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COLLEGE OF ENGINEERING

Prestressing 0.6" & 0.7" CFRP Strands *for* Highway Bridge Construction

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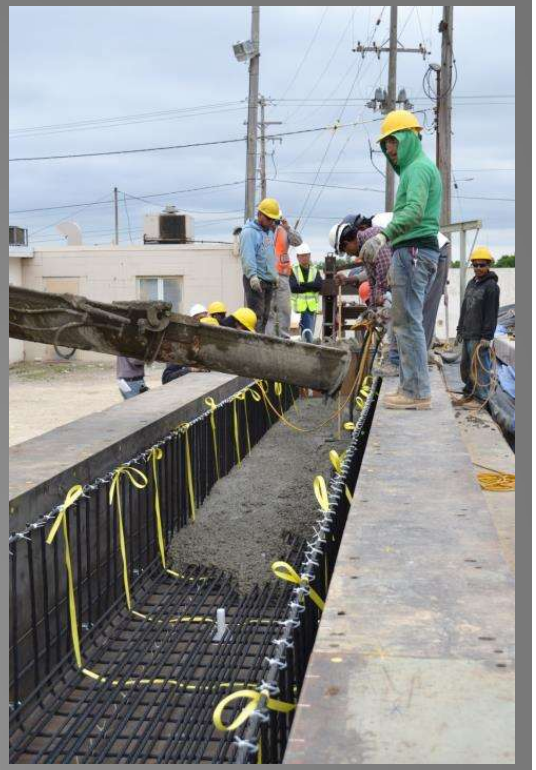
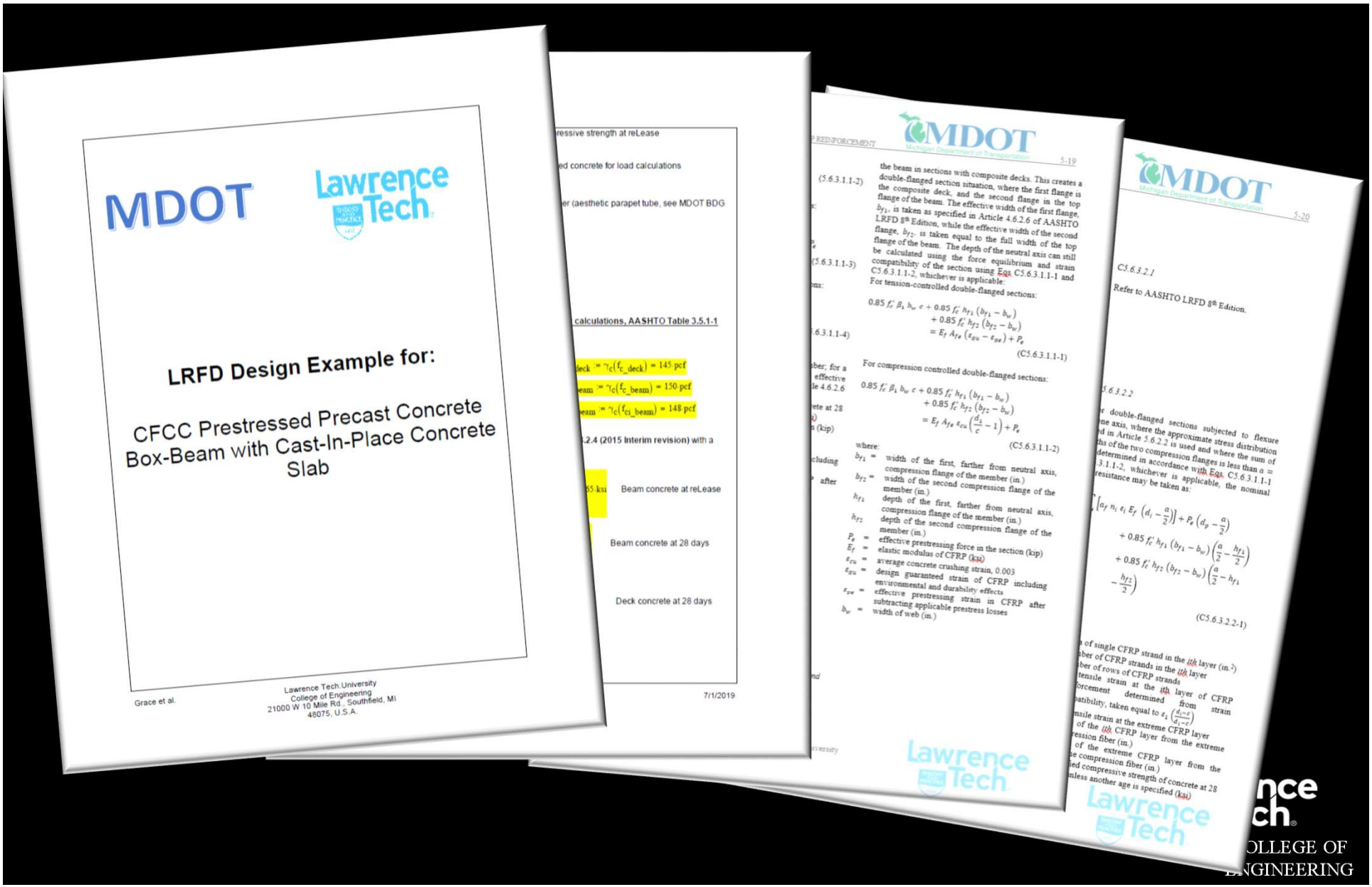
Bridge Street Bridge over Rouge River (2001)

MDOT CFRP prestressing/ post -tensioning deployments

- Pembroke Ave over M-39 (2011)
- M-50 over NS Railroad (2012)
- M-102 EB and WB over Plum Creek (2013 – 2014)
- I-94 EB & WB over Lapeer Road (2014)
- M-100 over Sharp Drain (2015)
- M-66 over West Branch River (2015)
- M-86 over Prairie Creek (2016)
- I-75 SB over Sexton-Kilfoil Drain (2017)
- M-3 over I-94 (2018)
- Brush Street over I-94 (2019)
- **Burns Ave over I-94 (2021)**
- **Cadillac Ave over I-94 (2021)**



MDOT Design Guidelines & Design Examples in 2019



Uni-axial Tensile Test of 0.6” & 0.7” CFCC Strands

Creep Rupture Strength of 0.7″ CFCC Strands

Test	No. of test specimens	Initial prestressing force (kip/strand)	Percentage to ultimate ($f_u \approx 113.9$ kip/strands)
Creep rupture	5	95.5	85 %

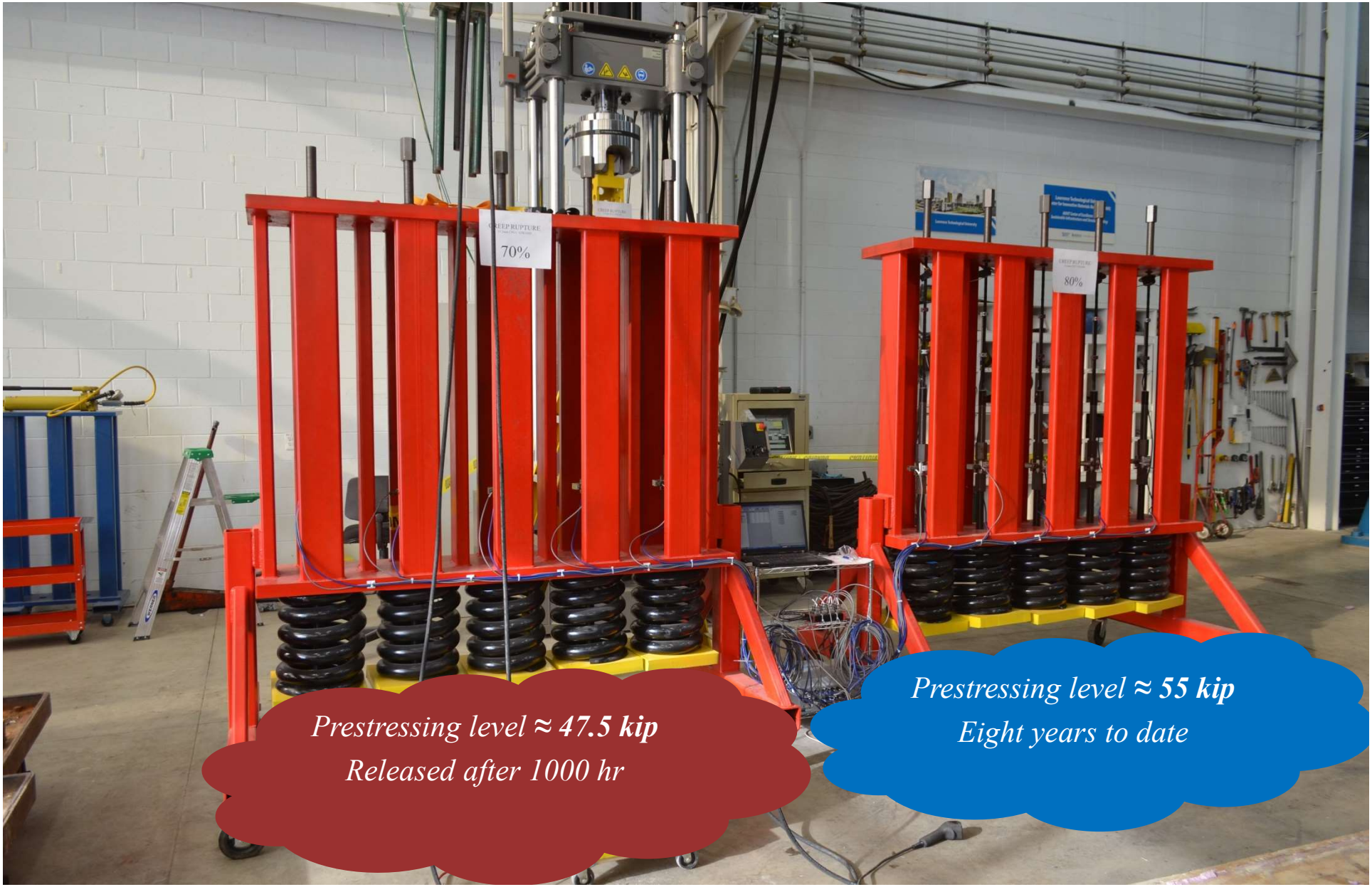
Creep Rupture Test of 0.6″ CFCC Strands

Test	No. of test specimens	Initial prestressing force (kip/strand)	Percentage to ultimate ($f_u \approx 70$ kip/strands)
Creep rupture	5	64.4	92 %

