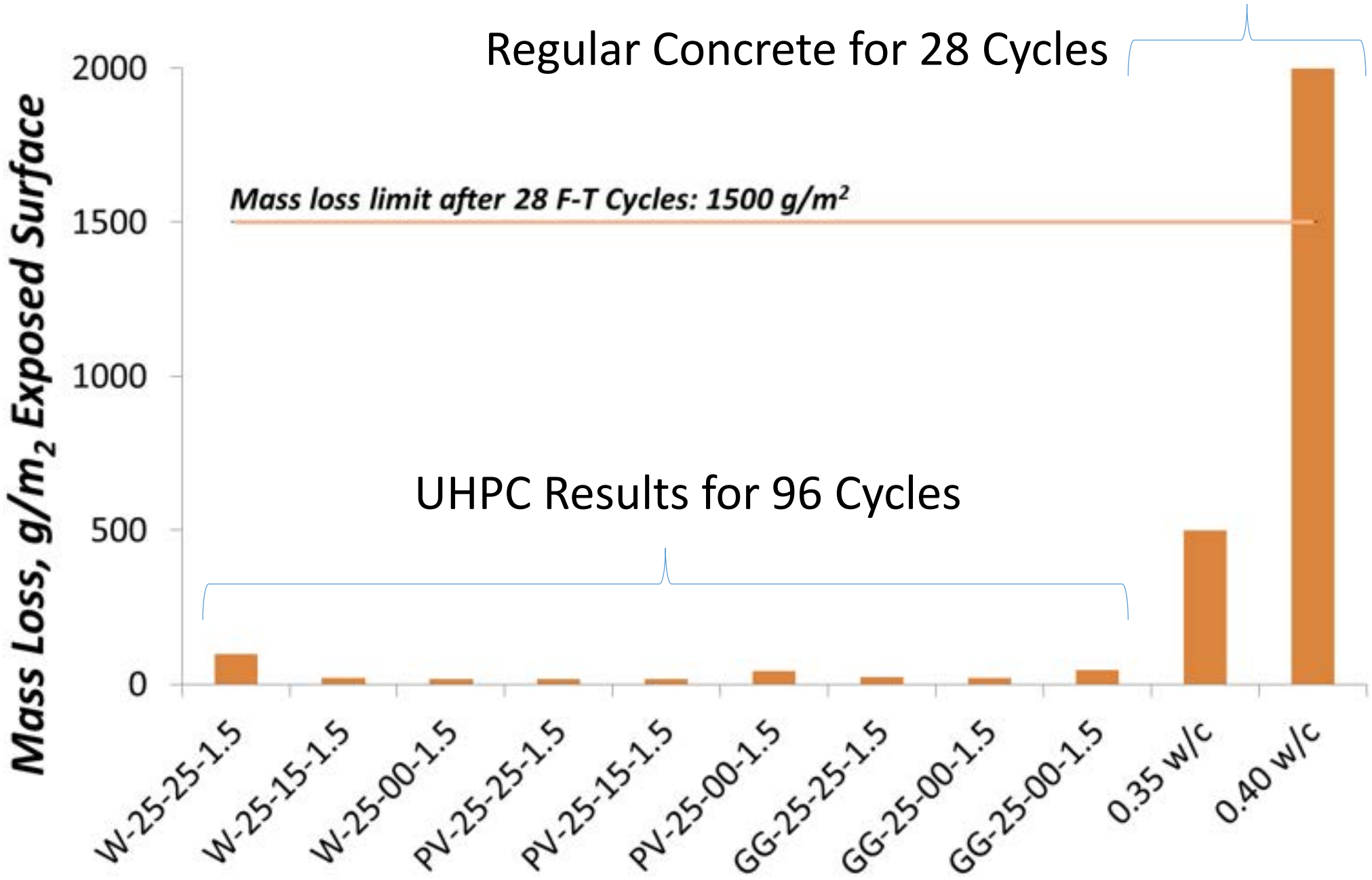
Developed for Michigan DOT in 2014

Material (Weight in pounds)				
Cement Blend	Mix A[1]	Mix B[1]	Mix C[1]	Mix D[1]
Portland Type 1L	653			
Slag Cement	653			
Silica Sand				
Sand I	398	396	395	394
Sand II	1590	1586	1582	1577
Silica Fume	327			
Water	276	272	268	264
High Range Water Reducer	20	26	33	39
Steel Fibers	265			


Sand II
500 micron


Sand I
500 micron

Freeze-Thaw Resistance RILEM TC 176-IDC



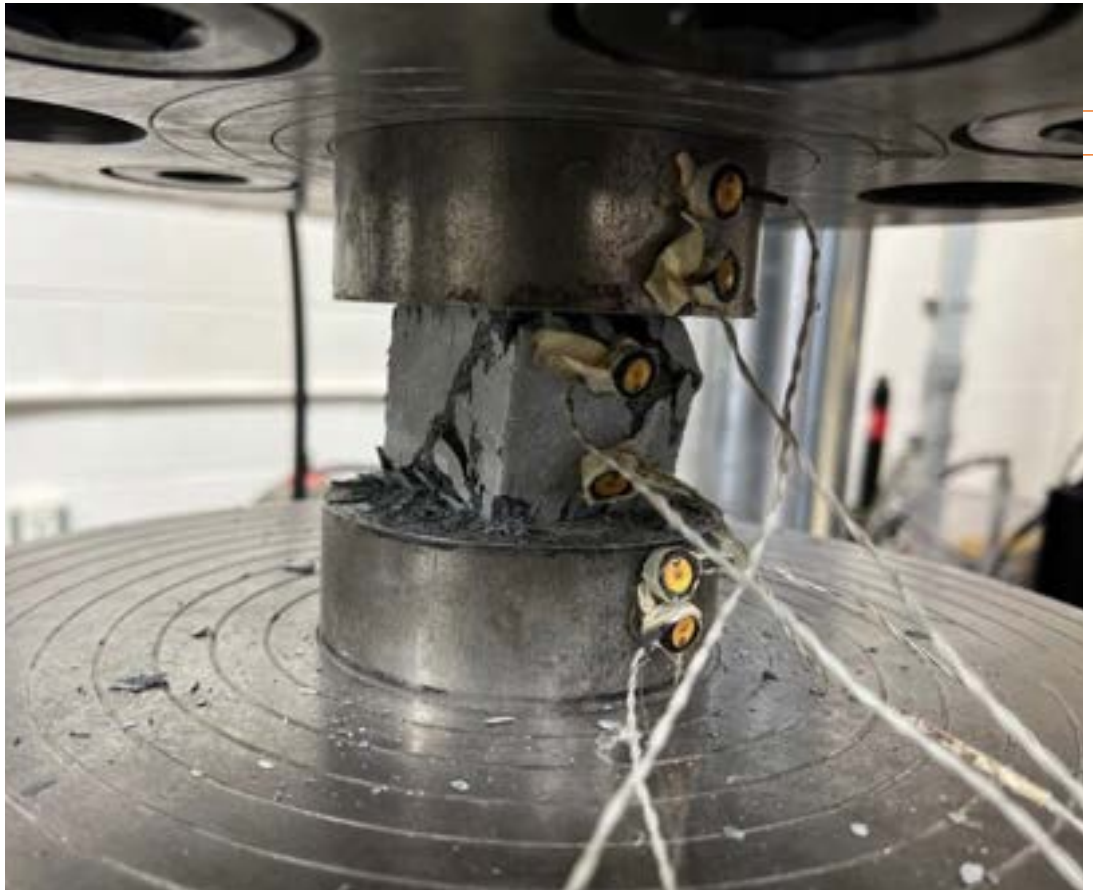
Rapid Chloride Test (ASTM C1202-12)

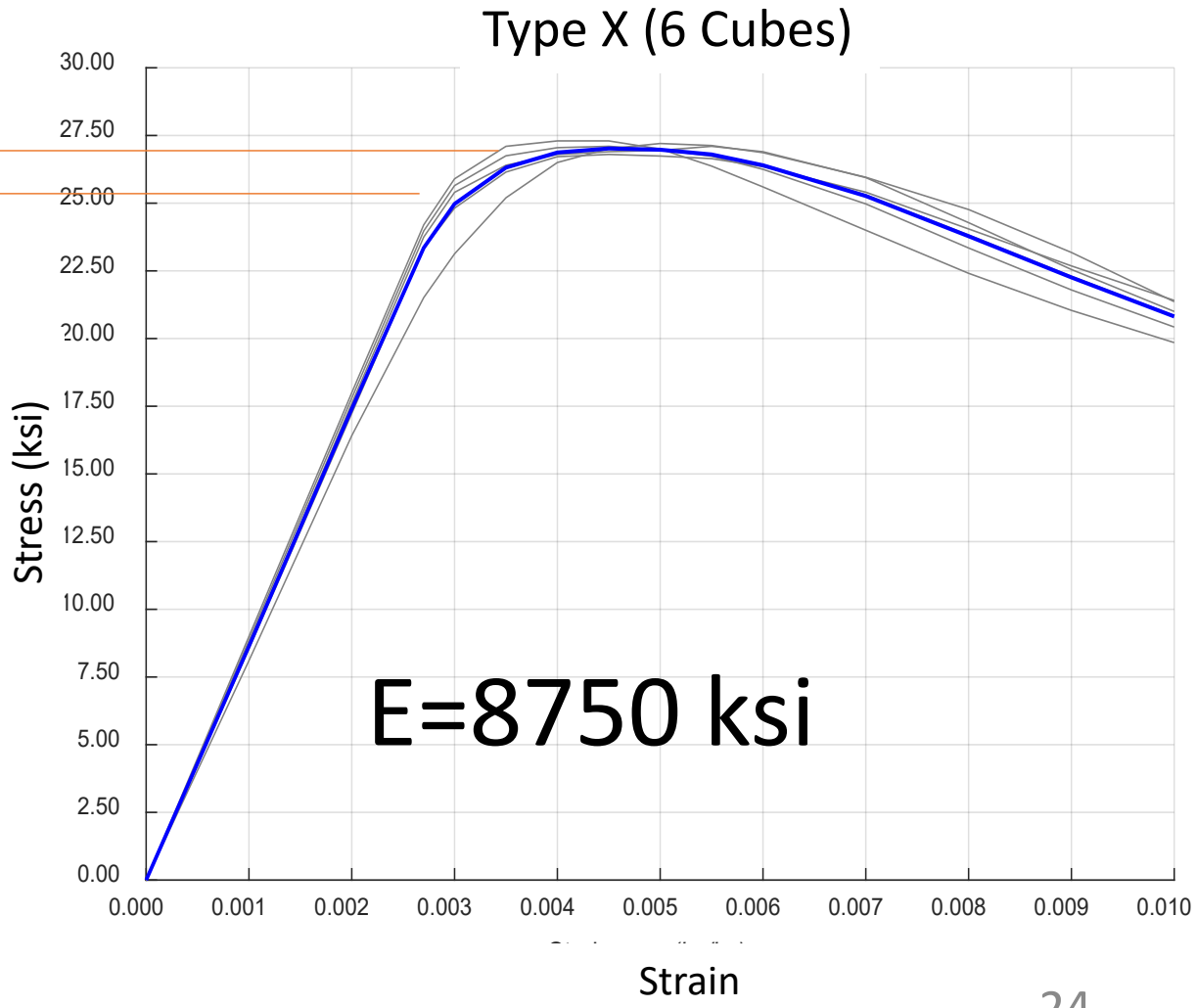
Mixing Protocol

- Dry mix for **15 minutes** (cements, silica fume, sands – including loading)
- Add water and HRWR over **1-2 minutes**
- Wait for turnover (fluidity), which usually occurs within **5 minute**s
- Mix another **5 minutes** after turnover
- Add fibers gradually over **10 minutes**
- Mix for **10 minutes** then cast

