Prestress Losses in UHPC and Hybrid Precast, Prestressed Bridge Girders

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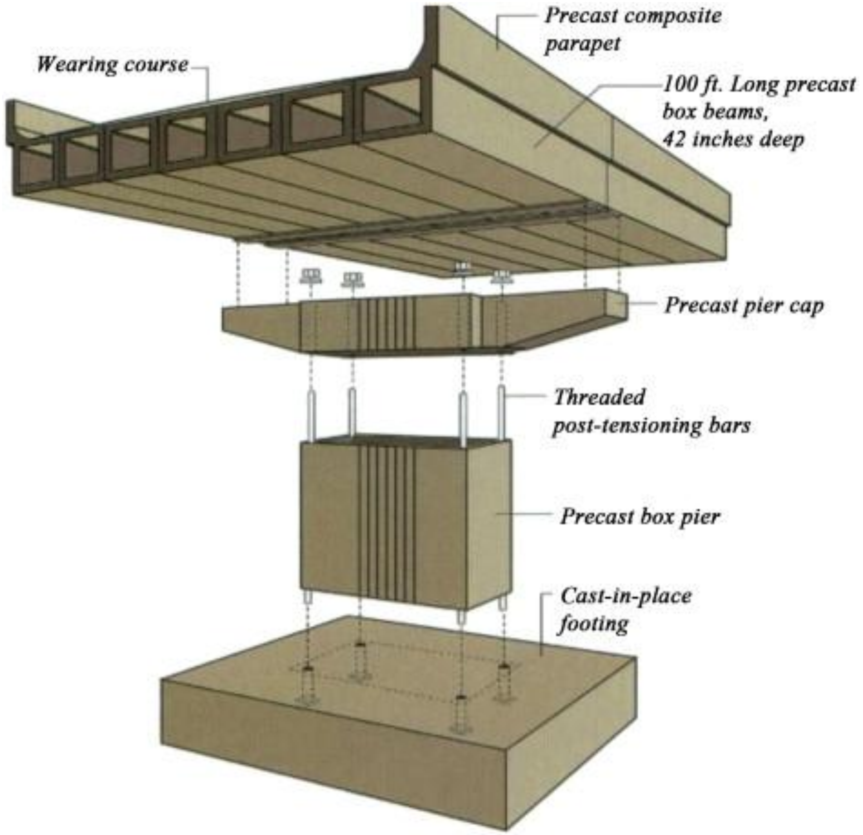
Outline

1. Introduction
2. Literature Review
3. Research Objectives
4. Approach & Methodology
5. Construction of Specimens
6. Results
7. Conclusions
8. Future Work

Introduction

Accelerated Bridge Construction (ABC)

- Prefabricated elements
- Advantages:
  - Site constructability
  - Traffic flow
  - Work zone safety
  - Project delivery time



(Photo courtesy of FHWA.)

Precast Prestressed Concrete Bridge Girders

- Cast offsite in a precast yard
- Typically pre-tensioned
- Cross-sections are standardized
  - Formwork is reused
  - Tendons stressed between bulkheads
- Concrete cast around tendon
- Prestress transferred when sufficient strength is achieved

Courtesy of Arkansas Department of Transportation

Design Consideration for Pre-tensioned Girders

- End region stresses
  - Concentrated forces from prestressing
  - Potential cracking
  - Transfer length
- Prestress losses
  - Immediate losses
  - Time-dependent losses
  - Heavily dependent on the concrete
- Shear Capacity

(Morcous et al. 2011)


(Okumus and Oliva 2013)

Motivation

- Bridge Joint Deterioration

Bridge Expansion Joint with Damage to Steel Armoring (Photo courtesy of Walt Peters, ODOT)

Bridge Expansion Joint with Offset on Both Sides of the Joint (www.toledoblade.com/local/2011/07/08/Defective-bridge-expansion-joint-causes-I-75-delays.html)

Motivation

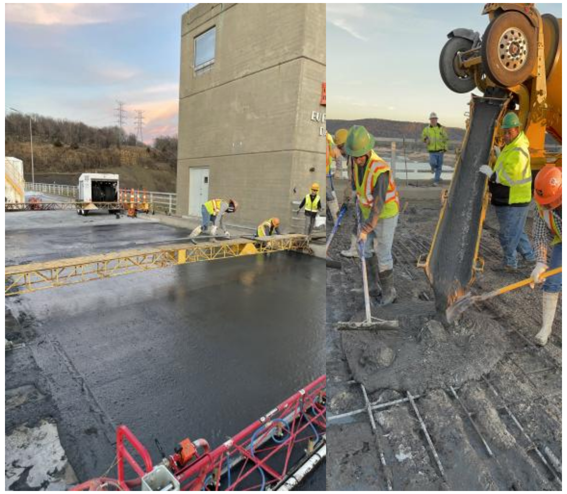
- End Region Deterioration

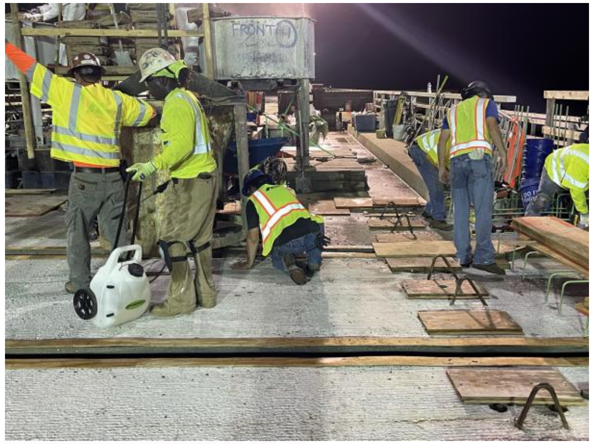
Spalling Along End Region Reinforcement in In-Service Prestressed Concrete Girder (Photo by Royce Floyd)

Spalling Around Prestressing Strand Ends in In-Service Prestressed Concrete Girder (Photo by Royce Floyd)

Ultra-High Performance Concrete (UHPC)

- High durability & strength
- Low permeability
- Freeze-thaw resistance
- Common Applications:
  - Bridge deck panel connections
  - Precast concrete elements
  - Expansion joints
  - Overlays





UHPC Placement for an Overlay and Precast Panel Connection (Eufaula Spillway Bridge, Oklahoma 2021 & 2023)

UHPC Prestressed Bridge Girders

- Innovative girder designs for mitigating high end region stresses
- High compressive and tensile strength
- Reduced crack width
- High cost

UHPC Precast Prestressed Concrete Girder (Steellike Concrete)

Hybrid UHPC-Conventional Concrete Prestressed Bridge Girders

- Potential solution
  - Cost saving
  - Efficient use of material
- UHPC only used at end regions
- Concerns
  - Continuity at interface
  - Construction
  - Overall girder behavior

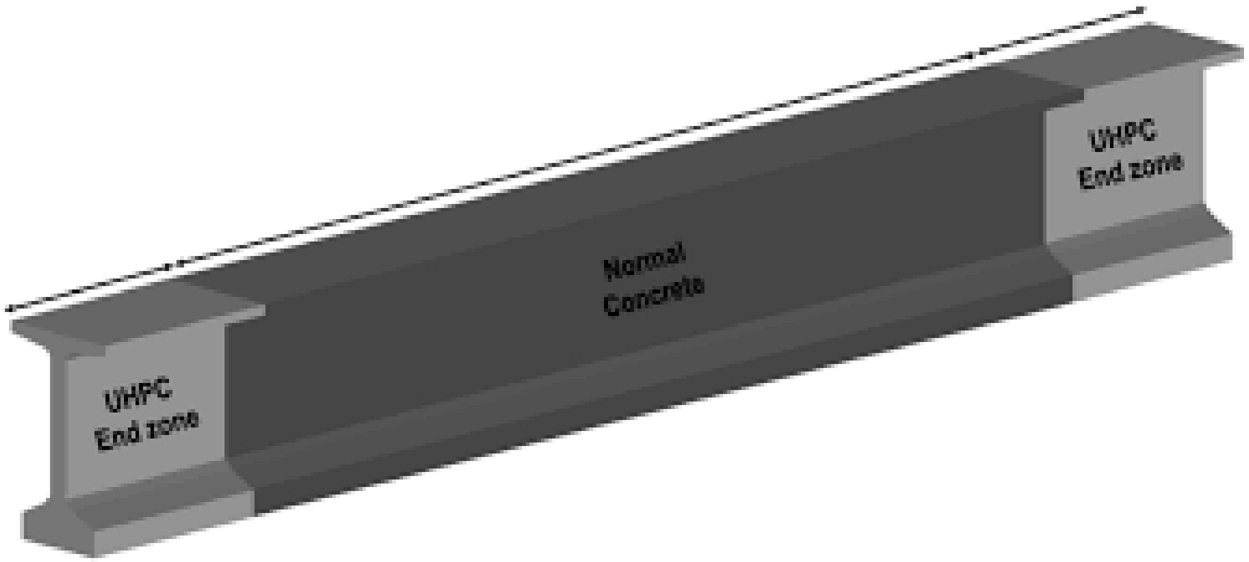


Illustration of Hybrid UHPC-Conventional Concrete Girder (Salah et al. 2023)