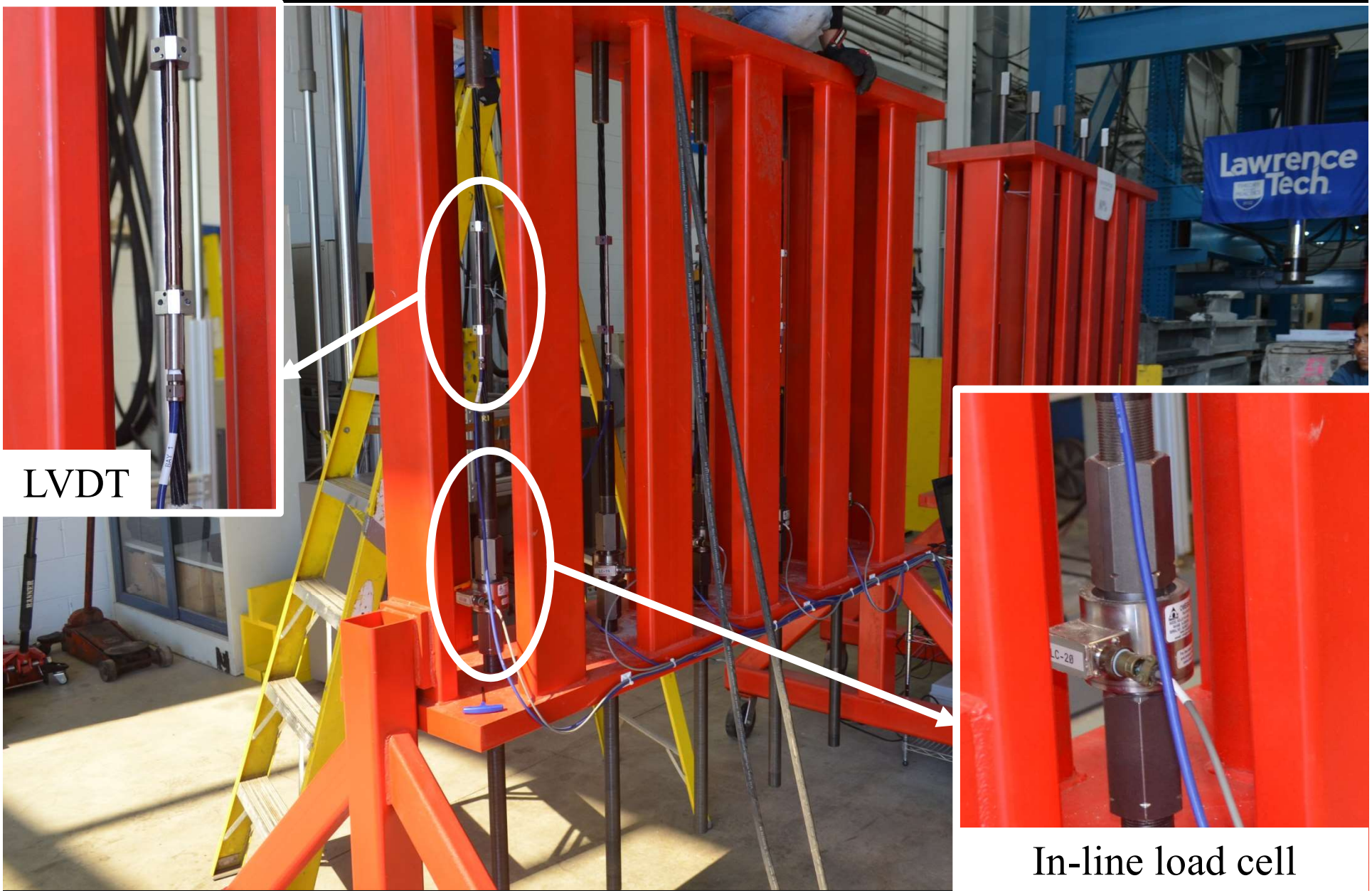
Relaxation of 0.7″ CFCC Strands

Test	No. of test specimens	Initial prestressing force (kip/strand)	Percentage to ultimate ($f_u \approx 113.9$ kip/strands)
Relaxation	5	94	80 %

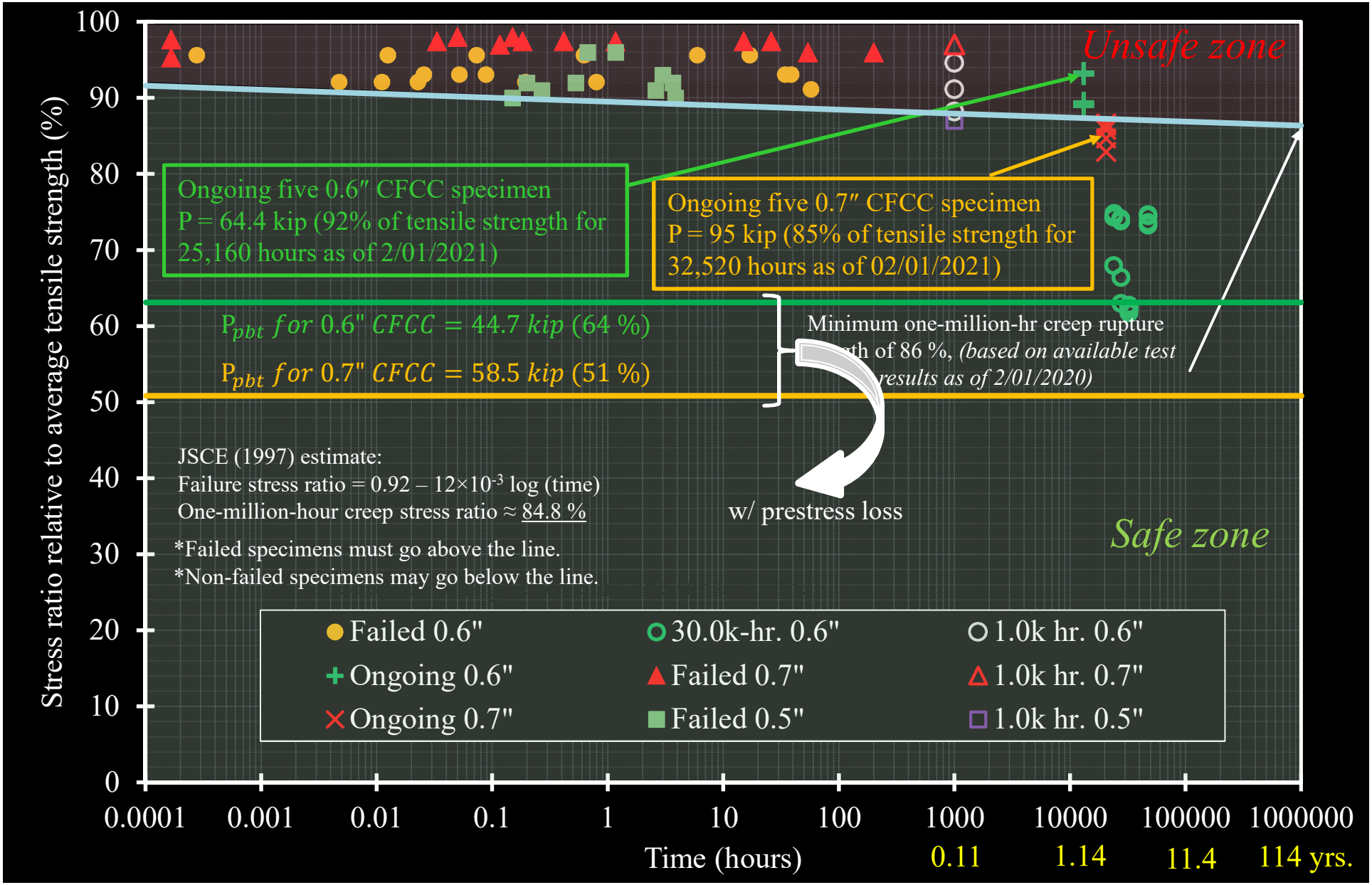
Creep Rupture of 0.6" CFCC (Ongoing since 2013)