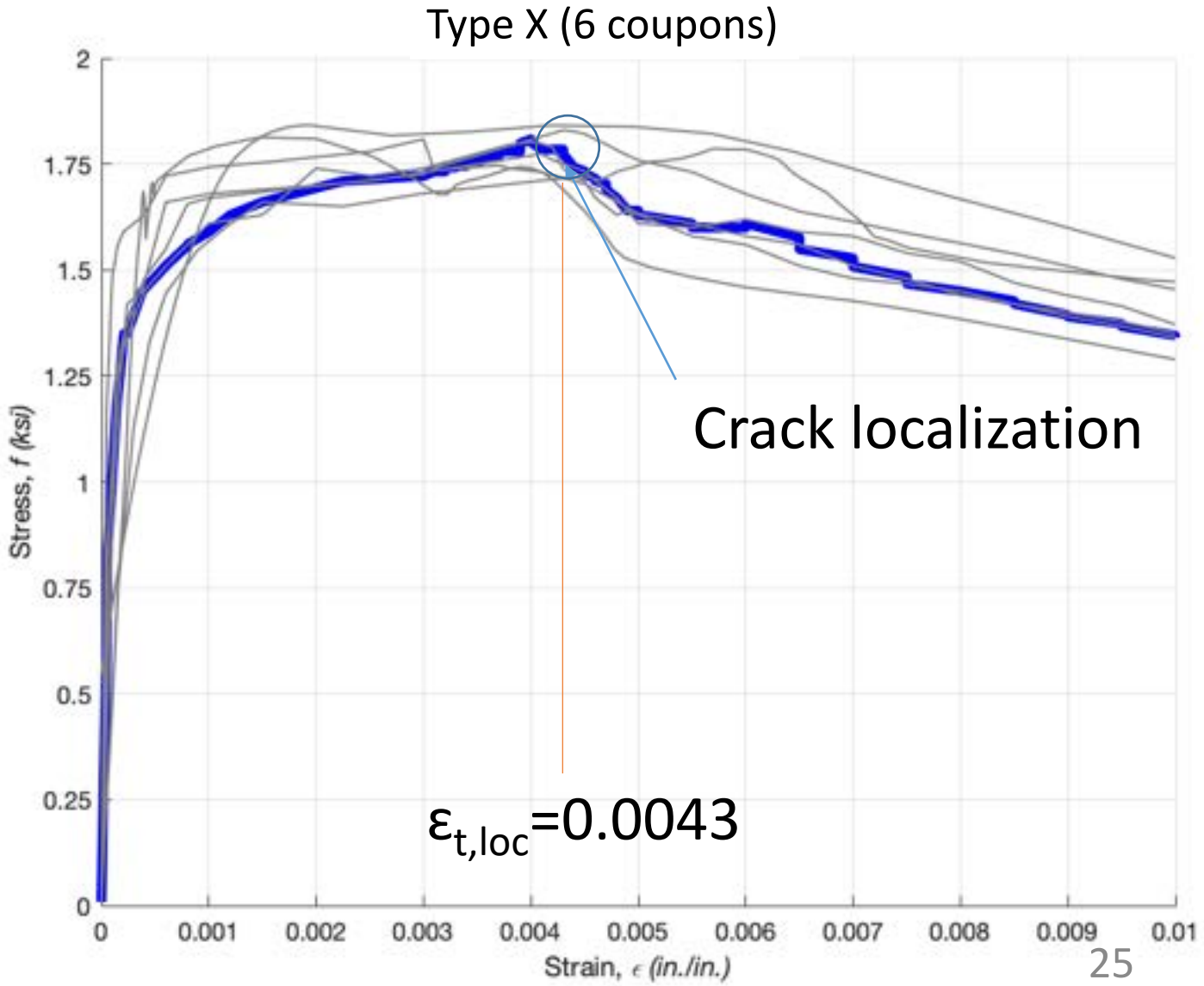
- VIDEO

Compressive Test Results





Direct Tension Test Results



Design Parameters

Test Parameters

f_c' = 27.5 ksi

ε_{cu} = 0.005

E = 8750 ksi

f_t = 1.82 ksi

$\varepsilon_{t,loc}$ = 0.0043

f_y = 60 ksi

Assumed Design Parameters

f_c' = 21.5 ksi

ε_{cu} = 0.004

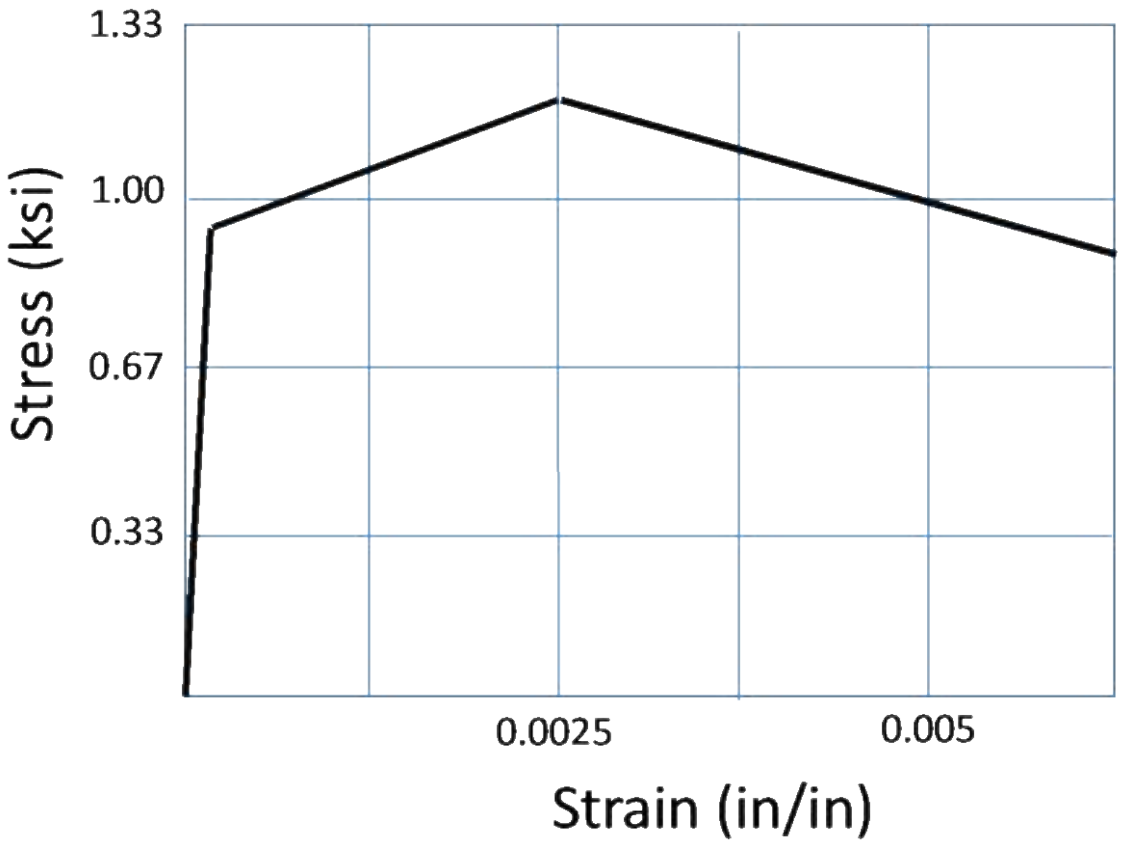
E = 7500 ksi

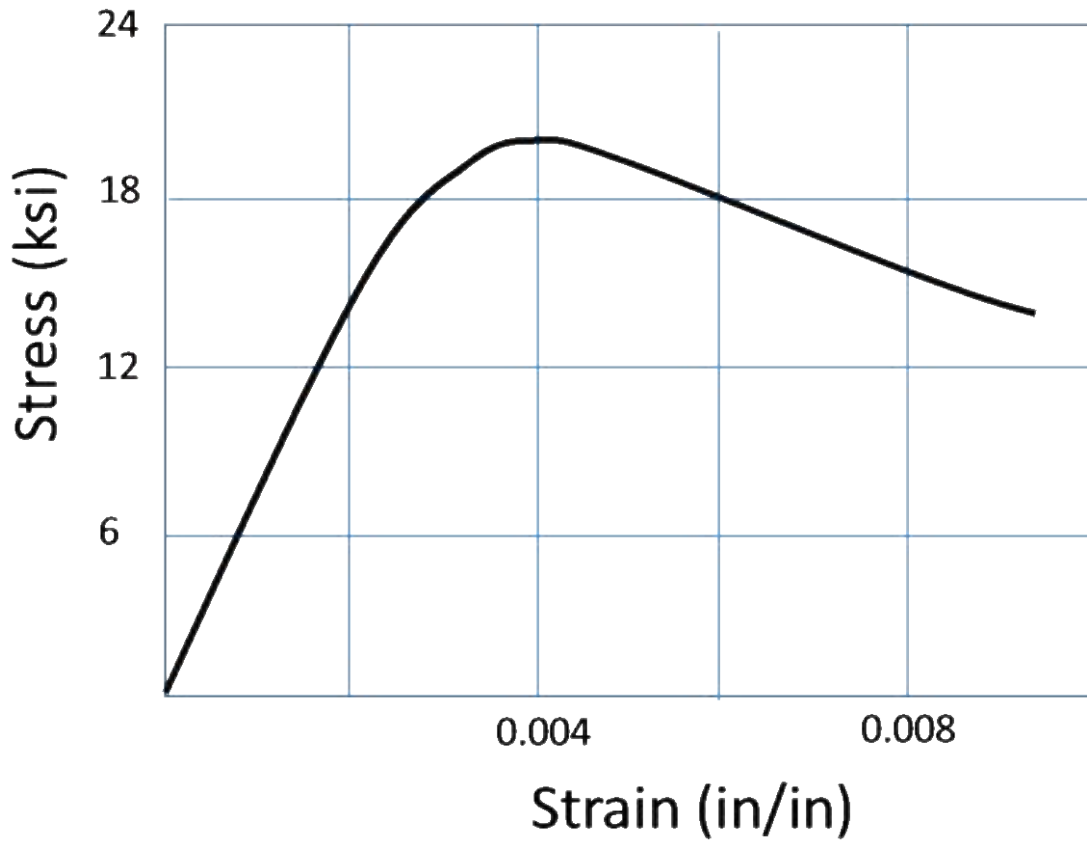
f_t = 1.15 ksi

$\varepsilon_{t,loc}$ = 0.0025

f_y = 60 ksi