Literature Review

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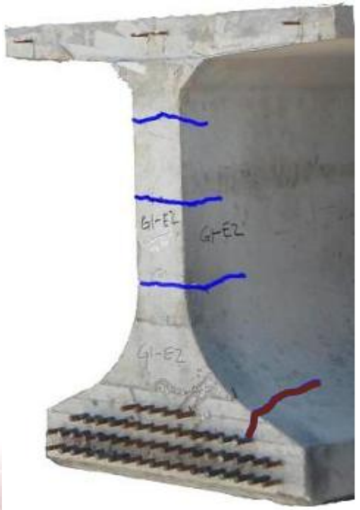
End Region Detailing for Crack Mitigation and Stress Limits

- Ross et al. 2013 & Ronanki et al. 2017
  - Evaluated end zone detailing
  - Impact on potential cracking
  - Finite element models for behavior prediction

Examples of End Region Cracking (Ronanki et al. 2017)



(Ross et al. 2013)

UHPC Prestressed Girders

- Graybeal 2006
  - Evaluated UHPC prestressed girders in flexure, shear and bond
  - High compressive and tensile strength
  - Longer span and less shear reinforcement
- Mohebbi and Graybeal 2022
  - Investigated long-term behavior of UHPC girders
  - Finite element model that matches with data

Load Test of UHPC Prestressed Concrete Girder(Graybeal 2006)

Hybrid UHPC-Conventional Concrete Prestressed Girders

- Li et al. 2020
  - Composite prestressed UHPC-Normal concrete T-girders
  - Analytical model to simulate flexural properties
- Choate et al. 2023
  - Shear behavior of hybrid beams
  - Continuity across the interface

UHPC to Conventional Concrete Interface after Testing (Li et al. 2020)

UHPC Stay-in-Place Formwork

- Limited research
- Similar concept by Azizinamini and Khodayari 2023
  - 3D-printed UHPC shell as stay-in-place formwork
  - Bridge columns

3D Printed UHPC Column Shell (Azizinamini and Khodayari 2023)

Prestress Losses of Full UHPC and Hybrid UHPC-Conventional Concrete Prestressed Girders

- Limited research on long-term behavior
- Mohebbi and Graybeal 2022
  - Detailed measurement and prediction of prestress losses for full UHPC girders
- Ammari and Ahlborn 2023
  - Thermal treatment
  - Improving time-dependent behavior

Research Objectives

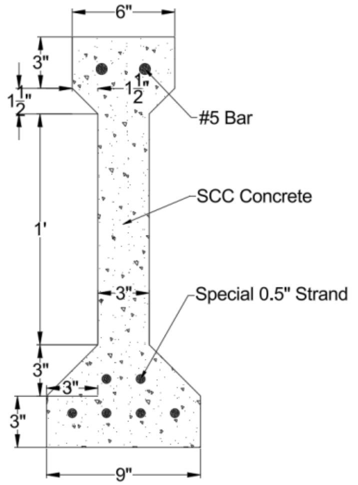
Research Objectives

- Measure prestress losses for half-scale AASHTO Type II UHPC prestressed bridge girders
- Investigate the effect of a hybrid UHPC-conventional concrete girder design on prestress loss behavior
- Evaluate the effectiveness of different design details for mitigating stresses in the girder end region and their effect on hybrid girder capacity

Approach & Methodology

Design Approach

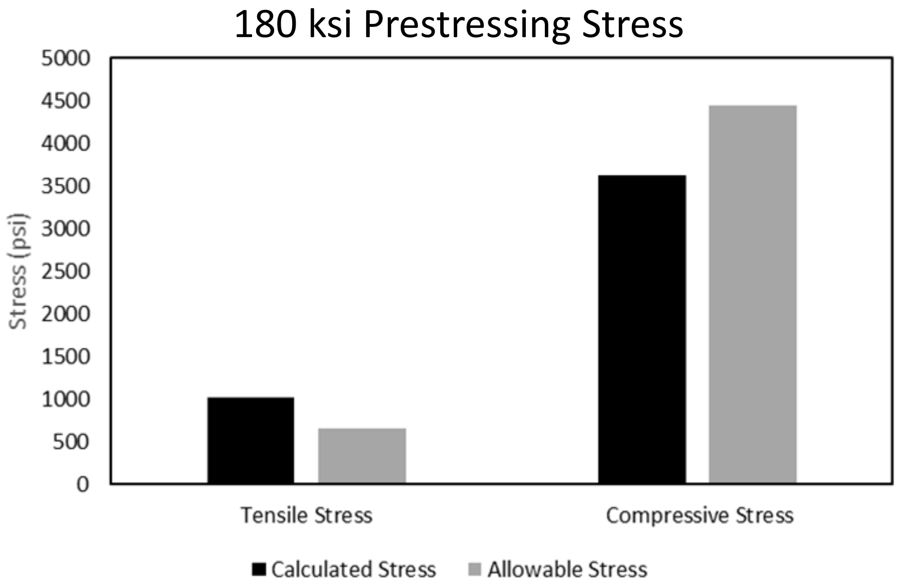
- Existing formwork
  - Approximately half-scale AASHTO Type II girders
  - 18 ft & 14 ft long
- Allowable stresses
  - Conventional concrete girder
  - AASHTO LRFD Bridge Design Specifications (2020)
  - 180 and 202.5 ksi prestressing stresses

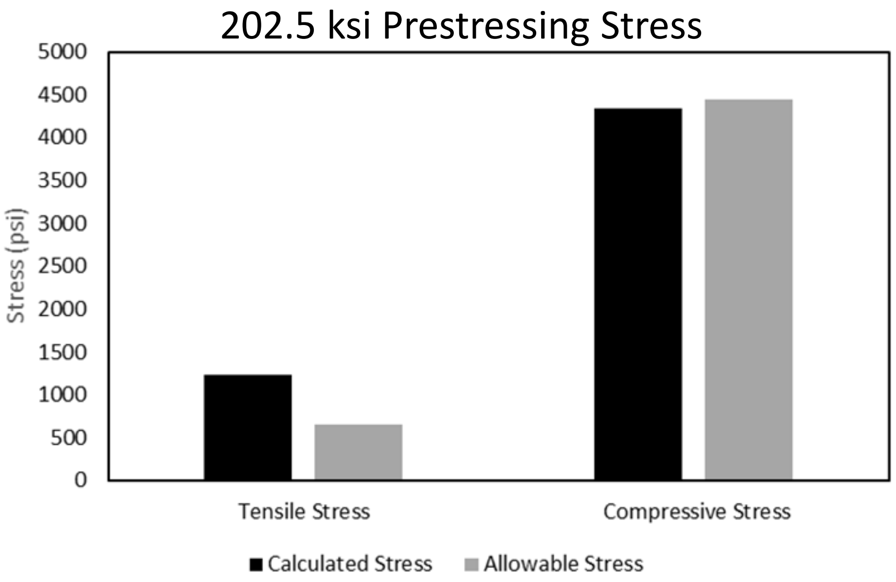


Test Specimen Cross-Section and Reinforcement

Design Approach

- Calculated vs Allowable concrete stresses
  - At release and f'_{ci} = 7,400 psi
  - Tensile stress exceeds allowable stress
  - Top steel reinforcement





Design Approach

- Self-Consolidating Concrete (SCC) & UHPC

SCC mix design (SSD)