Long Term Relaxation



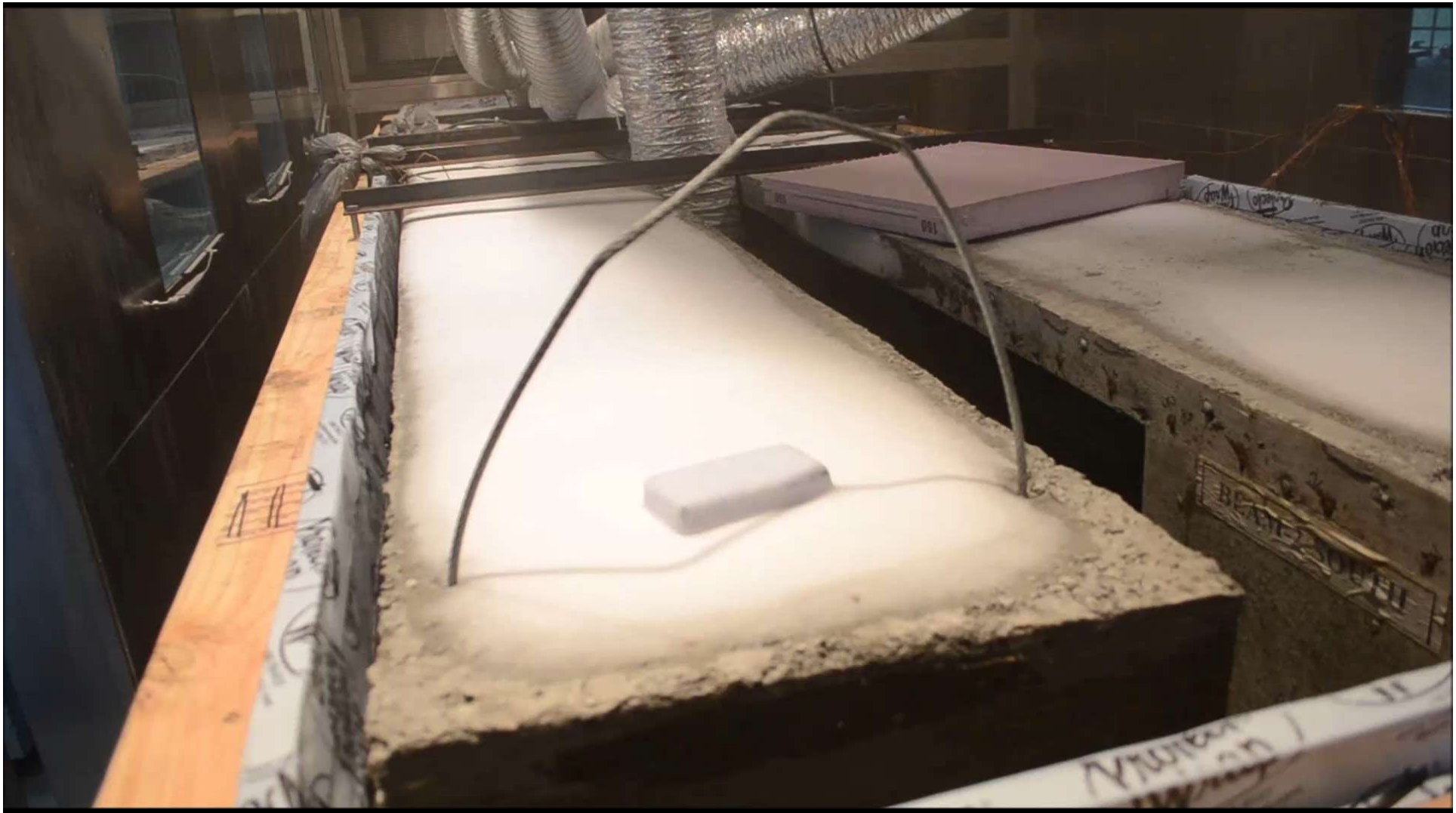
Summary of Creep Rupture Results



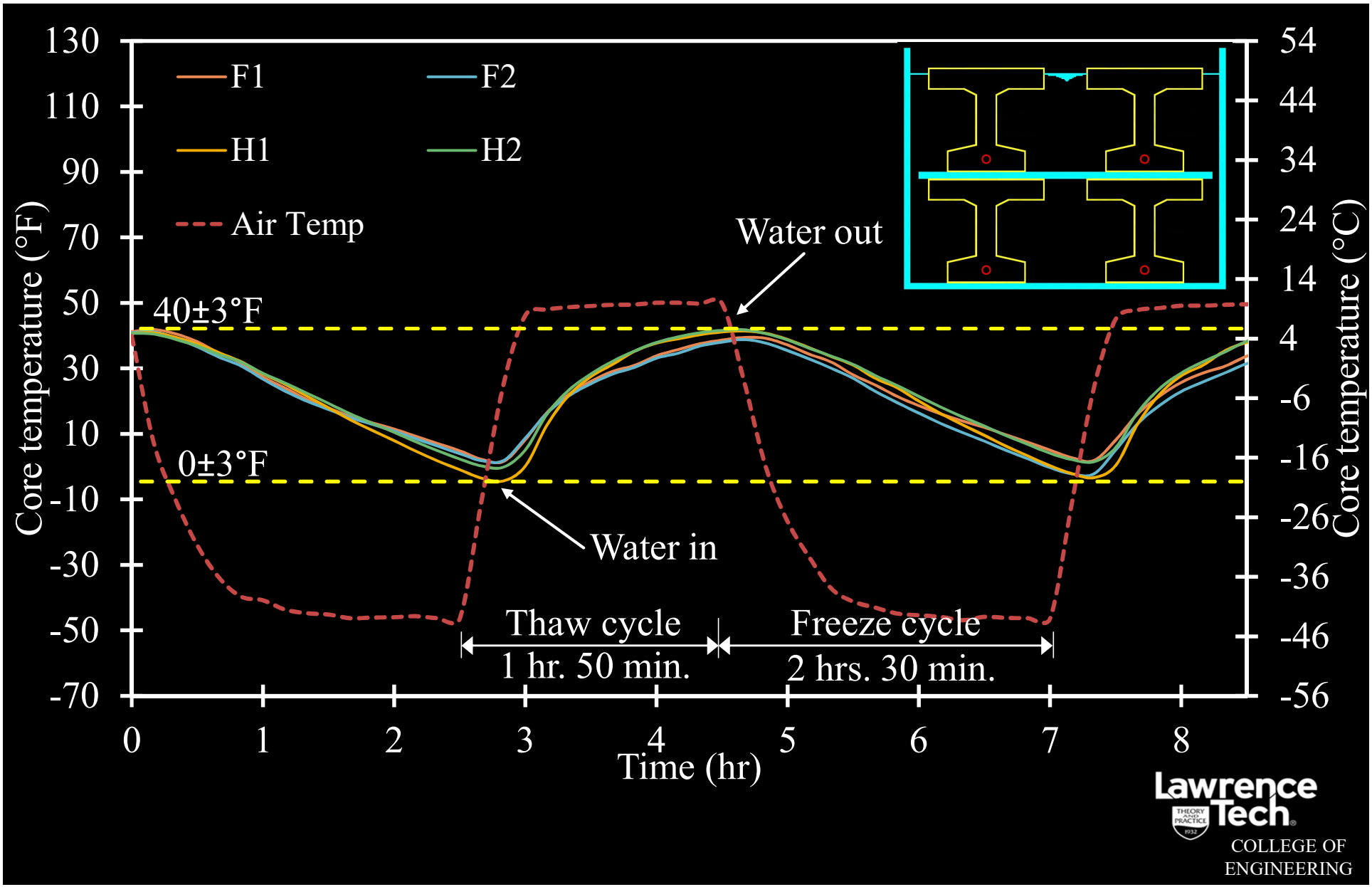
CFCC Prestressed Beam Under Freeze-Thaw Cycles

Tank for the beam specimens & loading frames for CFCC strands @ the environmental chamber

Freeze-Thaw Cycles



Freeze & Thaw Cycles of Four Beams (ASTM C666)



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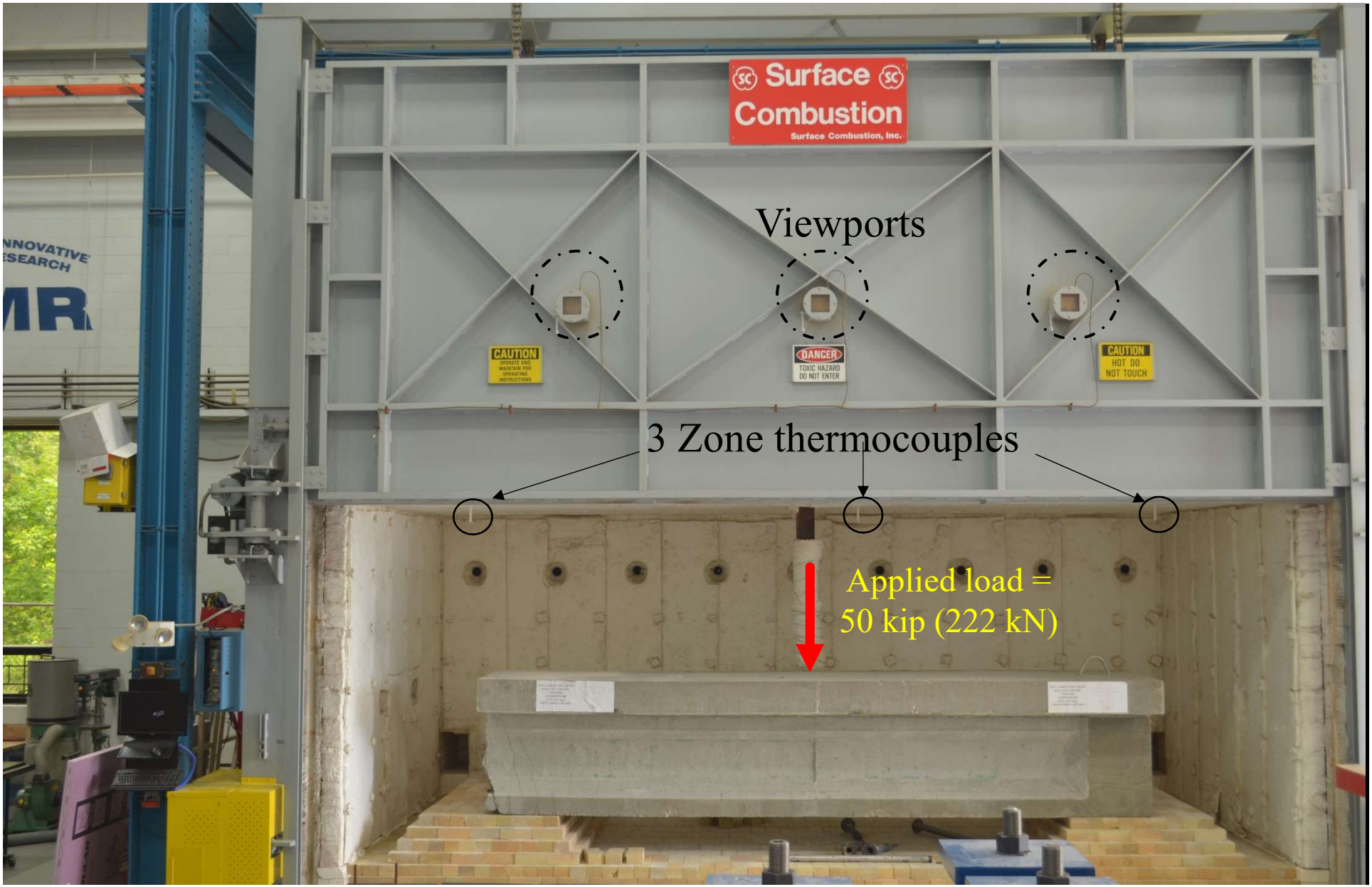
Fire Testing of Half-Scale Prestressed CFCC Beams

CFCC prestressed decked bulb T beam under fire/loading event (ASTM E119)