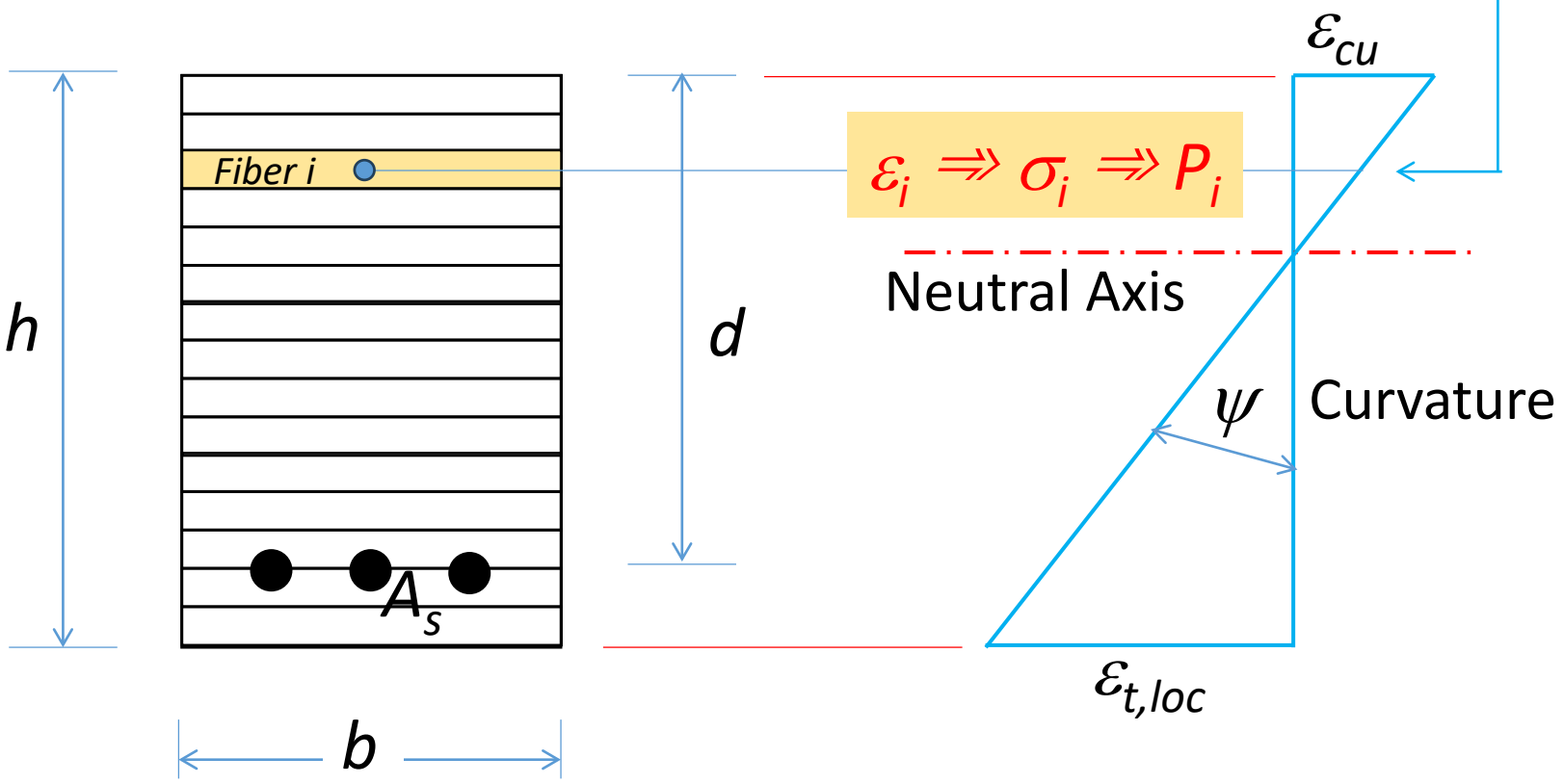
Assumed Material Properties





Moment Capacity:

Fiber Section Analysis



Axial Force in Section

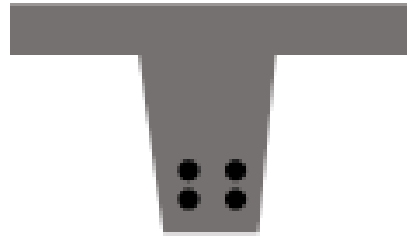
$$P = \sum_{i=1}^{n} \sigma_i A_i = \sum_{i=1}^{n} P_i$$

Iterate to achieve equilibrium

Moment Capacity

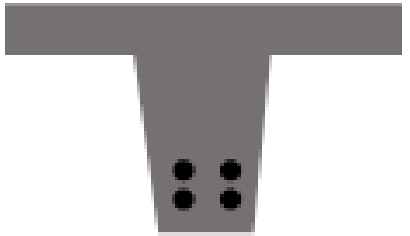
$$M_z = \sum_{i=1}^{n} \sigma_i A_i y_i$$

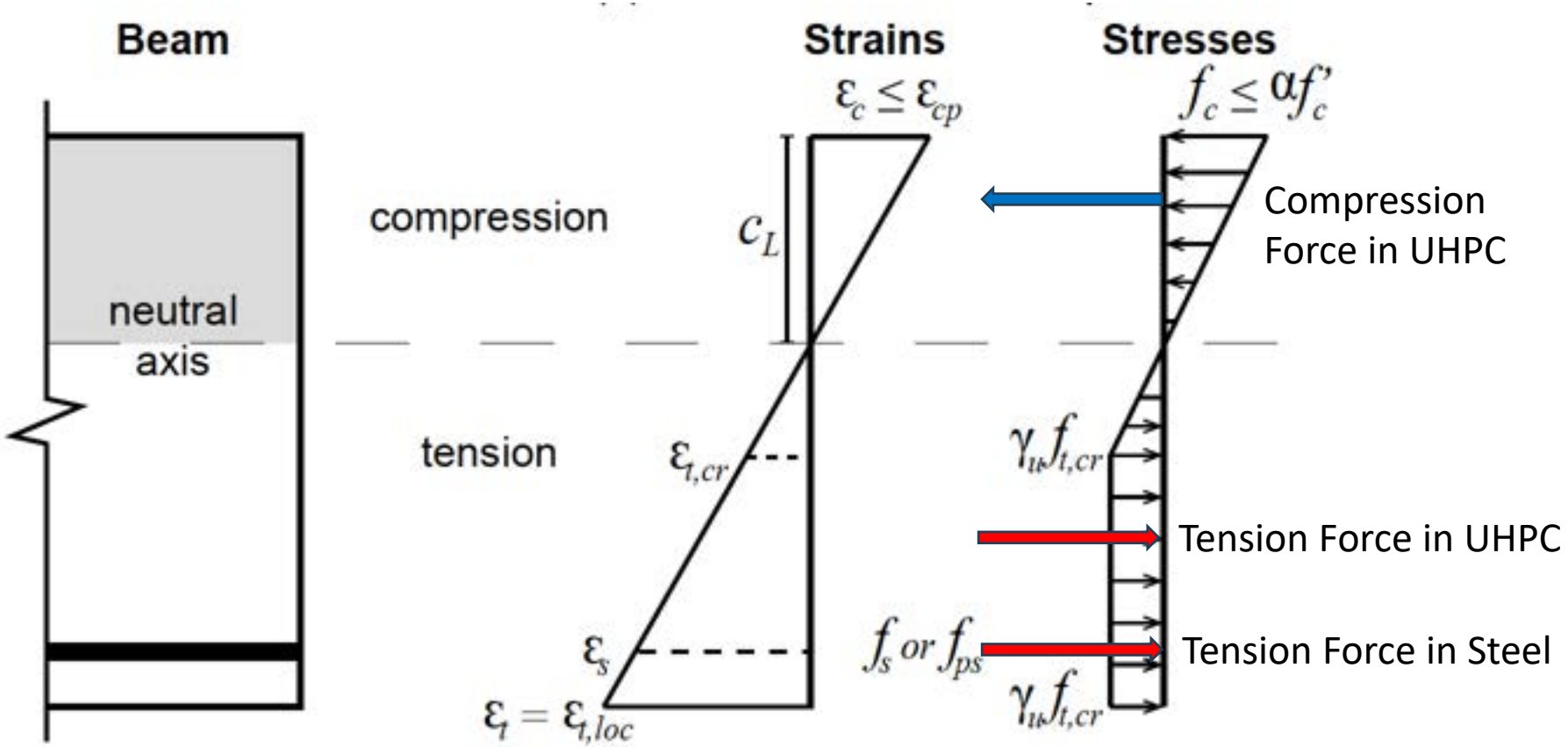
Moment capacity per 2 ft width



Moment Capacity:

FHWA Method





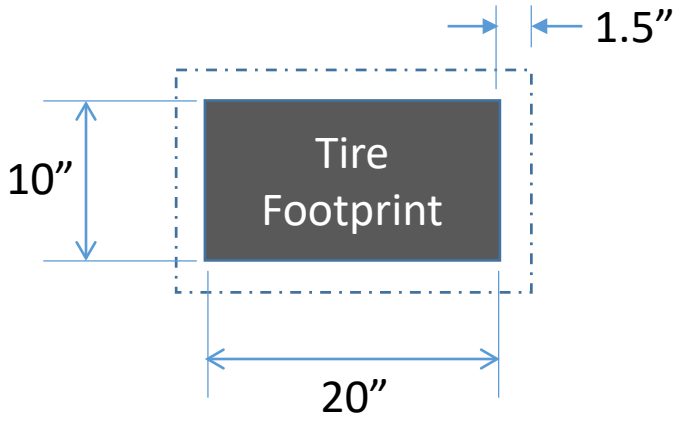
Shear and Punching Shear Capacity

Shear

$$V_{UHPC} = \gamma_u f_{t,loc} b_v d_v \cot\theta$$

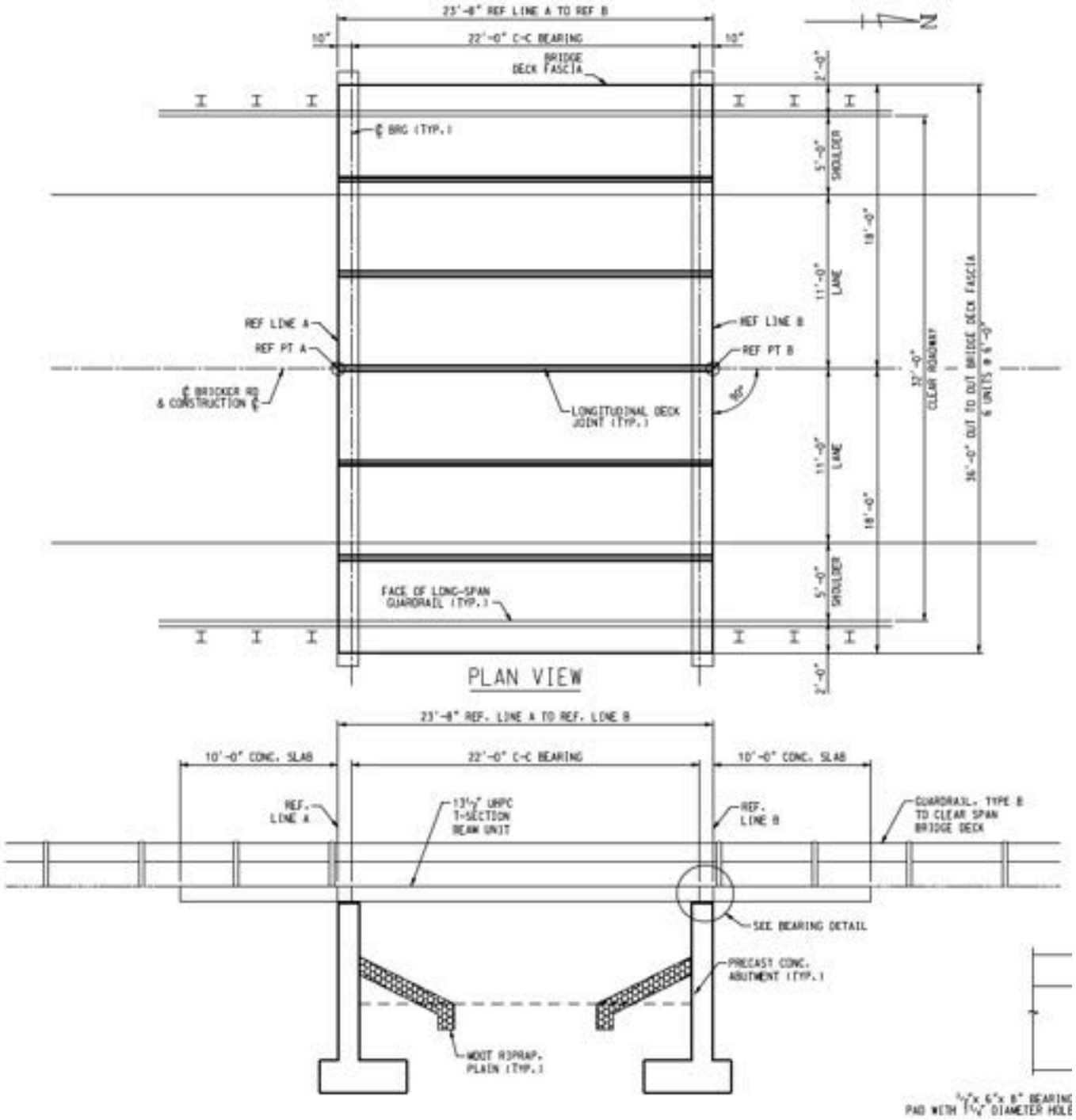
- Based on the Modified Compression Field Theory
- No stirrups required

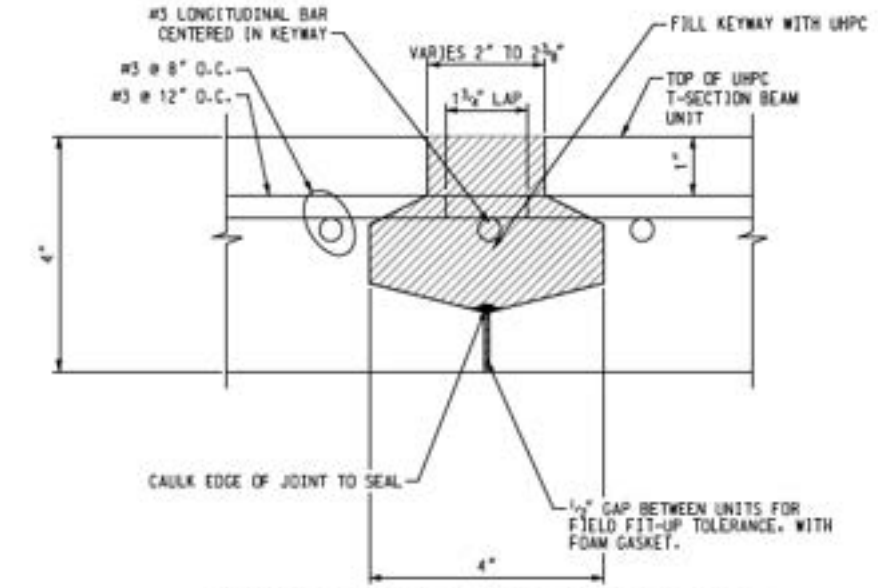
Punching Shear



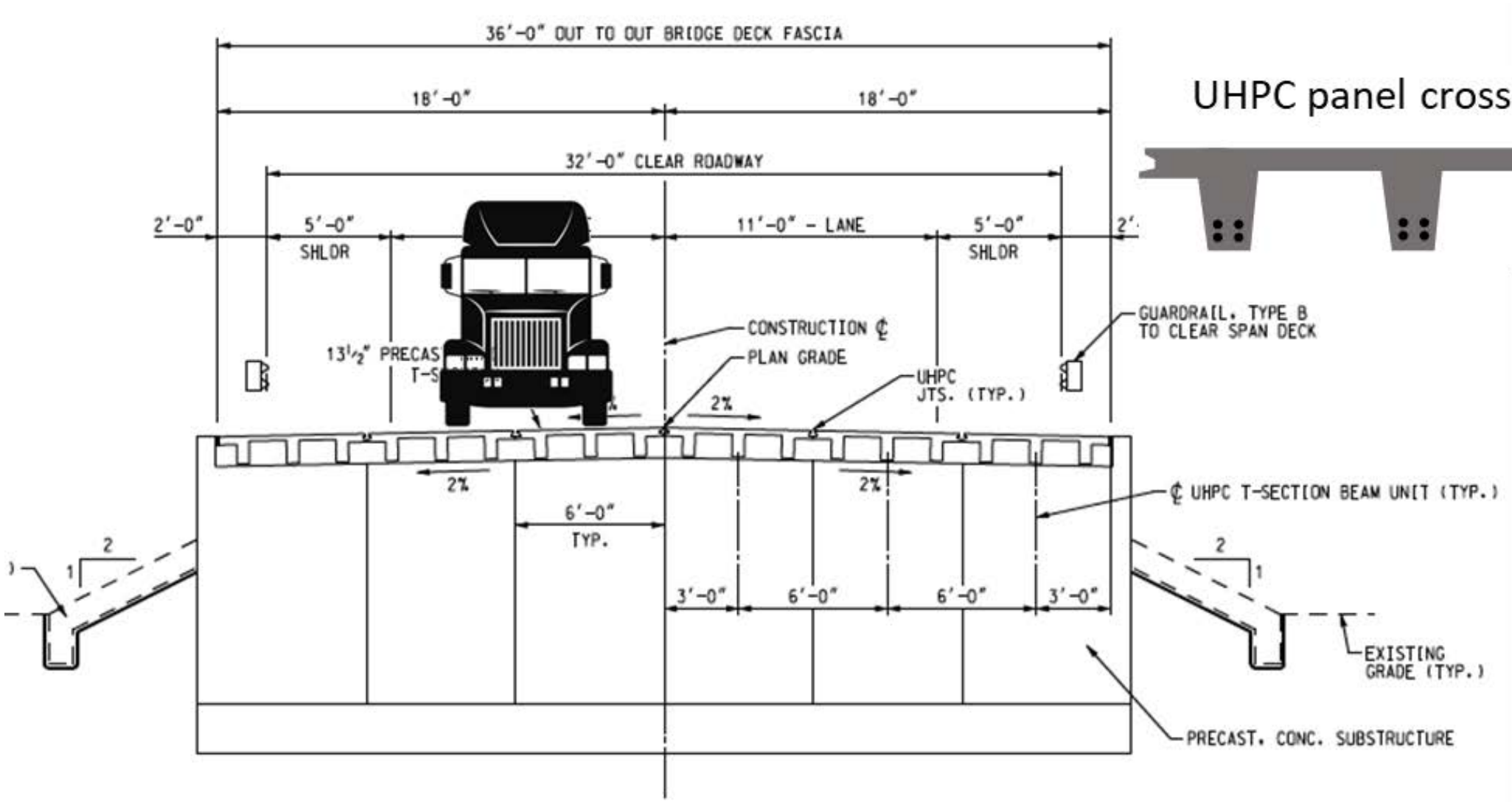
- No guidance available
- Conservative model showed 10x capacity