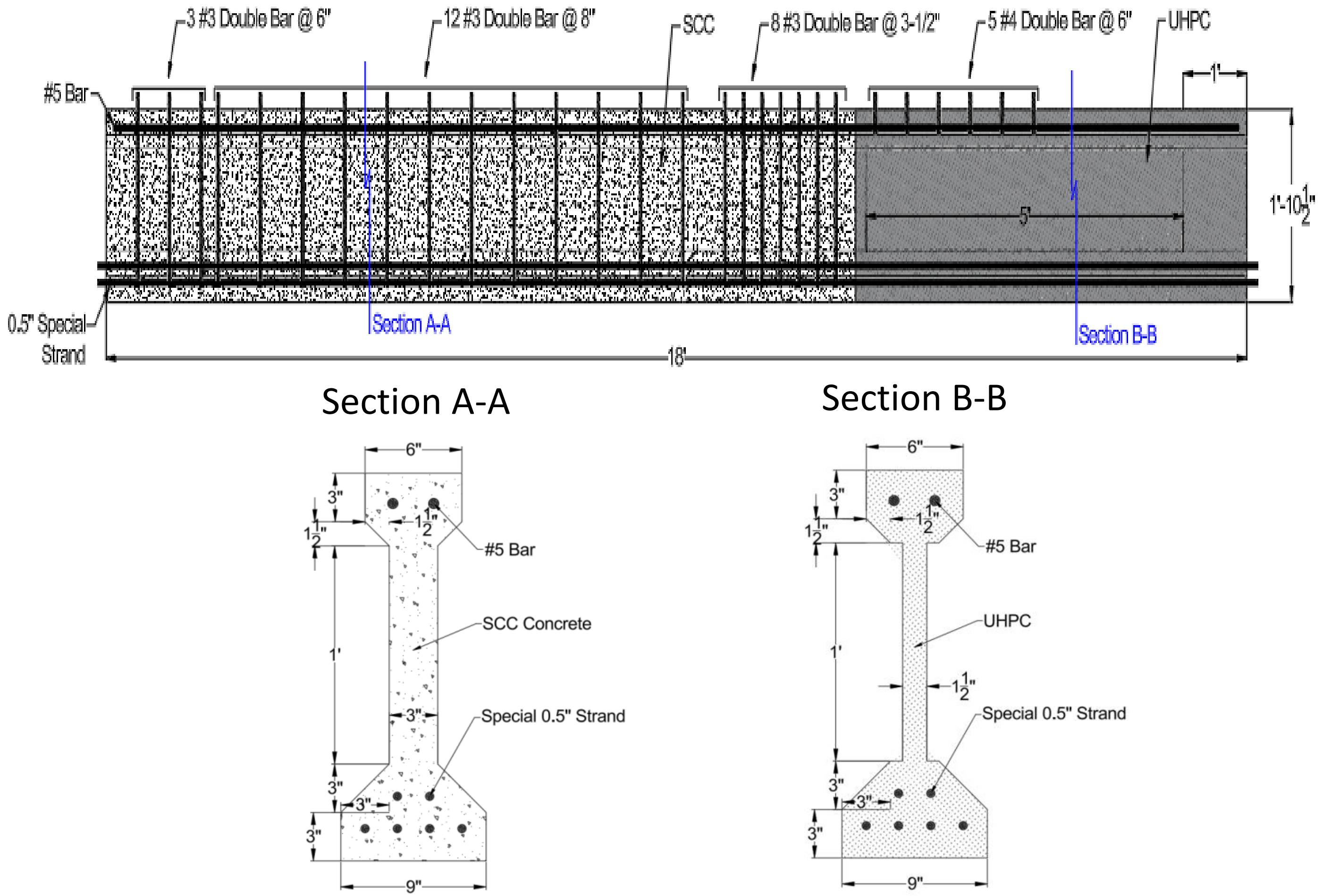
Constituent	Quantity
Sand (lb/yd^3)	1476
5/8 in. Coarse Aggregate (lb/yd^3)	1445
3/4 in. Coarse Aggregate (lb/yd^3)	-
Cement (lb/yd^3)	825
Water (lb/yd^3)	289
Adva Cast 575 HRWR Admixture (fl oz./cwt)	7-10

J3 UHPC Composition (weight ratios)

Constituent	Mix Proportion
Type I Cement	0.6
Silica Fume	0.1
Slag Cement	0.3
Masonry Sand (1:1 agg/cm)	1.0
w/cm	0.2
Steel Fibers	2% by volume
High Ranger Water Reducer Admixture	18-24 oz/cwt

Hybrid UHPC Prestressed Girders

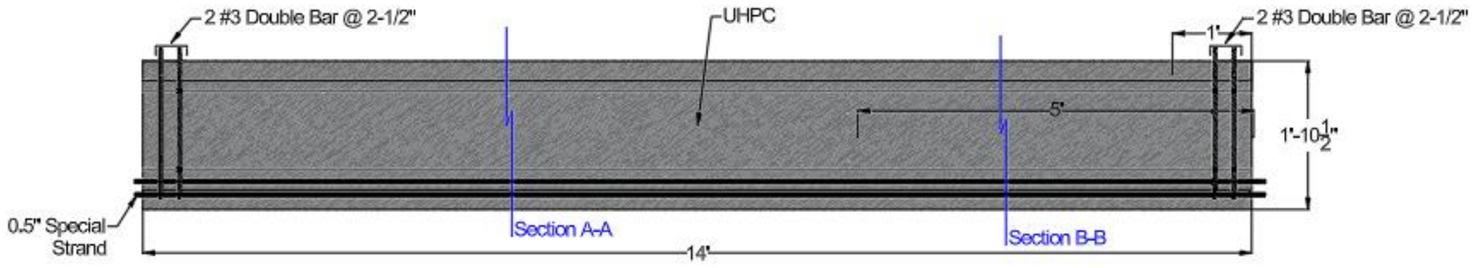
- Based on Choate (2023)
  - One End of UHPC and the rest SCC
  - Evaluate different end regions
  - 18 ft long
- Adequate shear reinforcement
  - Reduced web section at end region
- Bi-fluid interface
  - Showed excellent continuity



Design Details for Hybrid Beam Test Specimens

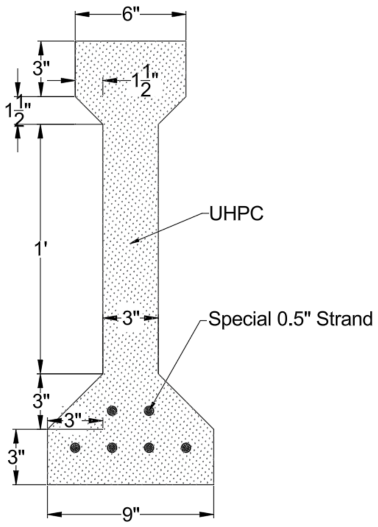
Full UHPC Prestressed Girders

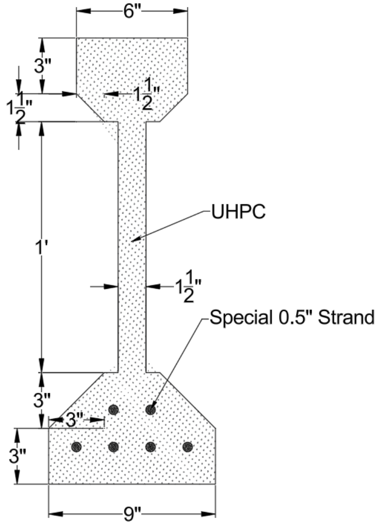
- No shear reinforcement
- Bursting reinforcement only
  - For end regions
  - Based on AASHTO Section 5.9.4.4
- 14 ft long
- In progress



Section A-A

Section B-B





Design Details for UHPC Beam Test Specimens

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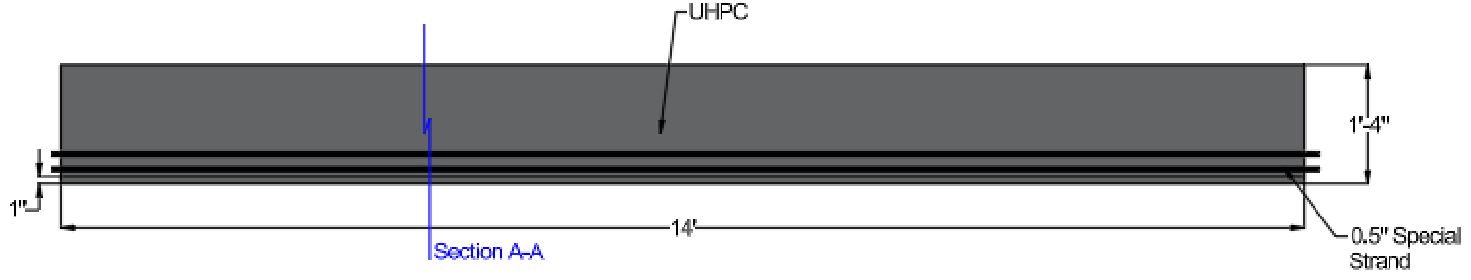
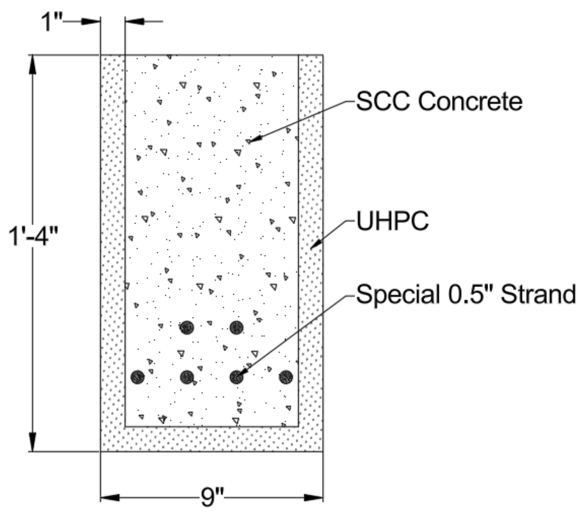
Stay-in-Place Formwork Prestressed Girders

- Rectangular section
  - 9 in. × 16 in.
  - Matching applied stresses of other beam specimens
- 14 ft long
- UHPC concrete shell
- SCC inside the shell
- In progress



Section A-A



Parameter Matrix

Specimen	Prestressing Stress (ksi)	Length of UHPC Reduced Web Thickness Section (ft)	Steel Fiber % by Volume	End Region Reinforcement
SCC	180	N/A	N/A	N/A
H-UHPC-SCC 1	180	5	2	N/A
H-UHPC-SCC 2	180	5	2	N/A
H-UHPC-SCC 3	202.5	5	2	N/A
H-UHPC-SCC 4	202.5	3	2	N/A
H-UHPC-SCC 5	180	3	2	N/A
UHPC 1	180	5	2	Min. rein.
UHPC 2	180	5	1	Min. rein.