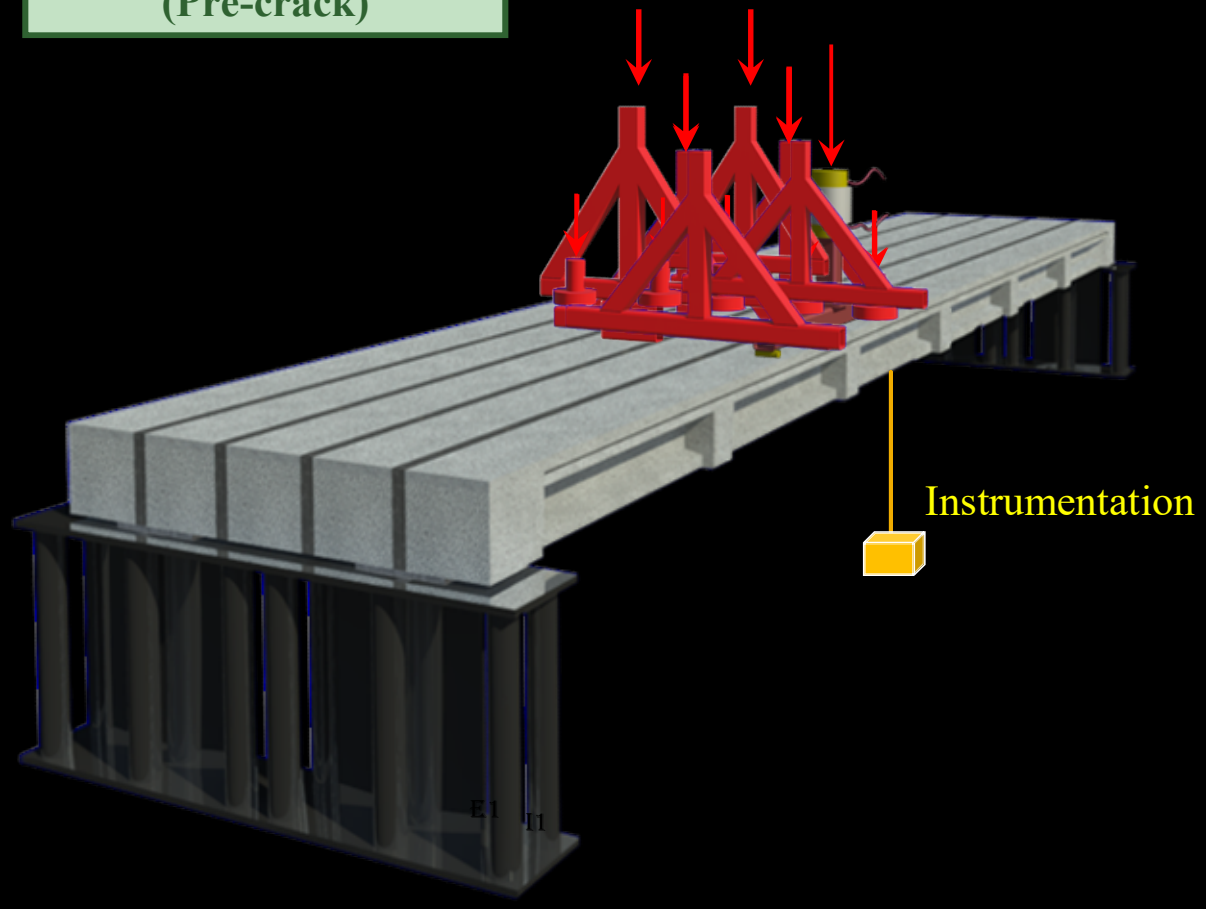
Fire Testing of Salvaged AASHTO I Beams



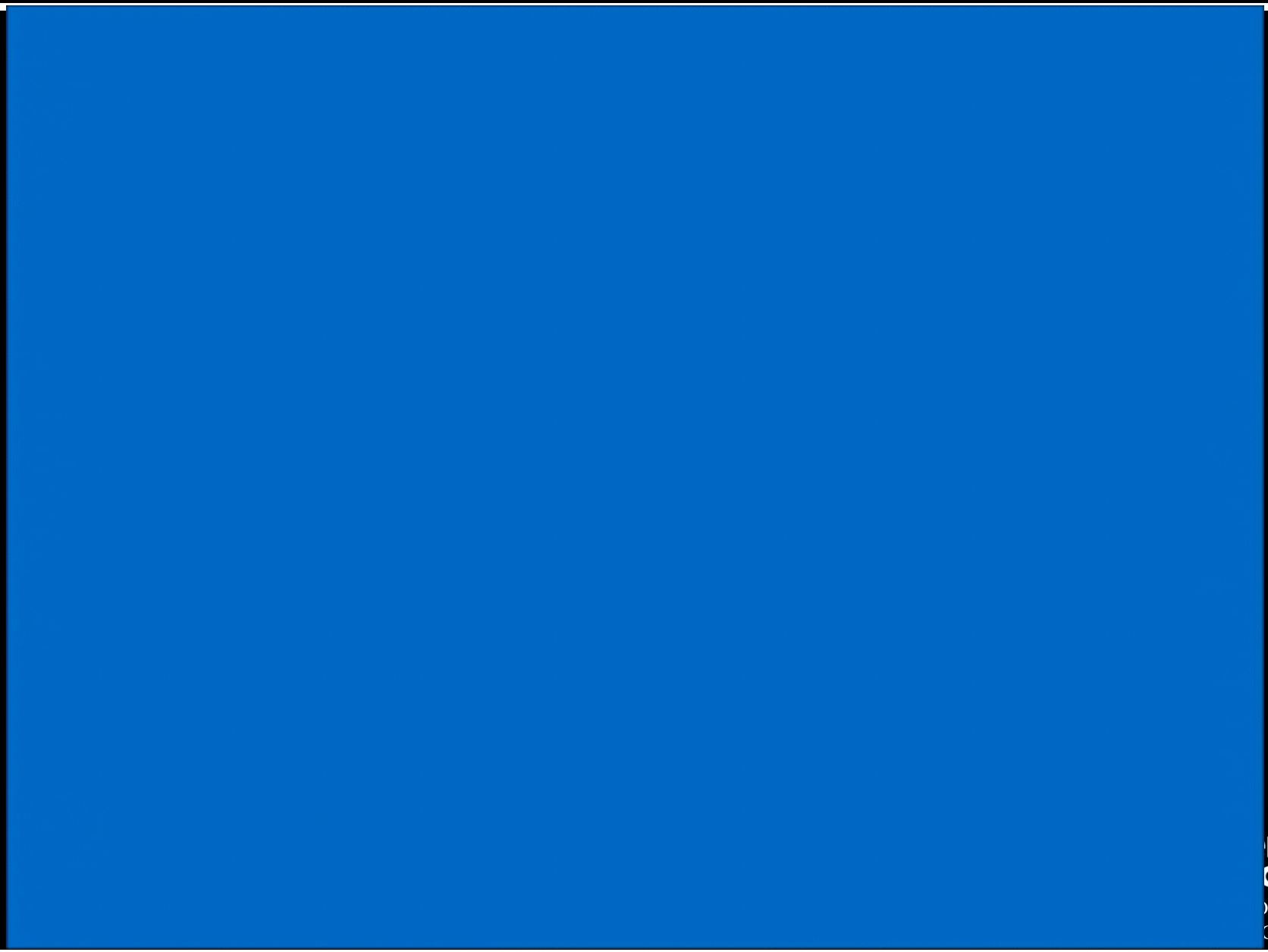
Failure of Prestressed CFCC Beam under Fire/Load Event

Bridge Model with 0.6" CFCC Strands

- Service Limit State → Load distribution test (Pre-crack)
- Post-cracking Limit State
  - Cracking load test
  - Load distribution test (Post-crack)
  - Shear-key crack test
  - Load cycles test
- Strength Limit State



Strength Limit State of 0.6″ CFCC Prestressed Bridge



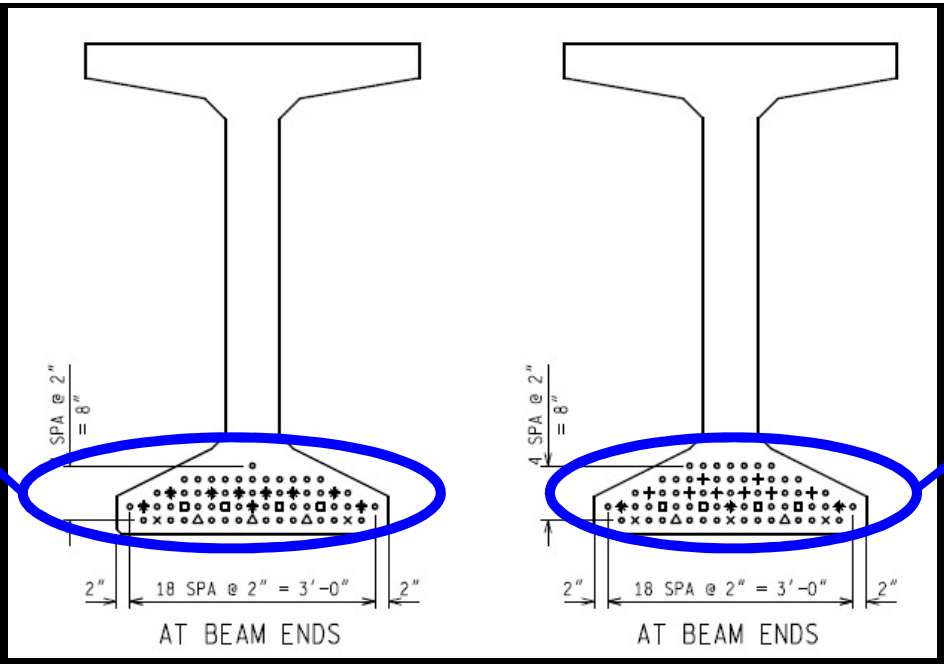
Load Distribution Test on 0.7″ CFCC Prestressed Bridge

Prestressing of I-75 Bridge Beams (2017)

Other beams

63 strands
$\emptyset = 0.6$“

35 kip/strand

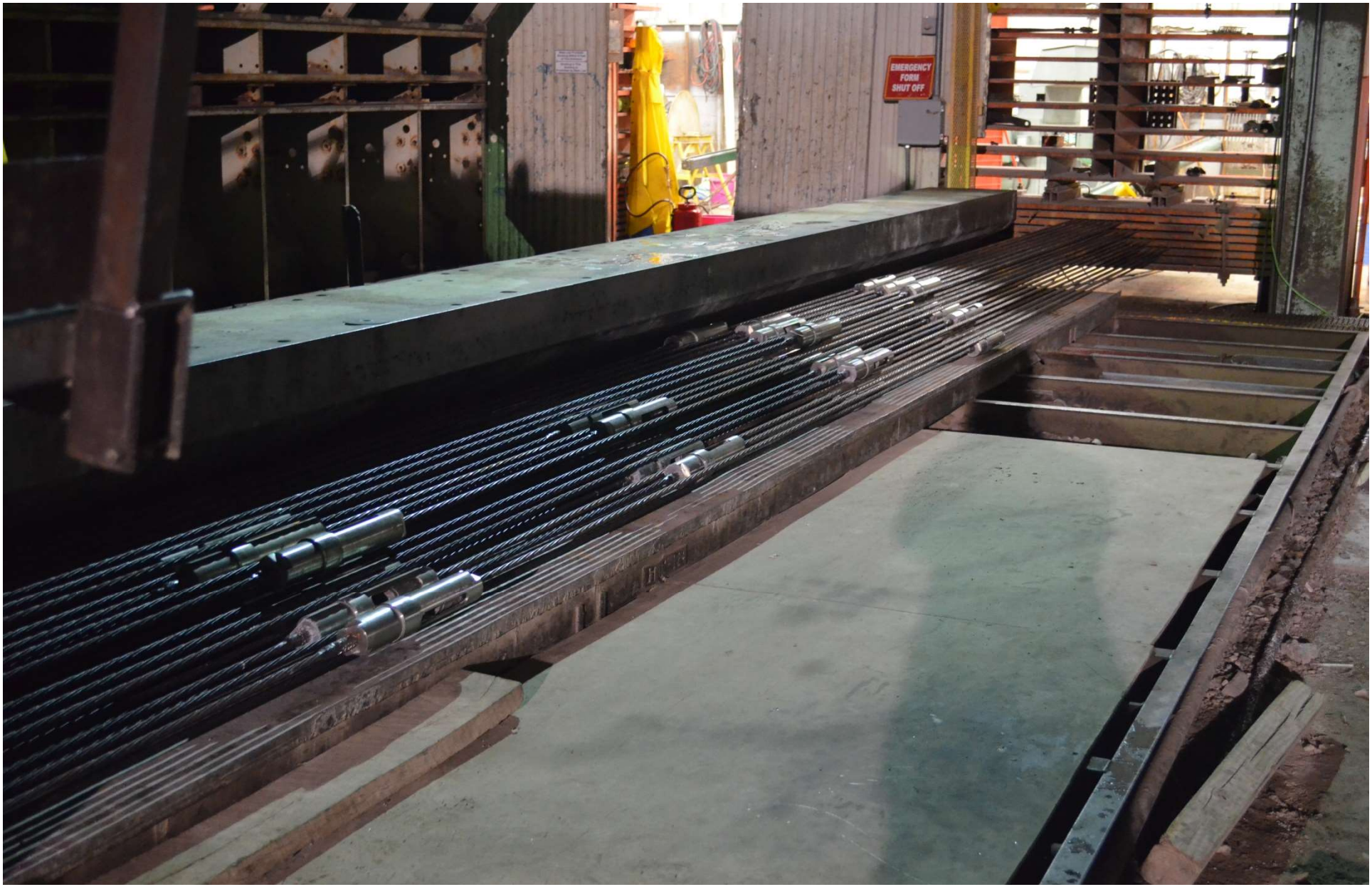


West fascia beam (WFB)