ST. CLAIR COUNTY ROAD COMMISSION
BRICKER ROAD OVER WHACKENBUSH DRAIN
03/09/22 UHPC SUPERSTRUCTURE DETAILS



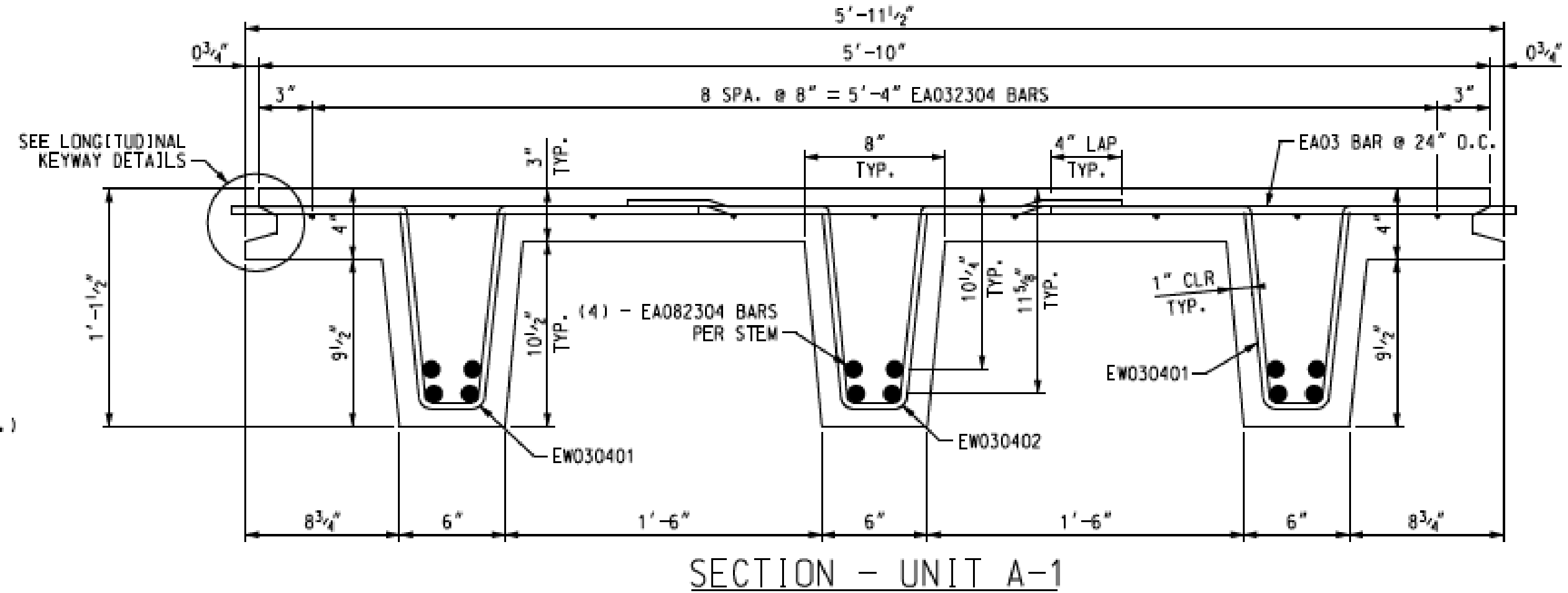


Bricker Road bridge over the Quackenbush Drain



UHPC panel cross-section

Novel Ribbed Deck Profile



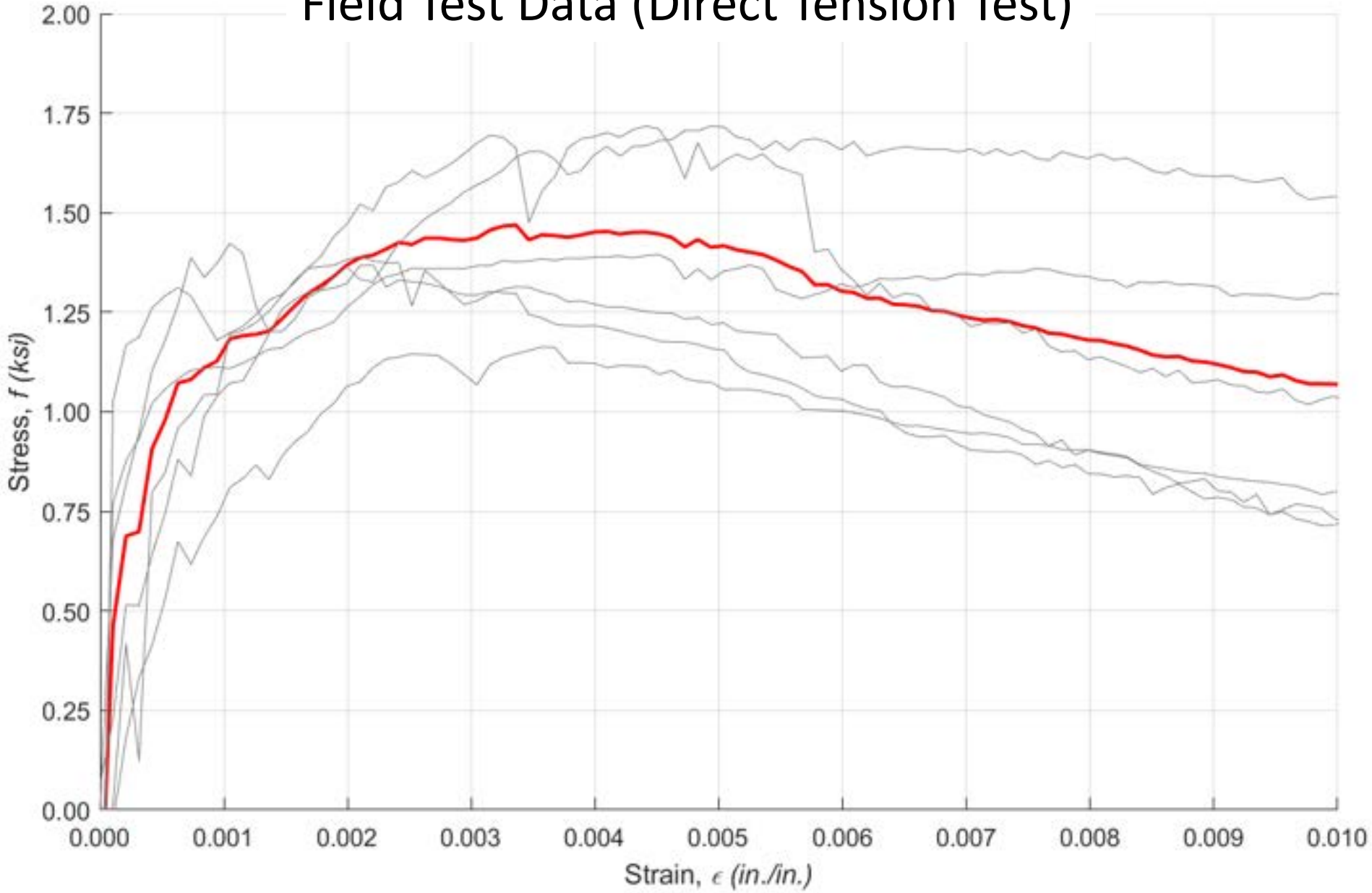
SECTION - UNIT A-1

Measured Strength Data

Pour Date	Curing Time (days)							
	3	4	5	7	10	11	14	28
12-Jul	15.1			20.2				25.0
14-Jul			16.7	20.6				23.4
15-Jul		17.6			20.7			23.5
18-Jul						19.1	20.2	24.1
19-Jul					18.9		22.4	23.7
Average	15.1	17.6	16.7	20.4	19.8	19.1	21.3	23.9

Mix Date: July 15th July 18th July 19th

Field Test Data (Direct Tension Test)