Specimen Construction

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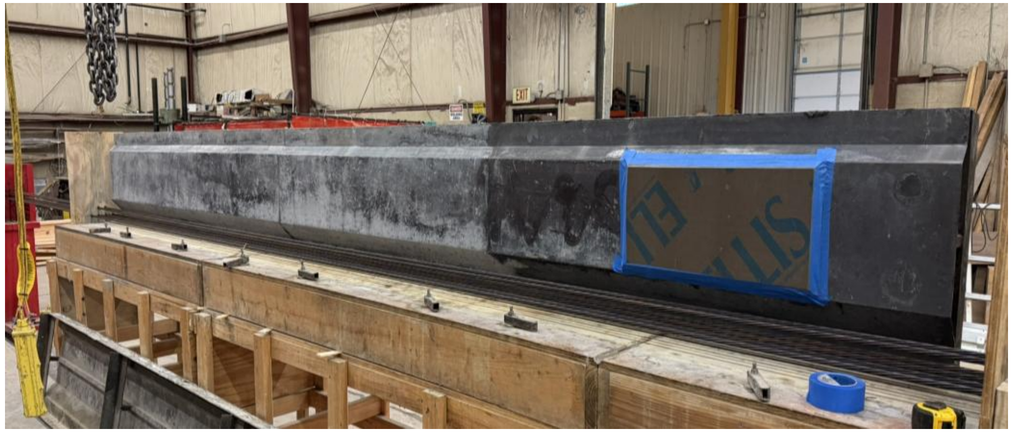
Hybrid UHPC Prestressed Girders

Formwork Side with 5 ft Web Insert in Place

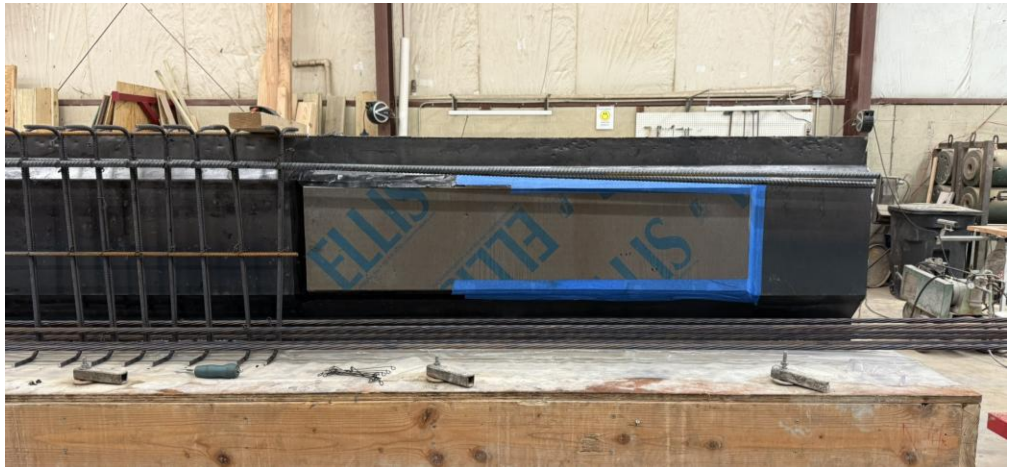
Formwork Side with 5 ft Web Insert and Reinforcement in Place



Formwork Side with 3 ft Web Insert in Place

Formwork Side with 3 ft Web Insert and Reinforcement in Place

Hybrid UHPC Prestressed Girders



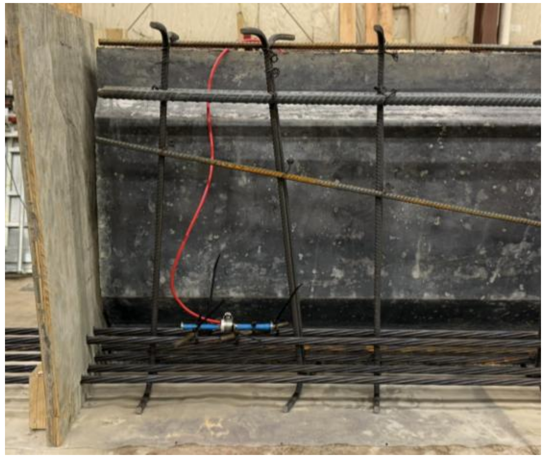
Close-up of 5 ft Web Insert with Reinforcement in Place

Close-up of 3 ft Web Insert with Reinforcement in Place

Hybrid Girder Specimen Layout on Prestressing Bed

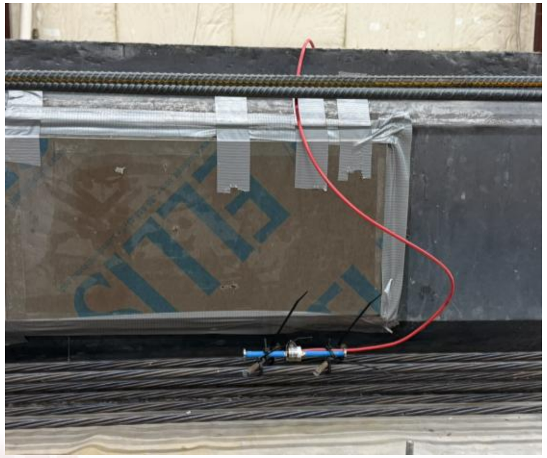
Hybrid UHPC Prestressed Girders

- Instrument placement
  - Three vibrating strain gauges



Strain Gauge in SCC End Region

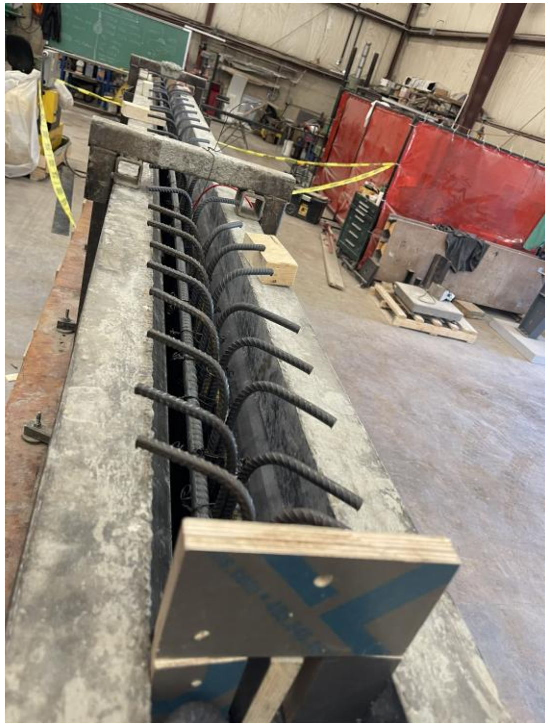
Strain Gauge at Mid-Span



Strain Gauge in UHPC End Region

Hybrid UHPC Prestressed Girders

- Complete formwork



SCC-UHPC Divider in Formwork

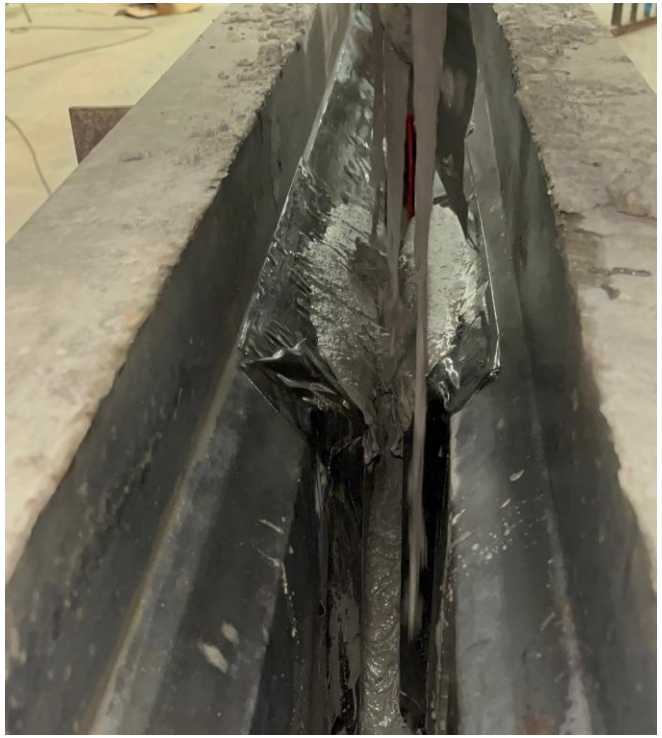
Completed Girder Specimen Formwork

Completed Formwork End View

Hybrid UHPC Prestressed Girders

- Casting Procedure
  - SCC and UHPC placed simultaneously
  - Flow rate continuously monitored
  - Divider was removed immediately after casting