69 strands
$\emptyset = 0.6$“

35 kip/strand

Beam Construction (CFCC-Steel Couplers)



Beam Construction (Prestressing Steel Strands)

Beam Construction

Bulb T beam after construction

Beam Construction (Completed Beam)

Truck Loading Test (I-75 Bridge)

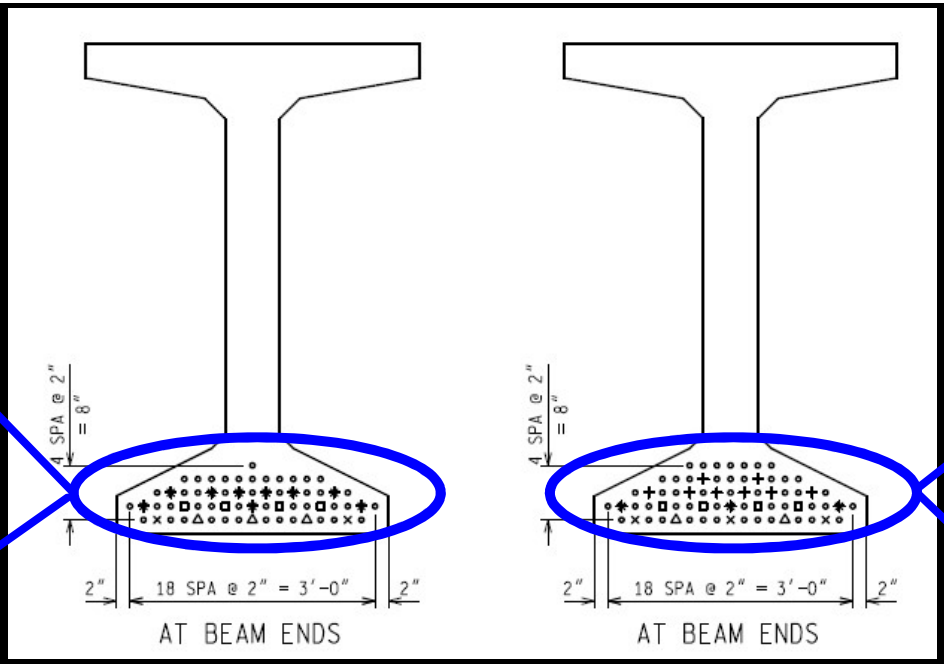
Prestressing of I-75 Bridge Beams

Other beams

63 strands
$\emptyset = 0.6$“

Possibly

38 strands ($\emptyset = 0.7$“)



West fascia beam (WFB)

69 strands
$\emptyset = 0.6$“

Possibly

42 strands ($\emptyset = 0.7$“)

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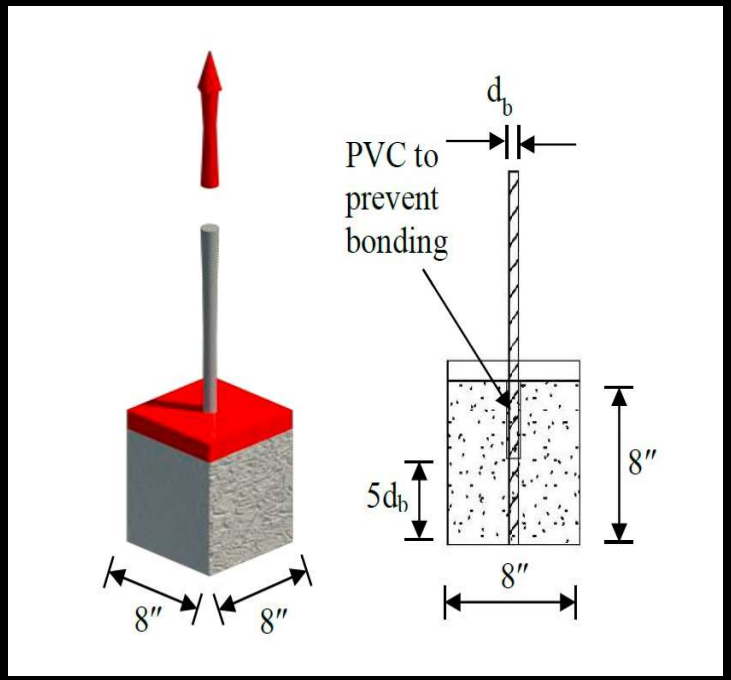
Bond Strength

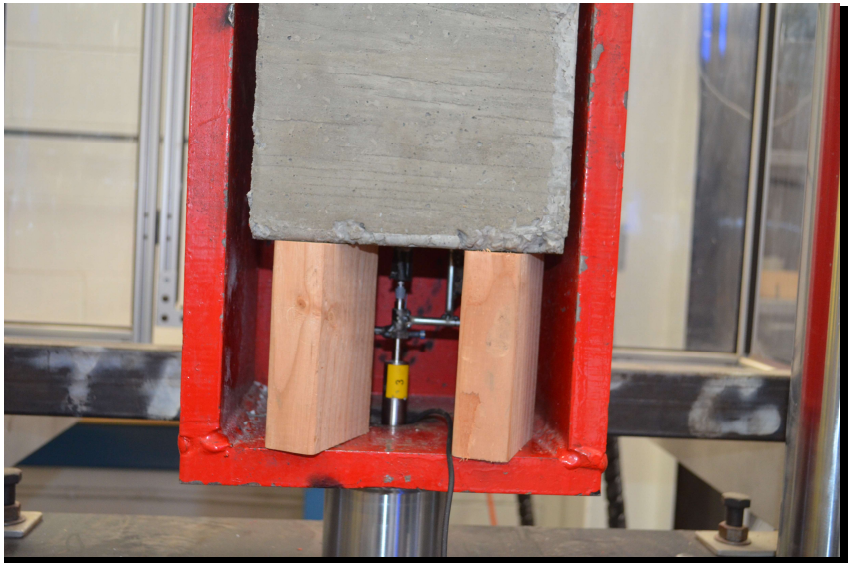
References:

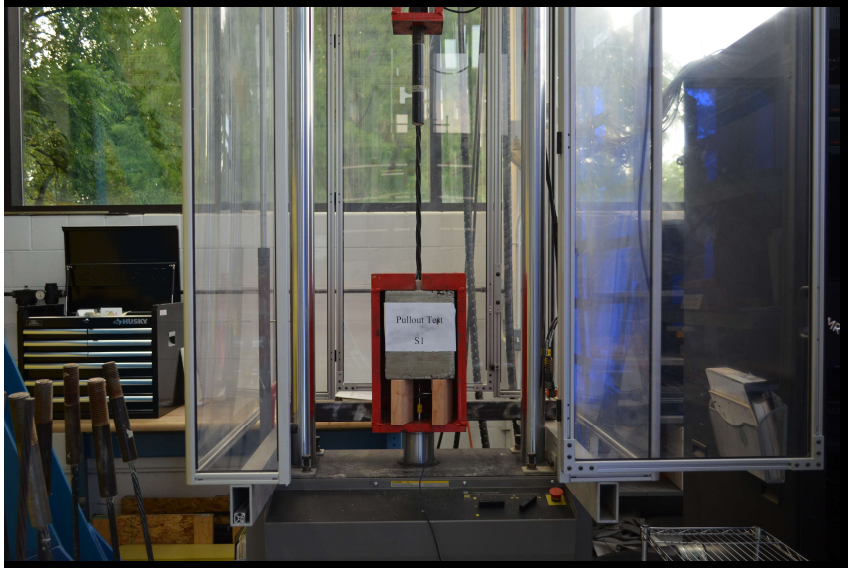
ACI440.3R-12-B.3 Test method for bond strength of FRP bars by **pullout testing**