Construction Process and Lessons Learned

Forms ready for casting

Loading sand

Adding water and HRWR

Adding steel fibers

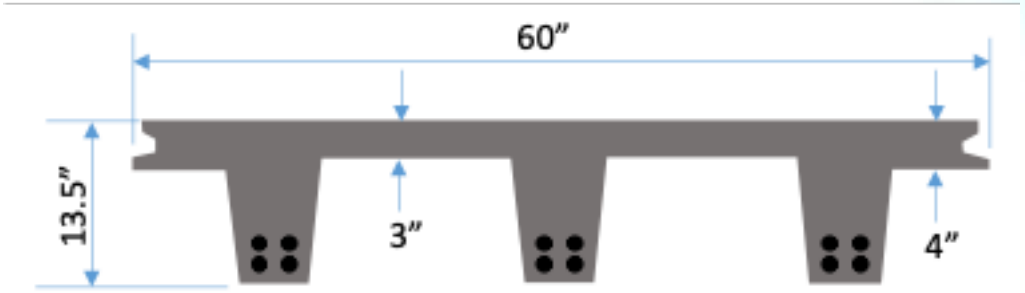
Casting UHPC

Casting UHPC

Finished Panel

Curing

Field cast closure pours



Superslim UHPC replacement deck panel

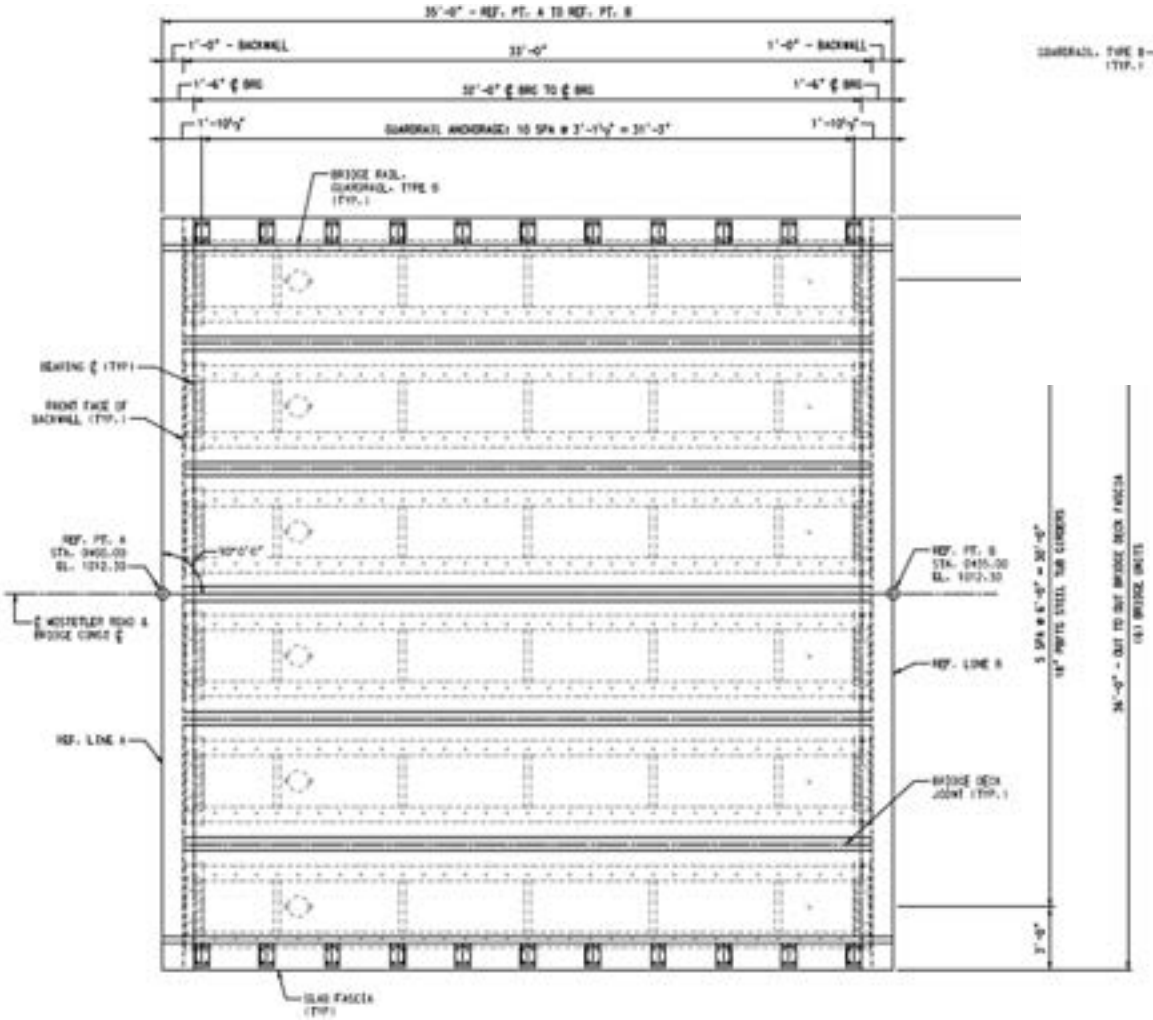
Ultra slim, ultra durable bridge

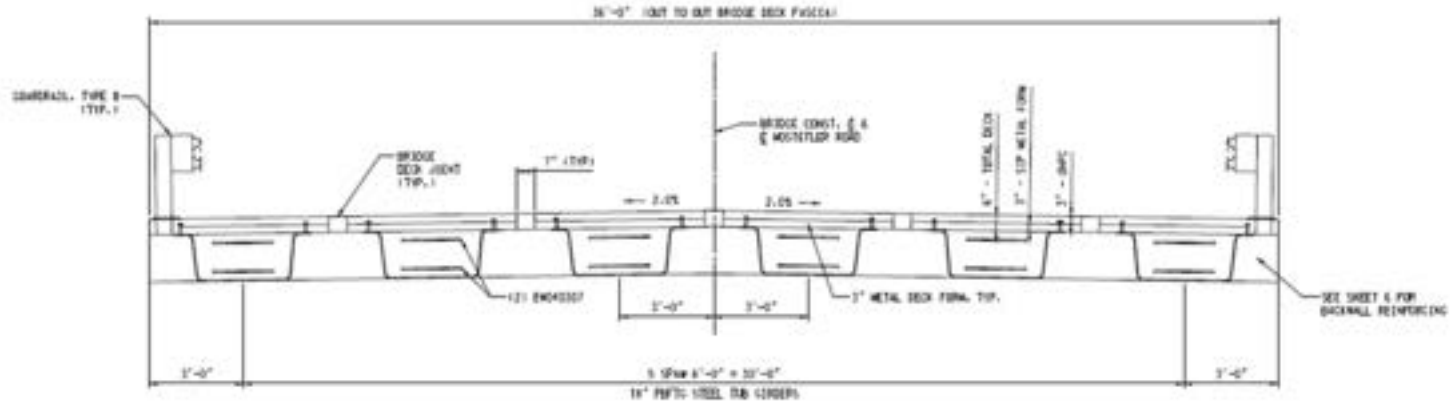
Weight savings about 2/3 (67%)

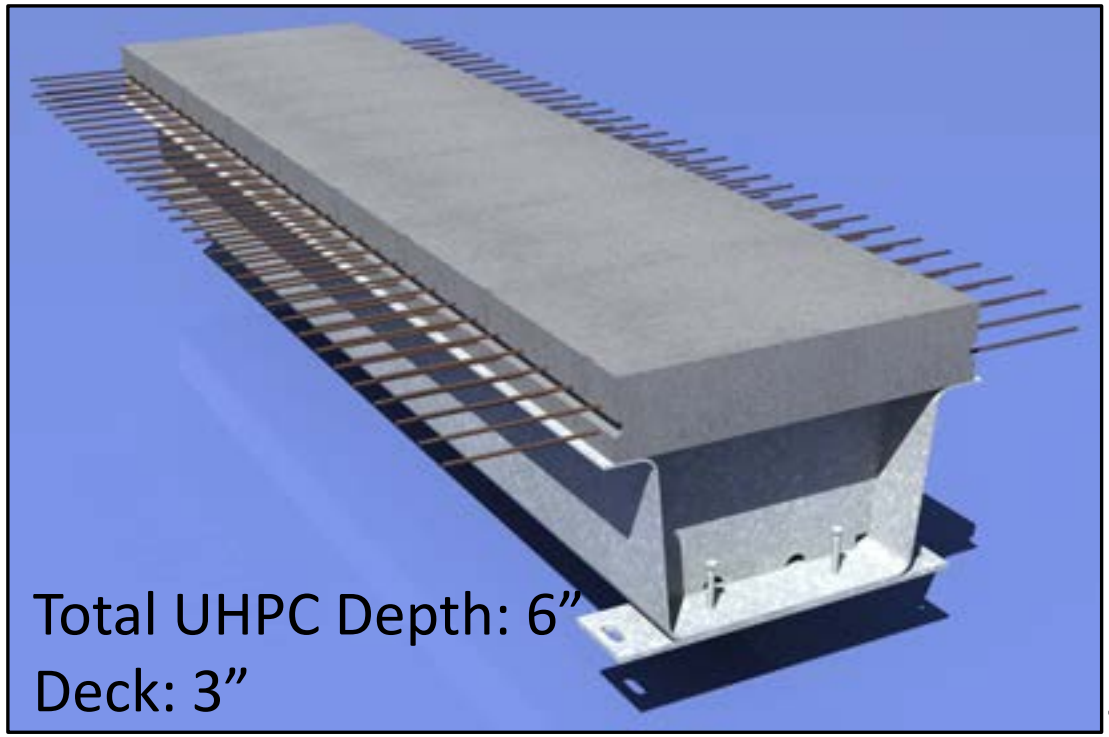
Substantial Short Term Savings

- Reported by County (Michael Clark and Bill Hazelton)
- MDOT 2022 Scoping Estimate Worksheet: $560,000
- St. Claire County cost: $379,000
  - Includes road work, new abutments & UHPC panels plus county labor & equipment
- Short Term Savings: $181,000 (32.3%)
- Long Term Savings: Discussed Later
- Many lessons learned

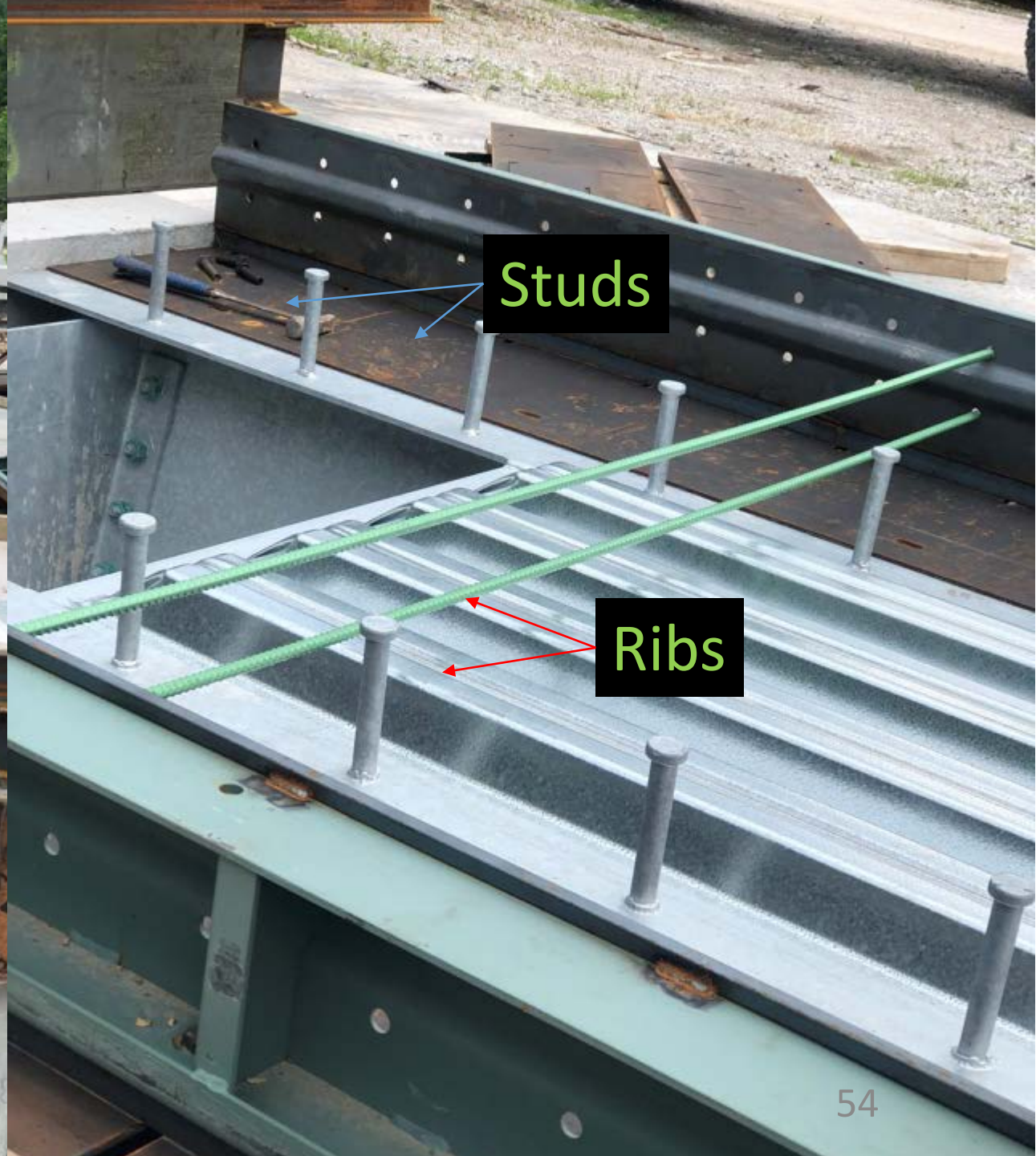
First bridge in the US with UHPC Deck Composite Tub Girders: Mostetler Road over Mostetler Creek Bridge - 2022







Courtesy Guy Nelson, Valmont Engineering


Studs
Ribs

UHPC was mixed in a truck


Clare County Bridge (Dewayne Rogers)
First bridge in the US with Open Recipe UHPC Deck Composite Tub Girders


Clare County Bridge (Dewayne Rogers)
First bridge in the US with Open Recipe UHPC Deck Composite Tub Girders