SCC placement



J3 UHPC placement at the reduced web section

Hybrid UHPC Prestressed Girders

- Complete specimen

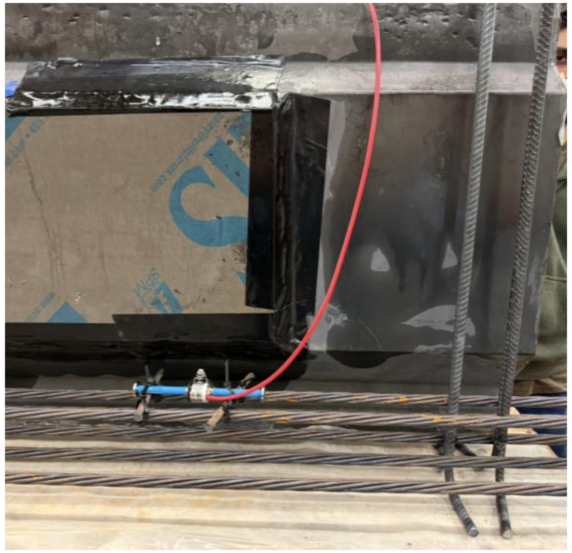
Completed Hybrid Specimen Showing Intermixing of SCC and UHPC

UHPC-SCC Interface After Casting

Full UHPC Prestressed Girders

- Similar construction process
- Same instrumentation
- Bursting reinforcement
- Reduced girder length

Formwork Side with UHPC Girder Reinforcement in Place



Strain Gage and End Region Reinforcement at Reduced Web Section

Full UHPC Prestressed Girders

- Complete specimen

UHPC Placement

Reduced Web Section End Region

Completed UHPC Girder Specimen

Stay-in-Place Formwork Prestressed Girders

- Trial specimens
  - Two 8 in. × 8 in. MORs
  - Evaluate bonding between concretes
    - Smooth vs grooved inserts
    - UHPC casted before SCC

Smooth Formwork Insert

Grooved Formwork Insert

Stay-in-Place Formwork Prestressed Girders

- UHPC shells
  - Thickness of 1 in.

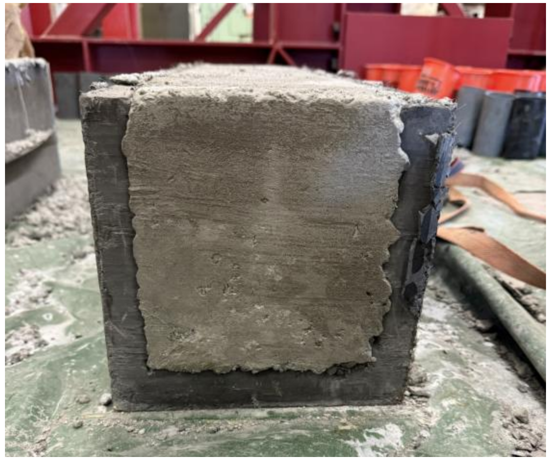
Formwork for Smooth Interface Shell

Formwork for Grooved Interface Shell

Grooved Interface Shell

Stay-in-Place Formwork Prestressed Girders

- Complete trial specimen


End View of UHPC Shell Specimen


Completed UHPC Shell Specimens

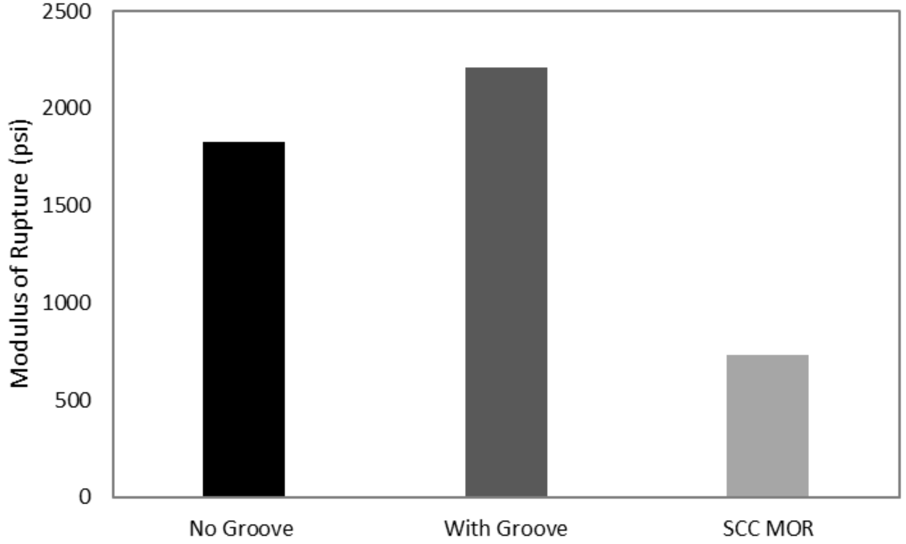
Results

Bonding Behavior of Concrete Shells

- Four-point testing
- Evaluate behavior
  - Excellent bonding
  - MOR compared to SCC MOR of f'c = 9,500 psi

Cracking of UHPC Shell Specimen Under Load

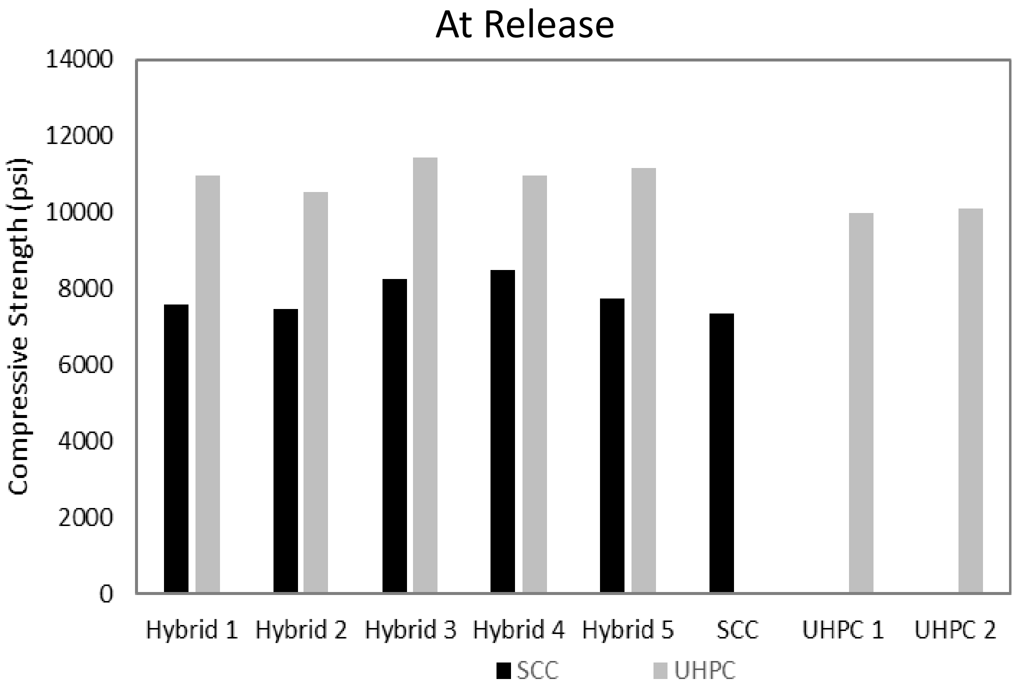
Fracture of UHPC Shell Specimen at Failure