ACI440.3R-12-B.7 Test method for tensile **fatigue** of FRP bars

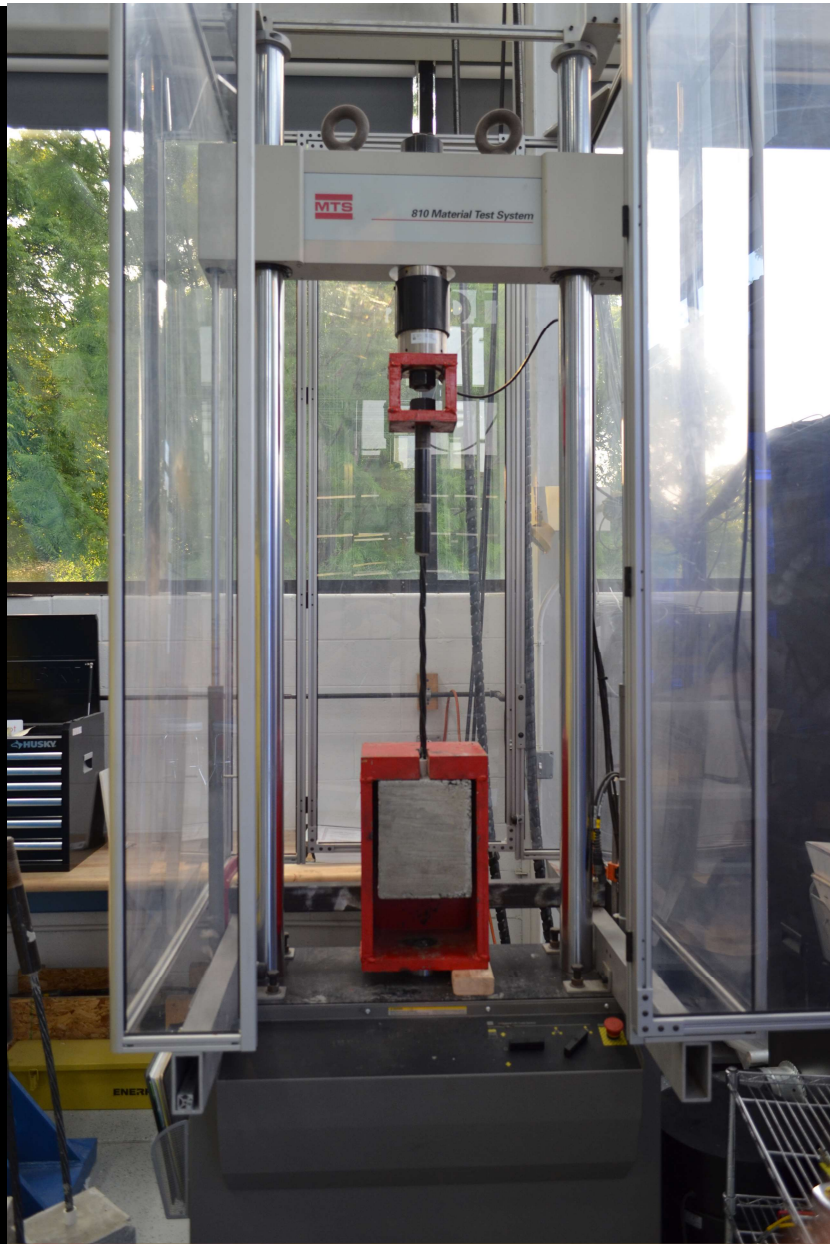


Pull-out Test of 0.6" & o.7" CFCC & Steel Strands

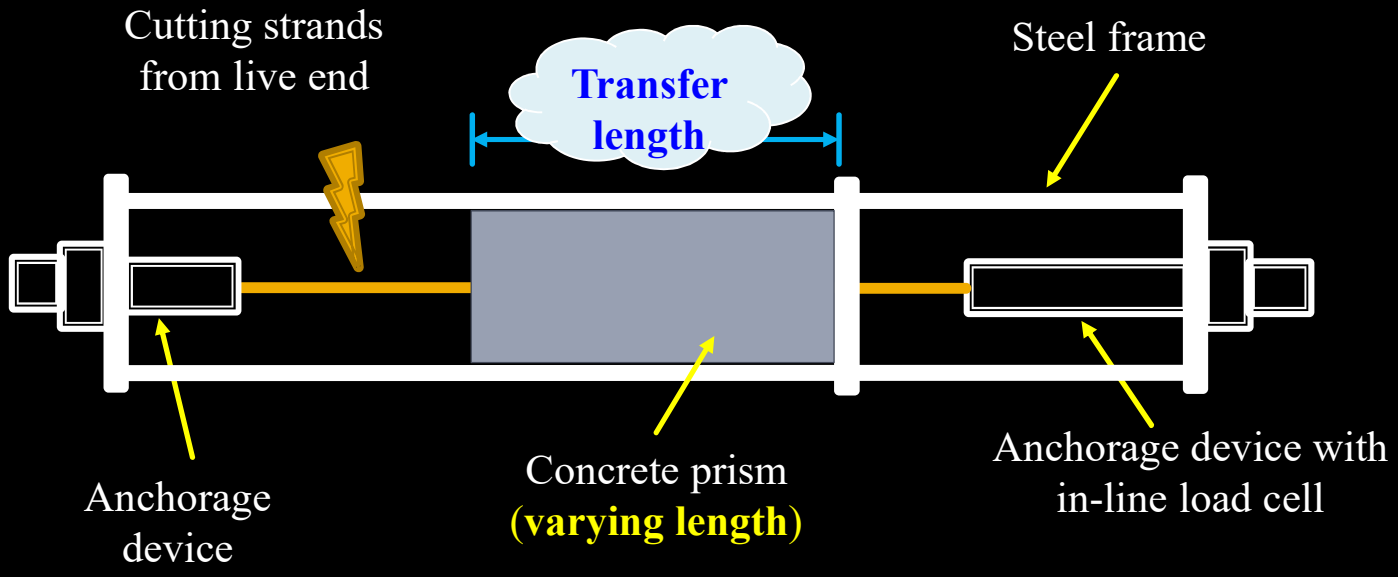




Loading rate: 0.25 in. (6.3 mm) / minute



Transfer Length



Transfer length:

Minimum length of concrete prism to eliminate CFRP strand slippage and loss of prestressing force recorded by in-line load cell

Prestressing Transfer & Development Length Specimens

Jacking force = 53 kip (for both transfer and development length specimens)

In-line load cell (transfer length specimens only)

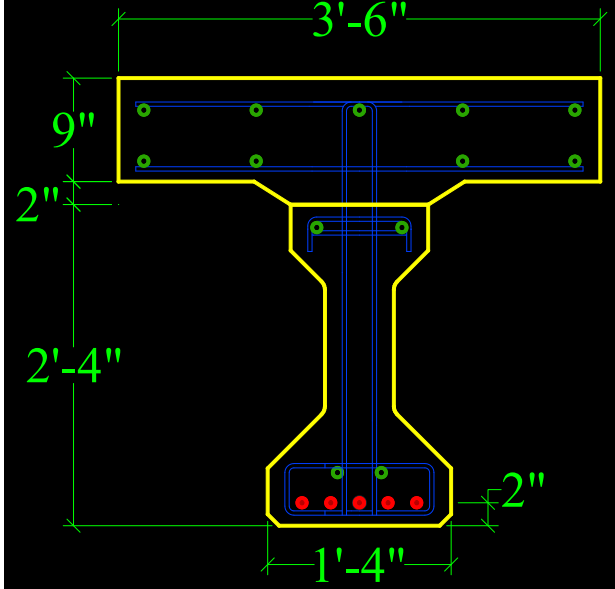
Steel chair

Hydraulic pump

Pressure cylinder

Flexural Testing of Full-Scale AASHTO I Beams

Beam length = 40 ft

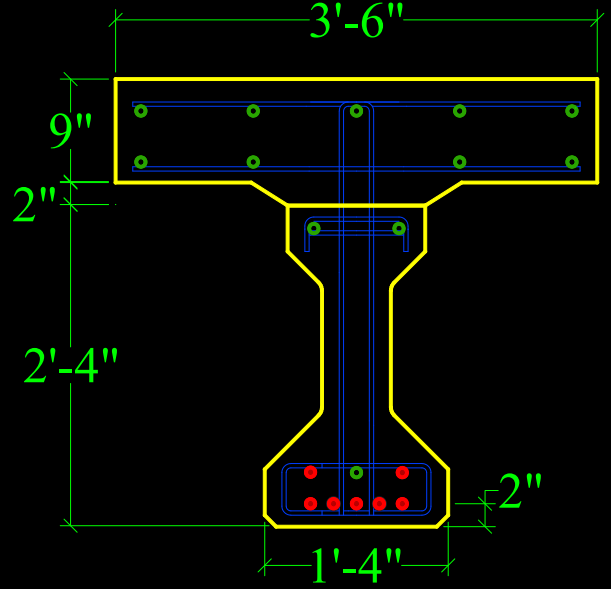


28" deep AASHTO I beam
w/ 0.7" CFCC strands

Prestressed strands = 5

Initial prestressing
$0.75 \times 0.9 \times P_{gu}$

$\approx 53\ kip/strand$

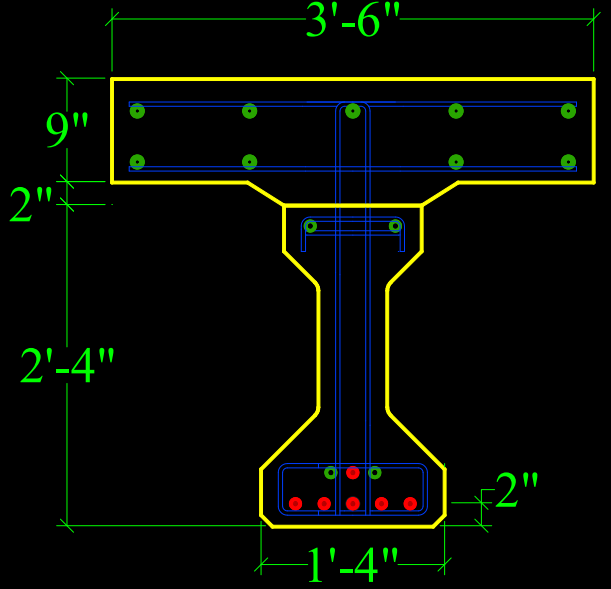


28" deep AASHTO I beam
w/ 0.6" CFCC strands

Prestressed strands = 7

Initial prestressing
$0.75 \times 0.9 \times P_{gu}$

$\approx 41\ kip/strand$



28" deep AASHTO I beam
w/ 0.6" steel strands

Prestressed strands = 6

Initial prestressing
$0.75 \times P_u$

$\approx 44\ kip/strand$

Strands spacing & cover = 2.0 in. in all directions

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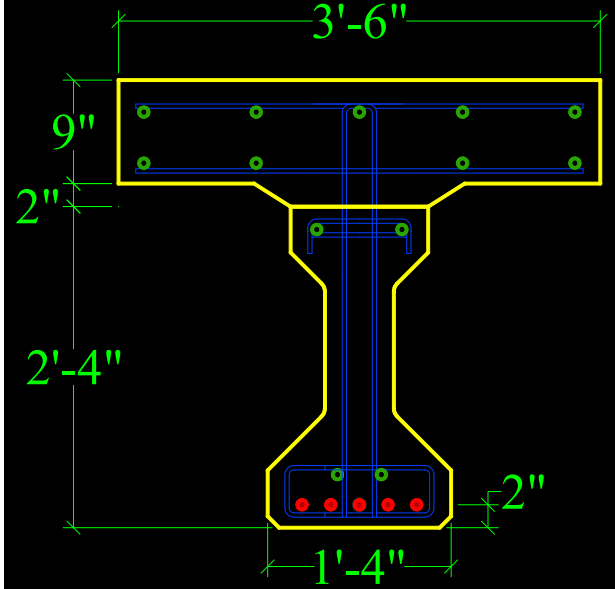
Flexural Testing of Full-Scale AASHTO I Beams

Beam length = 40 ft

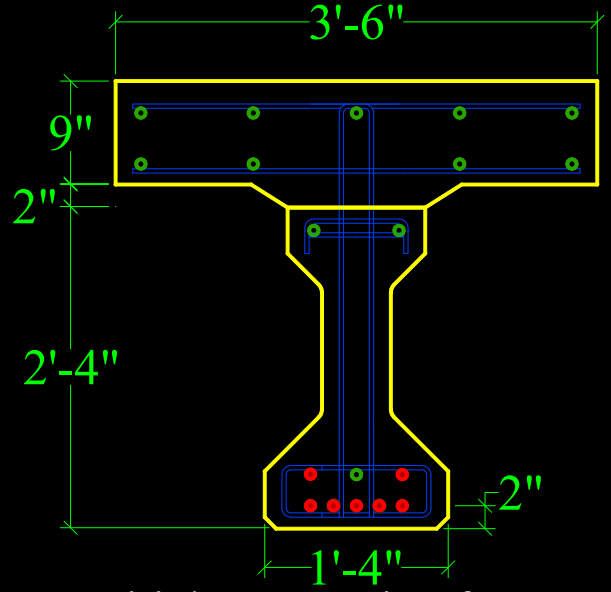


Initial prestressing force = 265 kip/beam

Nominal moment capacity (M_n) = 1181 kip.ft

Ø = 0.85 (Ductile failure)