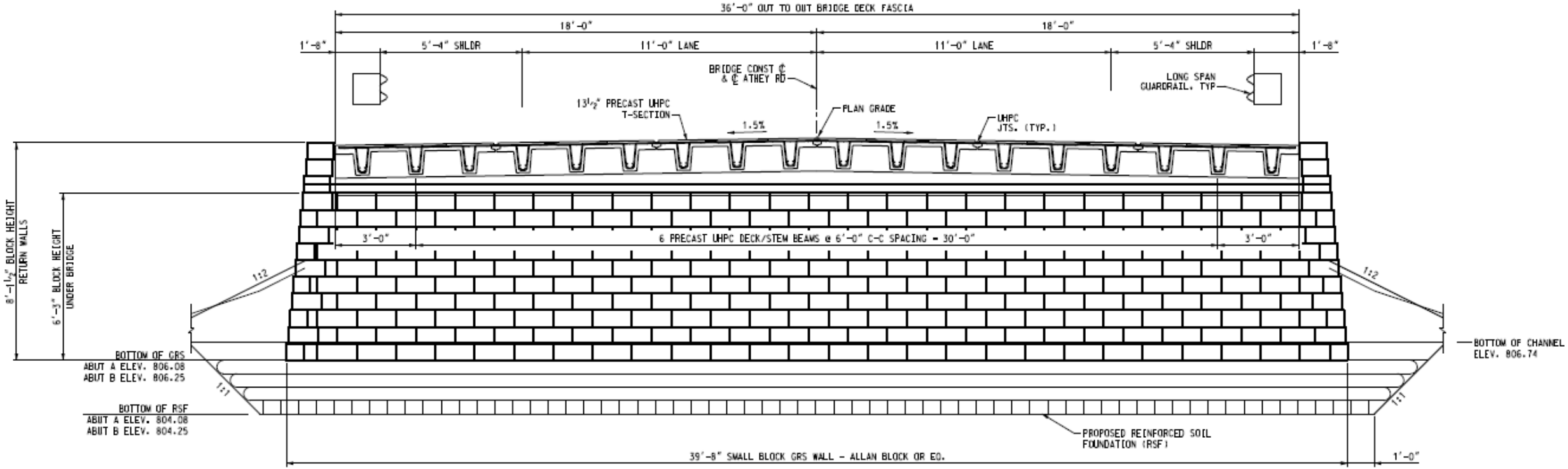
Guy Nelson: The installation was also made more efficient by the light weight of the UHPC/PBTG PBU's. The completed PBU's required only a third of the concrete in a conventional bridge superstructure, and less than a quarter of the weight of a concrete PBU.

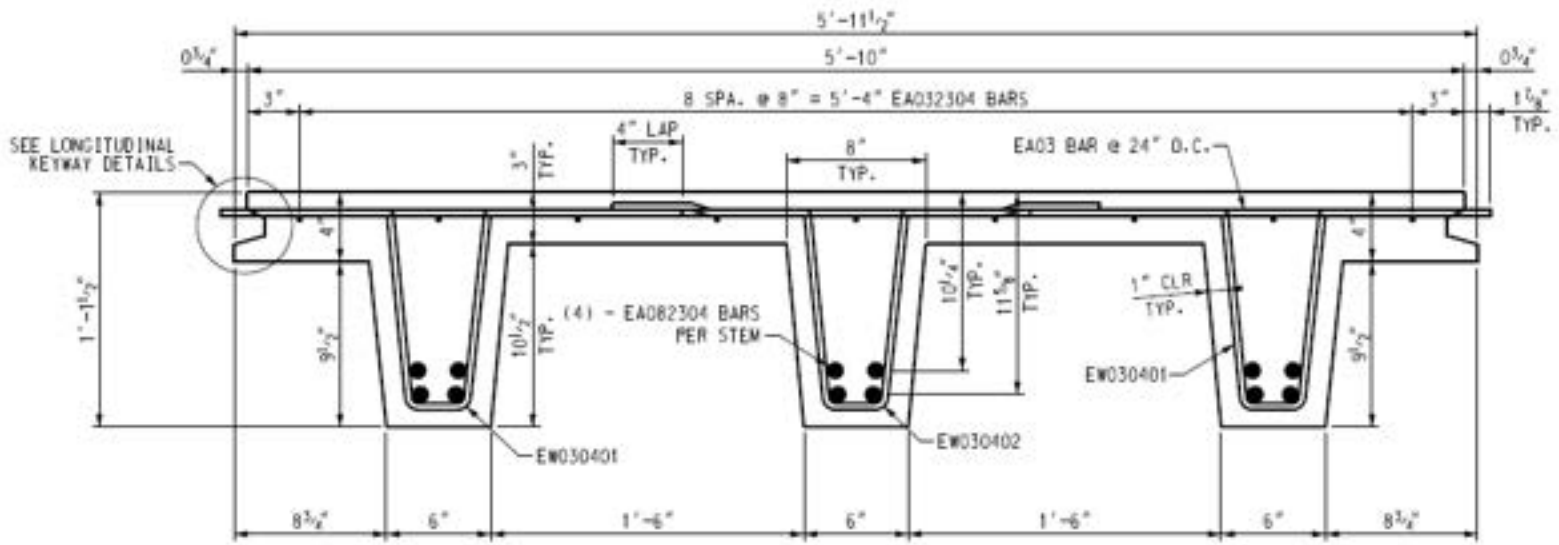
100-year maintenance-free service life

Substantial Short Term Savings

- MDOT bridge worksheet cost is $788,000
- Clare County bridge cost $534,000
  - Includes guardrail, paving, and epoxy overlay
- Short Term Savings: $254,000 (32.2%)
- Long Term Savings: Discussed Later
- Dewayne Rogers: "*Could have definitely saved money, but that's the learning curve. More to do with our experience than UHPC*."

Athey Road Bridge (Clare County, MI) - 2023





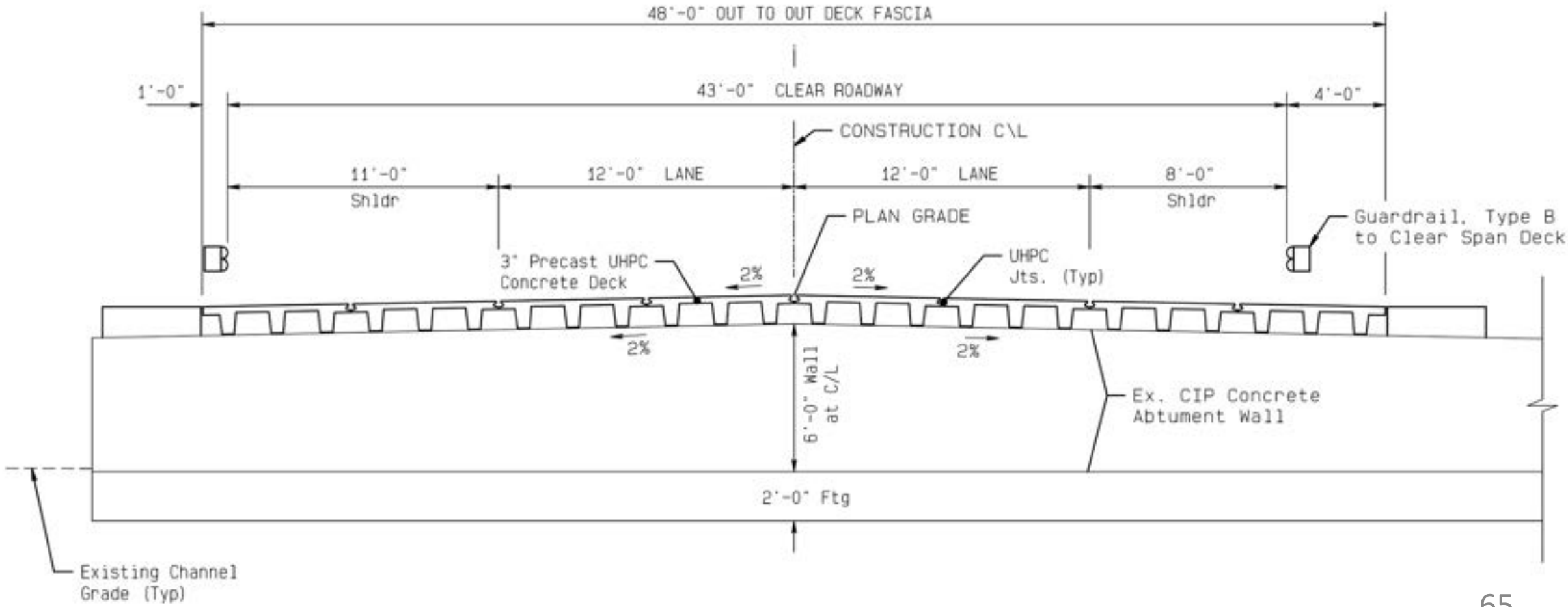
SECTION - UNIT A-1


SUPERIOR

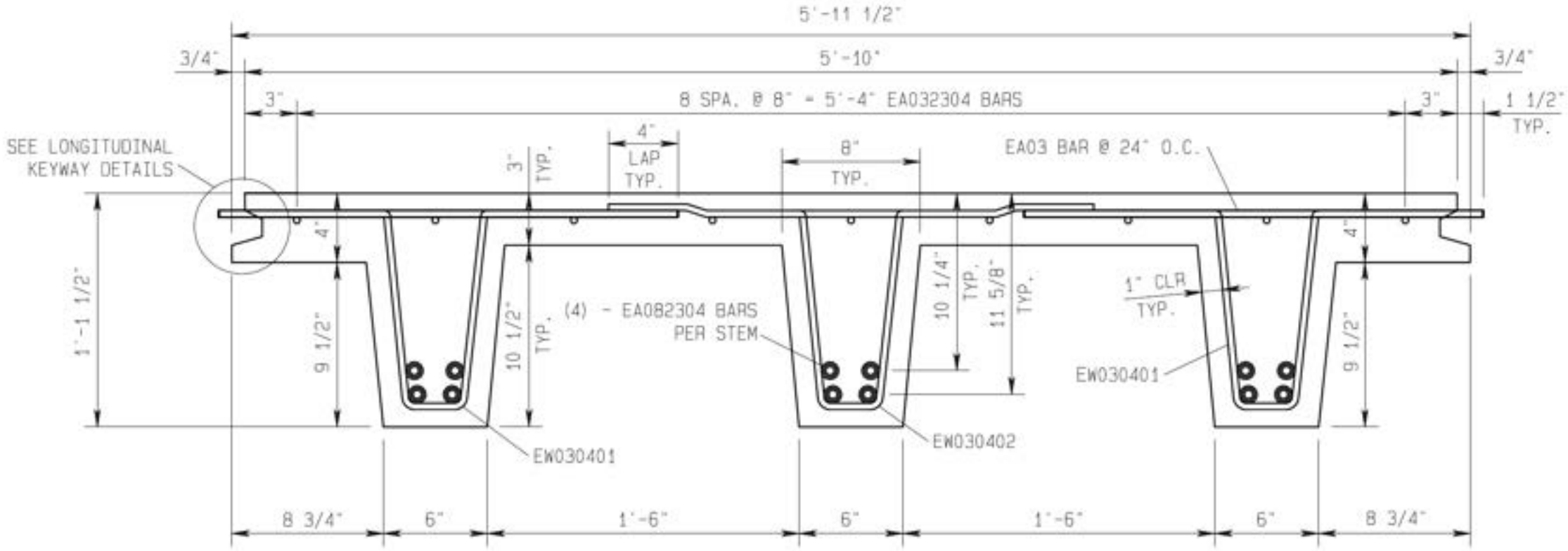
Again, Substantial Short Term Savings

- MDOT bridge worksheet cost is $550,000
- Clare County bridge cost $248,000
- Short Term Savings: $302,000 (55%)
- Long Term Savings: Discussed Later