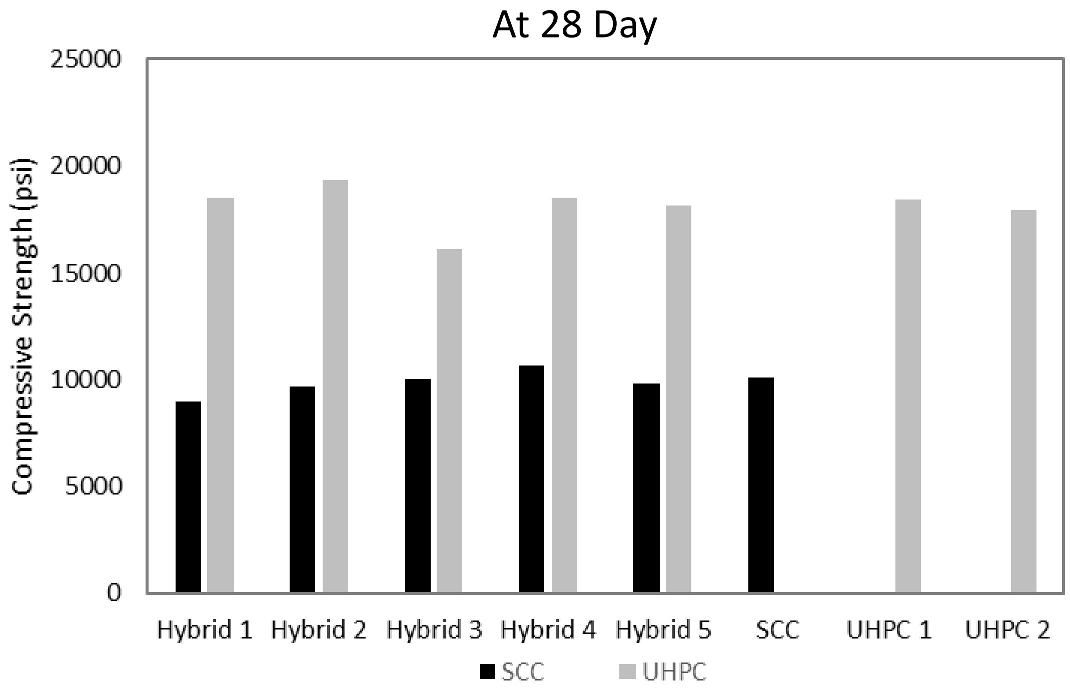


Failure Stress Comparison for UHPC Shell Specimens

Compressive Strength of Concretes

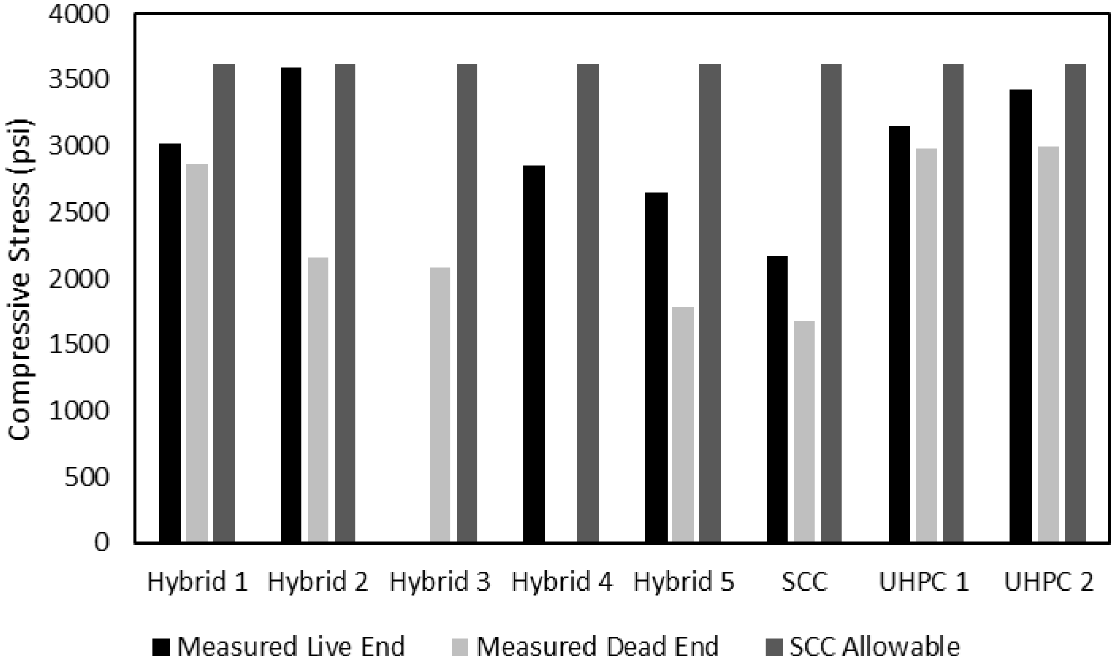
- Measured at prestress release and 28 days





Concrete Compressive Stress

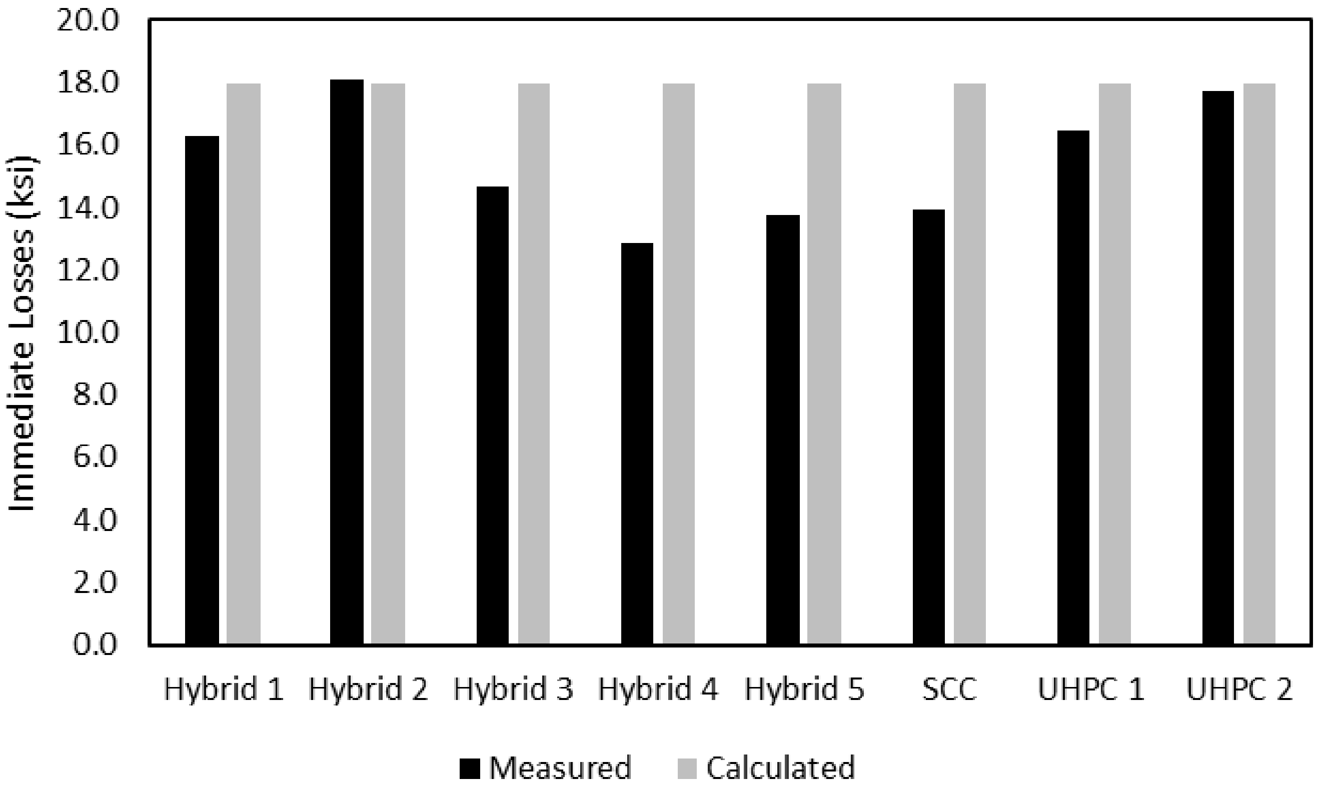
- At release
  - $E_{ci\text{-}uhpc}$ based on Graybeal equation (Russell and Graybeal 2013)
  - Compared to allowable stresses (AASHTO LRFD BDS 2020)
  - UHPC allowable = 6,400 psi
  - Obtained from measured strain



Concrete Compressive Stress Determined from Measured Strain

Prestress Losses

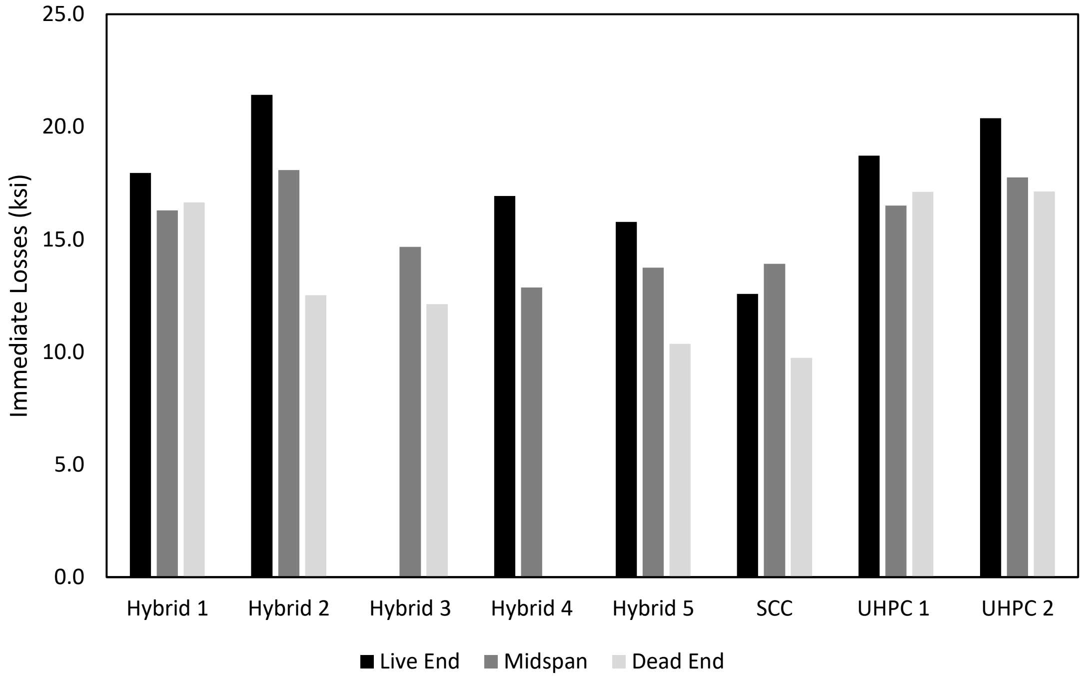
- Immediate Losses at Midspan
  – Prestress released 2 days after casting
  – Elastic shortening
  – Compared to AASHTO Refined Method