Resistance Moment capacity ($ØM_n$) = 1004 kip.ft

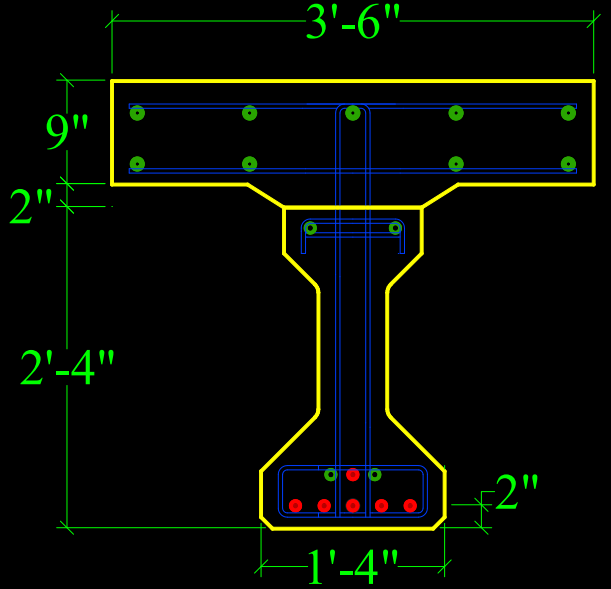


Initial prestressing force = 287 kip/beam

Nominal moment capacity (M_n) = 1292 kip.ft

Ø = 0.85 (Ductile failure)

Resistance Moment capacity ($ØM_n$) = 1098 kip.ft



Initial prestressing force = 264 kip/beam

Nominal moment capacity (M_n) = 1114 kip.ft

Ø = 1.0 (Tension controlled)

Resistance Moment capacity ($ØM_n$) = 1114 kip.ft

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Limit State Testing of 0.6″ Steel Prestressed Beam

Limit State Testing of 0.7″ CFCC Prestressed Beam

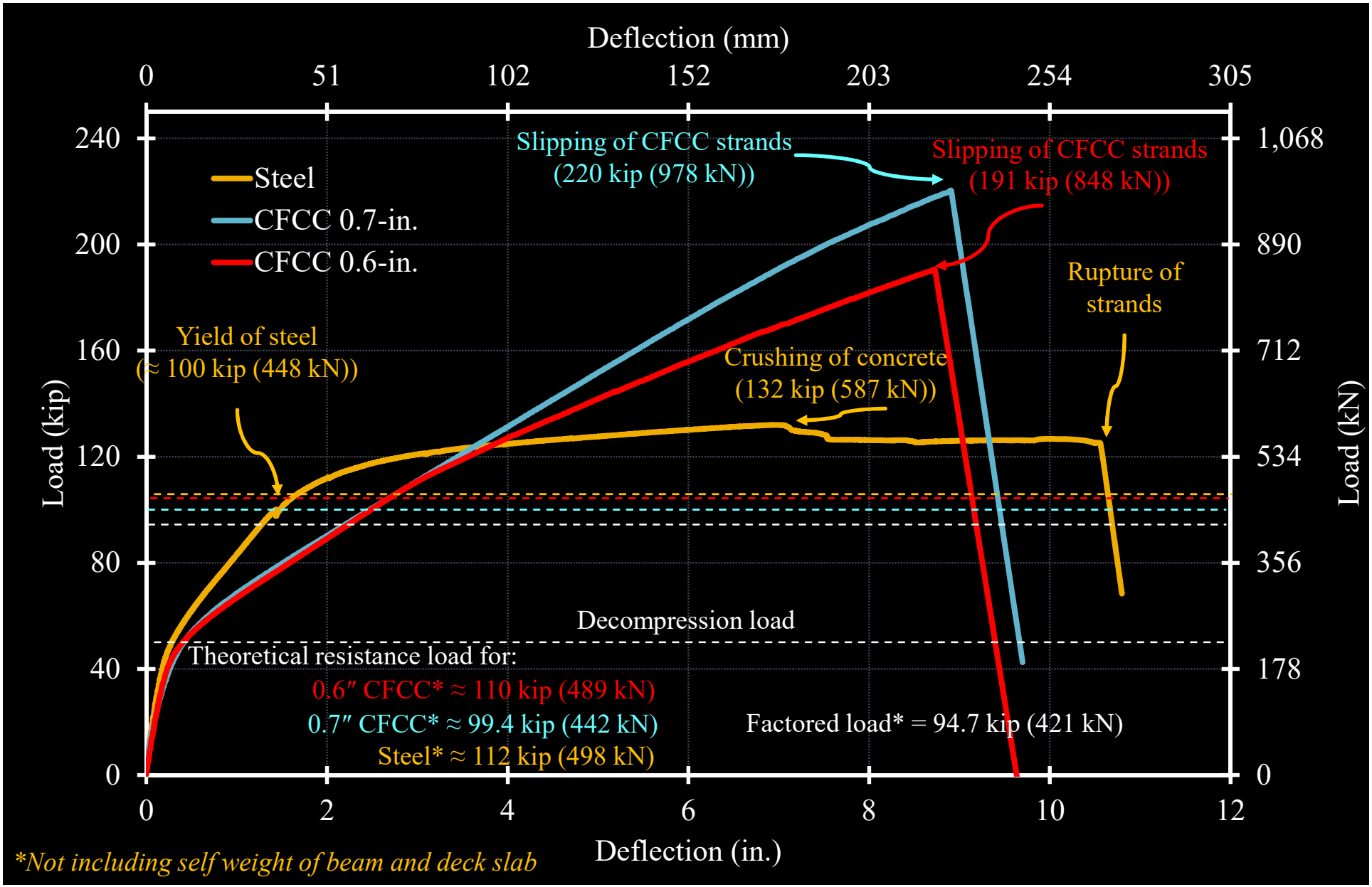
Failure of 0.7″ CFCC Prestressed Beam

Cracks at the soffit

Failure of 0.7″ CFCC Prestressed Beam

Rupture of the prestressing strands at failure after chiseling out concrete

Load vs. Mid-span Deflection of Three Beams

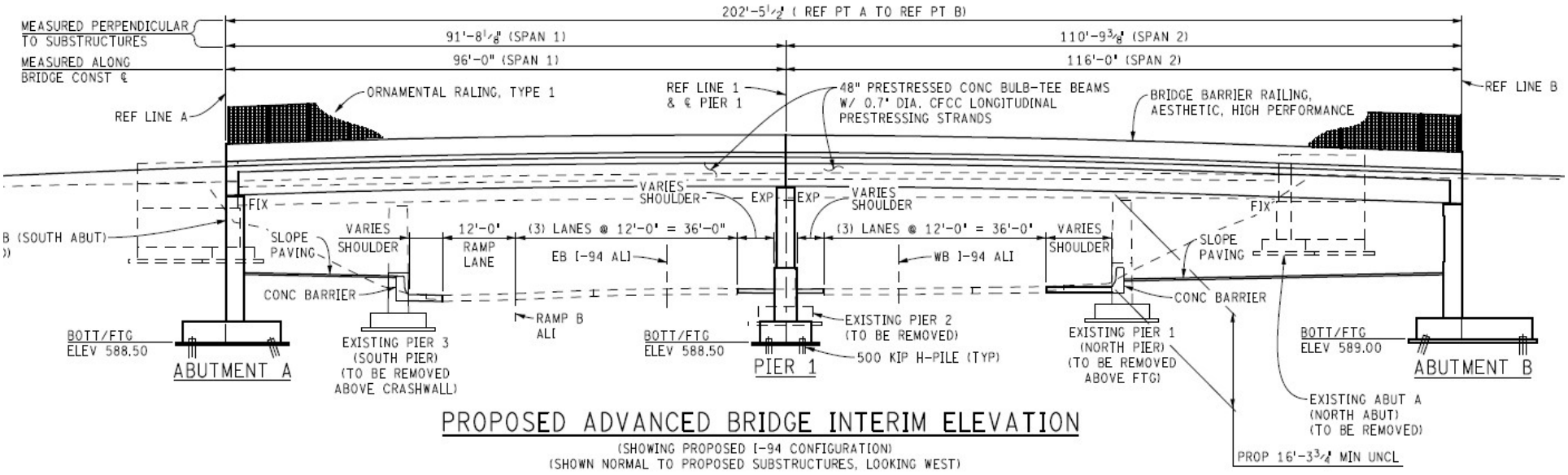


**Not including self weight of beam and deck slab*

Bridges in Michigan with 0.7″ CFCC Strands

Cadillac Ave. Bridge over I-94	Detroit	2021
Burns Ave. Bridge over I-94	Detroit	2021

Cadillac Ave. Bridge over I-94 (Design Phase)

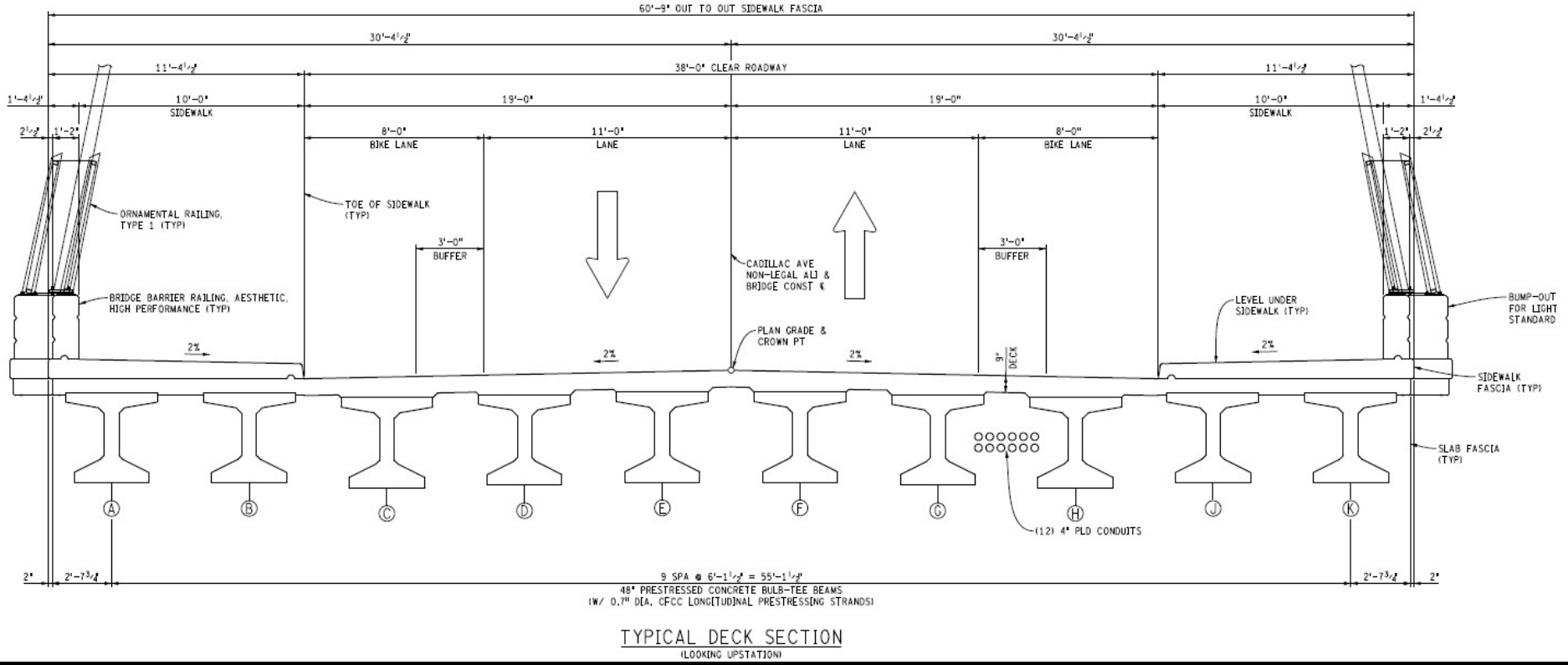


PROPOSED ADVANCED BRIDGE INTERIM ELEVATION

(SHOWING PROPOSED I-94 CONFIGURATION)
(SHOWN NORMAL TO PROPOSED SUBSTRUCTURES, LOOKING WEST)