Gratiot Road Bridge Over Moak Drain (St. Clair County, MI) - 2023



Same Everything – But …



¼ Lower Fiber Usage

- NCHRP-IDEA testing showed that striated steel fibers at lower dosage can provide performance similar to smooth steel fibers
- The test showed that a dosage of 1.25% - 1.5% by volume could replace 2% by volume of traditional fibers
- Bridge will be cast in late August 2023

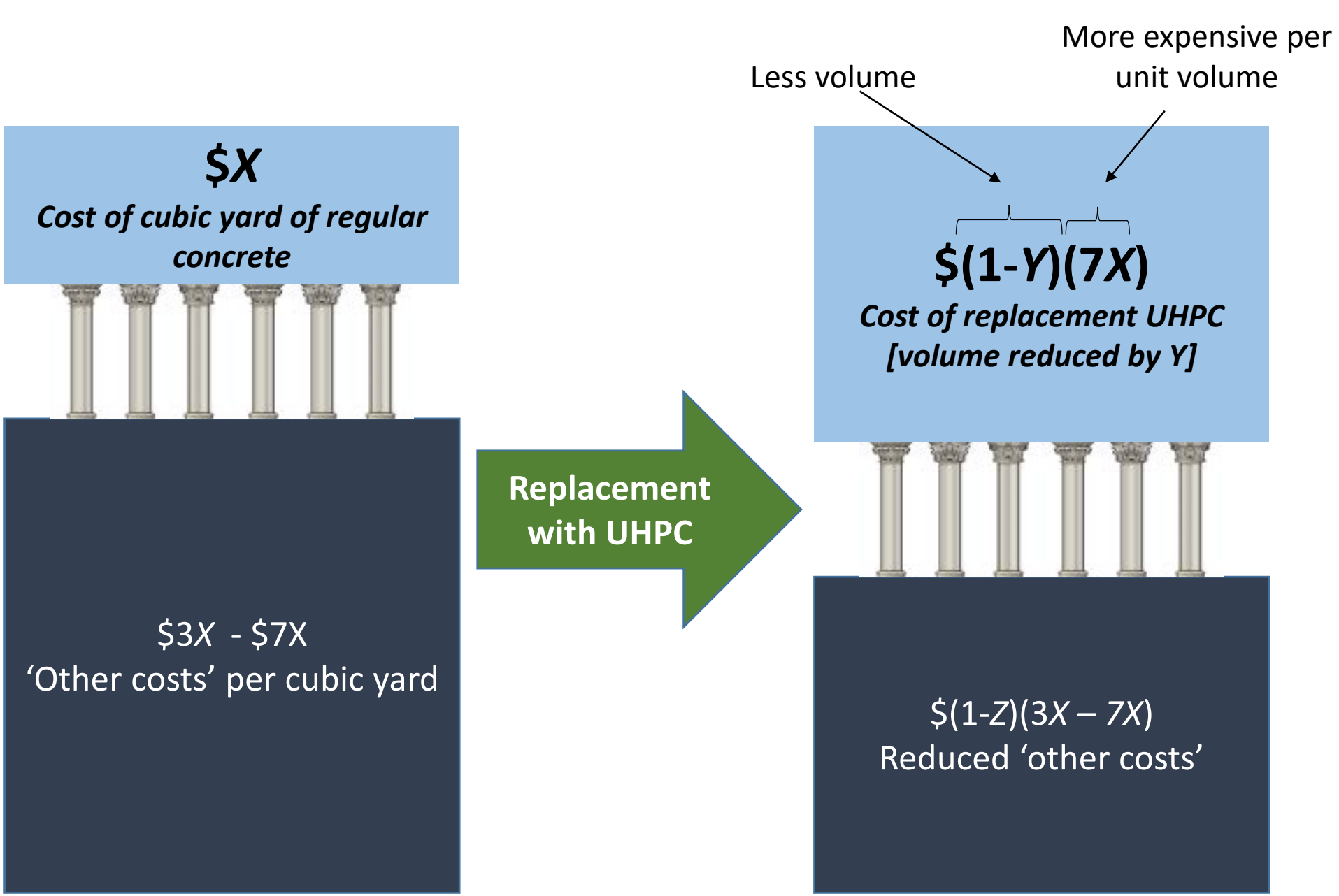
NCHRP IDEA 235 Test Data

	V_f (%)	ε_t	f_t (ksi)
Type X	1.0	0.0023	1.18
	1.5	0.0030	1.35
	2.0	0.0042	1.79
Smooth	1.0	0.0016	1.09
	1.5	0.0022	1.28
	2.0	0.0026	1.66

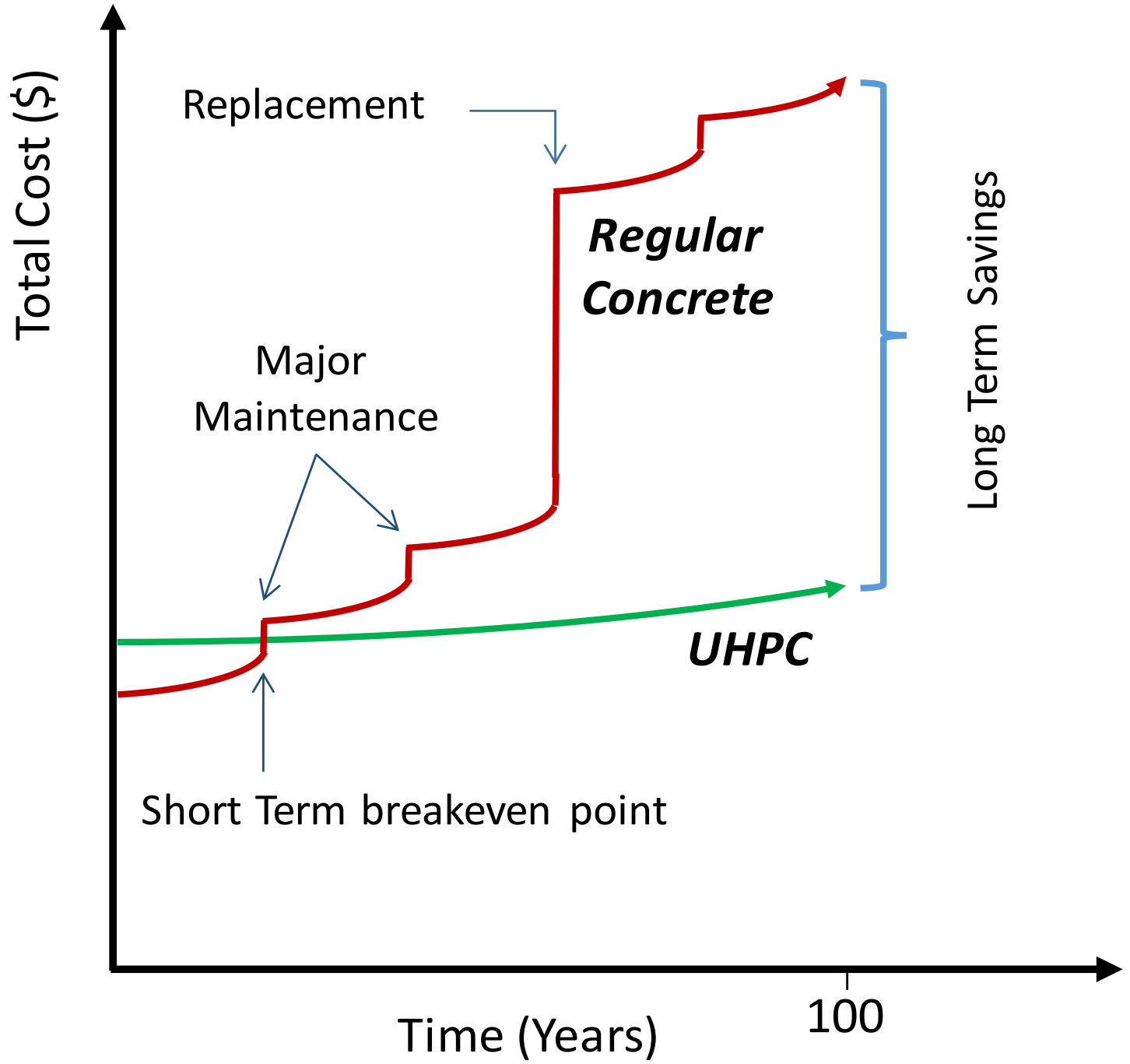
Type X fibers are:

- Compliant with the Buy America Act
- Made in the USA
- Commercially available from HiPer Fiber, LLC

The Cost Argument



Real Opportunity for Cost Savings



UHPC Usage in Michigan

- Michigan is a pioneer in UHPC technology
- In 2012 and 2016, MDOT funded a pair of studies at the University of Michigan that produced a non-proprietary UHPC that many researchers are using across the US.
- The State is host to several firsts in UHPC usage:
  - First bridge with open-recipe UHPC closure pour (St. Clair County 2018)
  - First bridge with open-recipe UHPC composite deck (Clare County 2022)
  - First bridge with open-recipe UHPC full deck (St. Clair County 2022)
  - First bridge to use 1.5% by volume steel fiber dosage (St. Clair County 2023)

Final Thoughts: Cost Considerations

- The cost of open-recipe UHPC ranges from $1377 to $1675 per yard in 2023
  - It used to cost $890 in 2019
- UHPC provides cost savings along two fronts
  - Short term savings due to lighter superstructure
    - Cheaper transportation cost
    - Easier and cheaper handling (needs smaller cranes on construction site)
    - Smaller substructure system
  - Long term savings due to extreme durability
    - Minimal maintenance (reduces citizen annoyance)
    - Extremely durable deck (projected life of 100 to 150 years) with minimal maintenance)
    - Significantly lower replacement costs

UHPC Presents a Compelling Case

- UHPC can be cheaper in both the short run (32+% savings in shown examples) and long run (substantially so)
- Its unique properties enable innovation and outside-the-box thinking.
- Certainly, there are problems, as is true with any new technology.
  - Problems are surmountable
- UHPC technology is a game changer that will transform our transportation infrastructure into an ultra-durable and ultra-resilient system.

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