Comparison of Measured and Calculated Elastic Shortening at Midspan

Immediate Prestress Losses

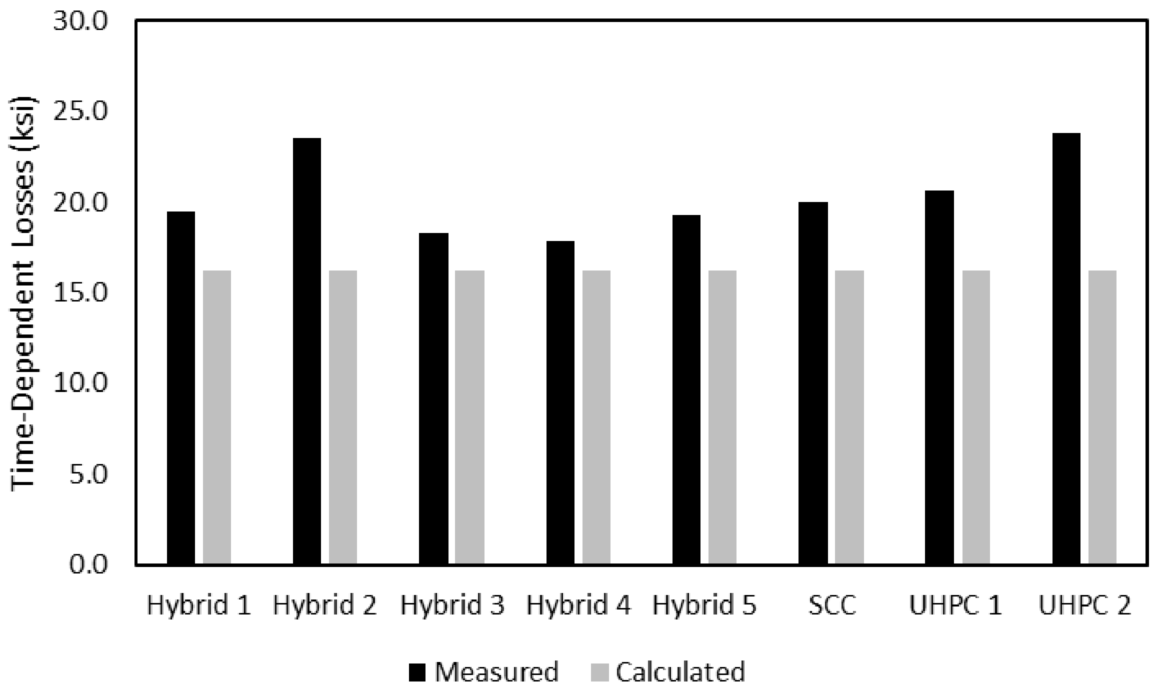
- End Regions vs Midspan
  - Elastic shortening



Comparison of Measured Elastic Shortening at Midspan and the End Regions

Time-Dependent Prestress Losses

- Creep & Shrinkage at midspan
  - At 35 days



Comparison of Measured Creep and Shrinkage Losses at Midspan 35 days after Prestress Release

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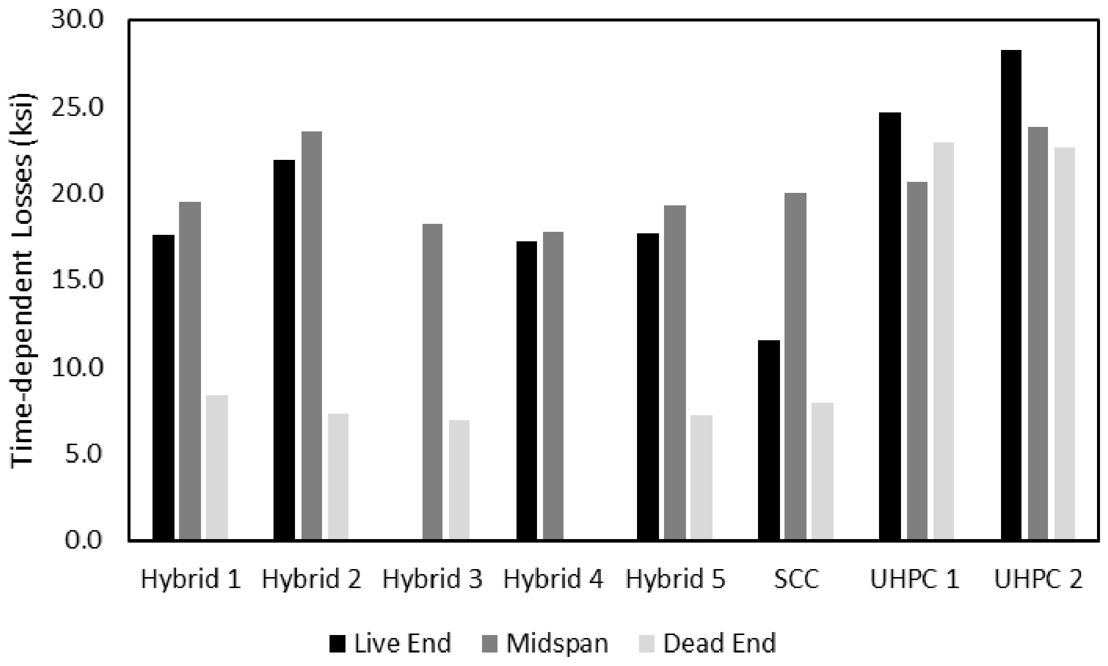
Time-Dependent Prestress Losses