Span 1: 96 ft (29.3 m) Span 2: 116 ft (35.4 m)

Cadillac Ave. Bridge over I-94 (Design Phase)



TYPICAL DECK SECTION
(LOOKING UPSTATION)

Proposed: Ten 48" (1220 mm) bulb T beams with 0.7" (17 mm) CFCC strands

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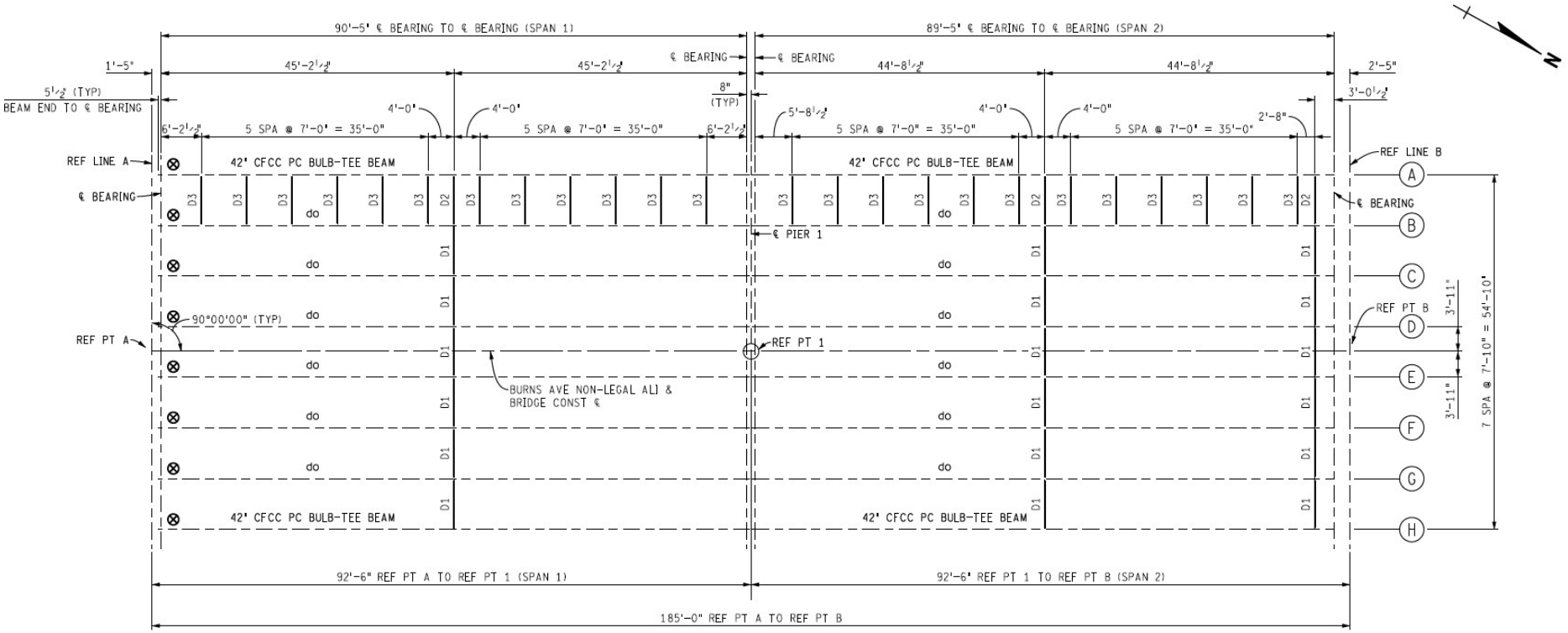
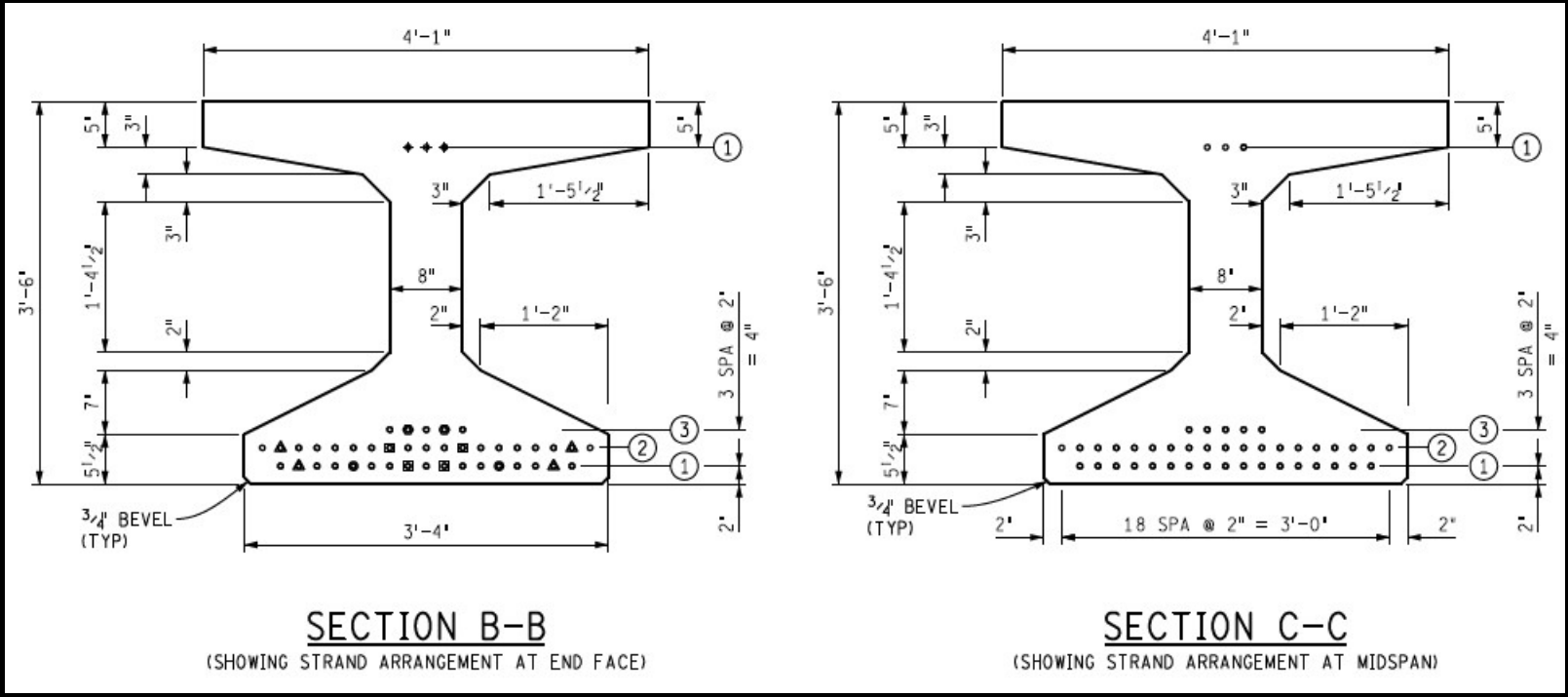
Burns Ave. Bridge over I-94 (Design Phase)



ERECTION DIAGRAM

Burns Ave. Bridge over I-94 (Design Phase)



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Design Updates (2019/2020)

	Steel strands	CFCC strands	CFCC strands
Diameter ($in.$)	0.6	0.6	0.7
Cross sectional area ($in.^2$)	0.217	0.179	0.234
Ultimate/guaranteed strength (ksi)	$f_u = 270$	**$f_{gu} = 370$ (66 kip/strand)**	**$f_{gu} = 370$ (86 kip/strand)**
Environmental reduction factor	1.0	0.9	0.9
Allowable prestressing stress immediately before transfer (f_{pbt}) or jacking stress (f_j)	AASHTO LRFD ($f_{pbt} \leq 0.75\, f_u$)	MDOT Guide **($f_{pbt} \leq 0.75\, f_{gu}$)**	MDOT Guide **($f_{pbt} \leq 0.75\, f_{gu}$)**
Allowable f_{pbt} (ksi)	202.5 (44 kip/strand)	277.5 (49.7 kip/strand)	277.5 (65 kip/strand)
Including environmental reduction factor of 0.9	44 kip/strand	44.7 kip/strand	58.5 kip/strand
No. of prestressing strands	100	98	75
Allowable Conc. tension under Service III Limit State (ksi)	$0.19\sqrt{f_c'}$	0	0

Center for Innovative Materials Research (CIMR)

QUESTION !!

Thank you

Limit State Testing of 0.6″ CFCC Prestressed Beam

Design Guidelines in 2017

	Steel strands	CFCC strands
Diameter ($in.$)	0.6	0.6
Cross sectional area ($in.^2$)	0.217	0.179
Ultimate/guaranteed strength (ksi)	$f_u = 270$	$f_{gu} = 339$
Environmental reduction factor	1.0	0.9
Allowable prestressing stress immediately before transfer (f_{pbt}) or jacking stress (f_j)	AASHTO LRFD ($f_{pbt} \leq 0.75\, f_u$)	*Dated limit* ACI 440-4R-04 ($f_j \leq 0.65\, f_{gu}$)
Allowable f_{pbt} or f_j (ksi)	202.5 (44 kip/strand)	220 (39.4 kip/strand)
Including environmental reduction	44 kip/strand	35.5 kip/strand
No. of prestressing strands	100	124
Allowable concrete tension under Service III Limit State (ksi)	$0.19\sqrt{f_c'}$	0

Failure of 0.6" CFCC I-Beam

Extensive spalling of concrete after 24 hours of fire test