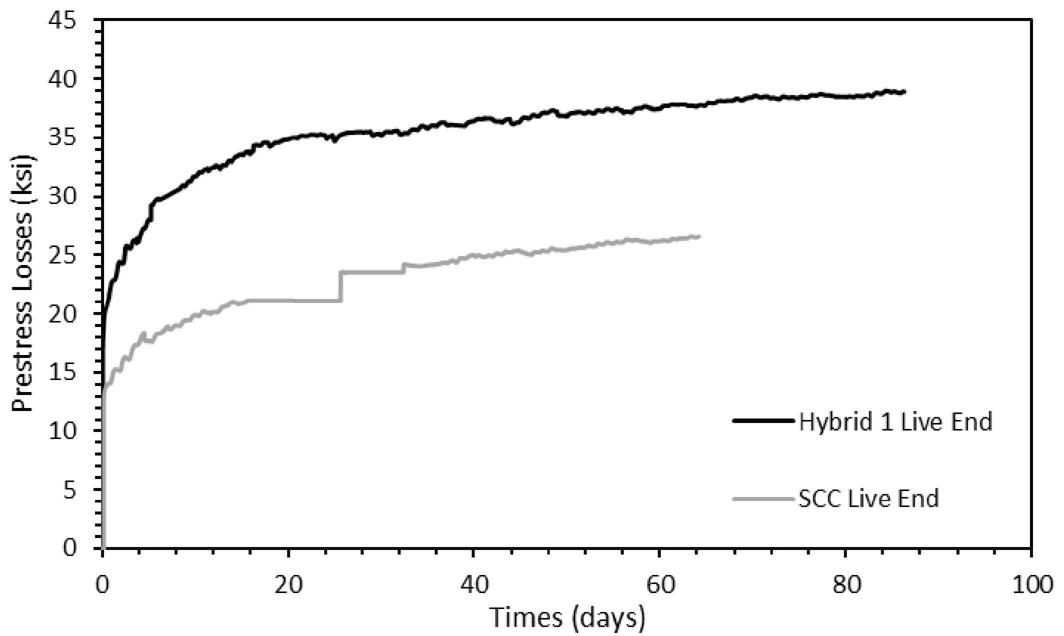
- End Regions vs Midspan
  - At 35 days



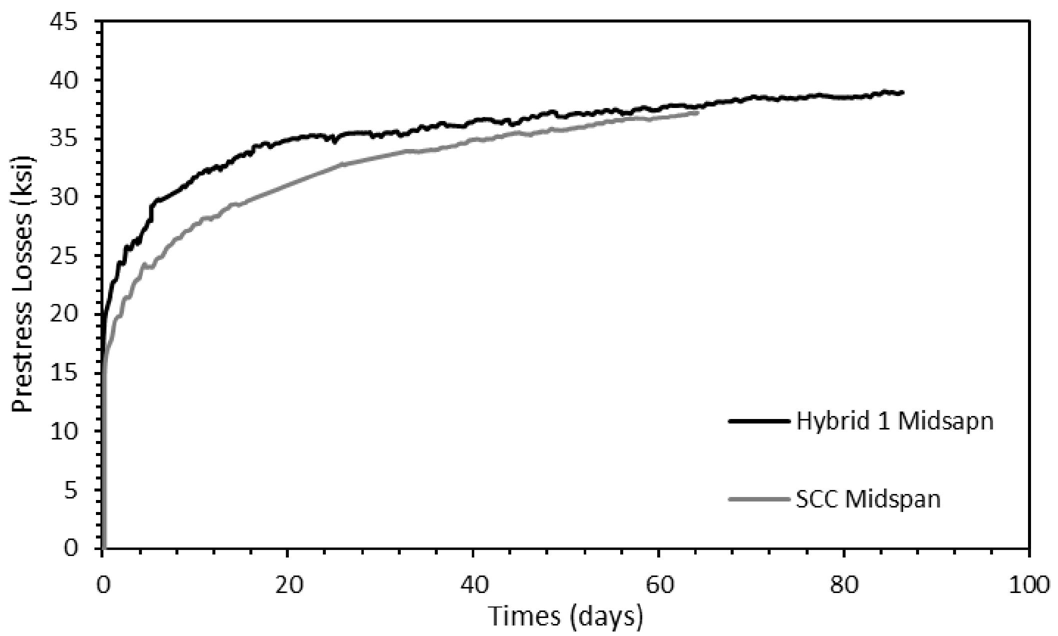
Comparison of Measured Creep and Shrinkage Losses at Midspan and End Regions 35 days after Prestress Release

Overall Behavior

- H-UHPC-SCC 1 vs SCC girders



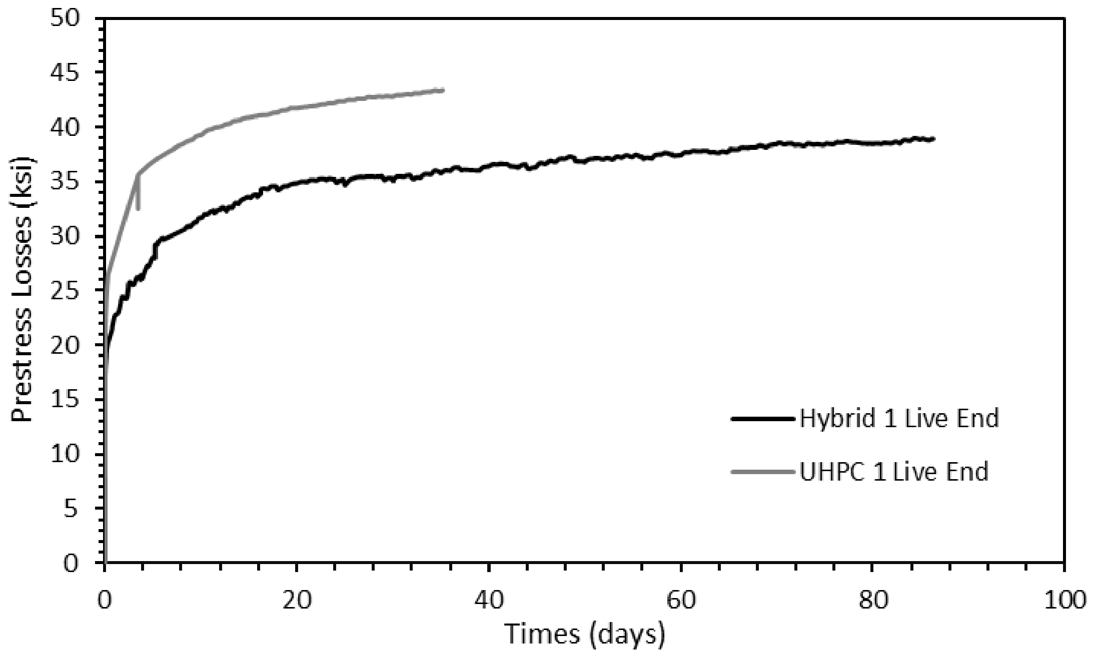
Measured Prestress Losses Over Time for one Hybrid and one SCC Girder at the End Region Nearest Prestress Release



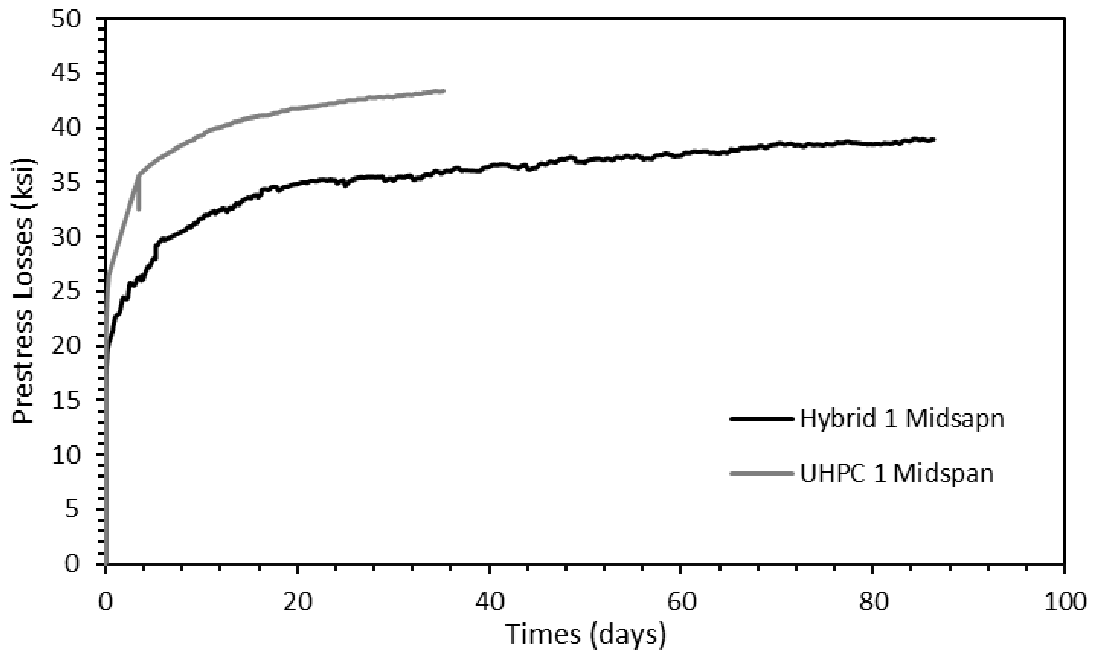
Measured Prestress Losses Over Time for one Hybrid and one SCC Girder at Midspan

Overall Behavior

- H-UHPC-SCC 1 vs UHPC 1



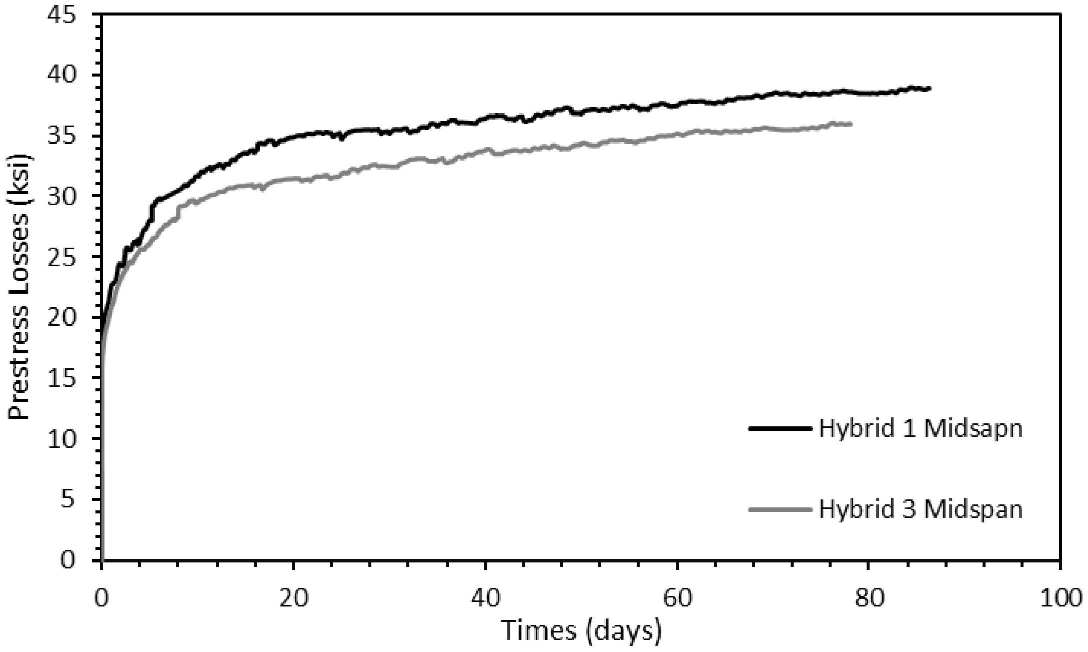
Measured Prestress Losses Over Time for one Hybrid and one UHPC Girder at the End Region Nearest Prestress Release



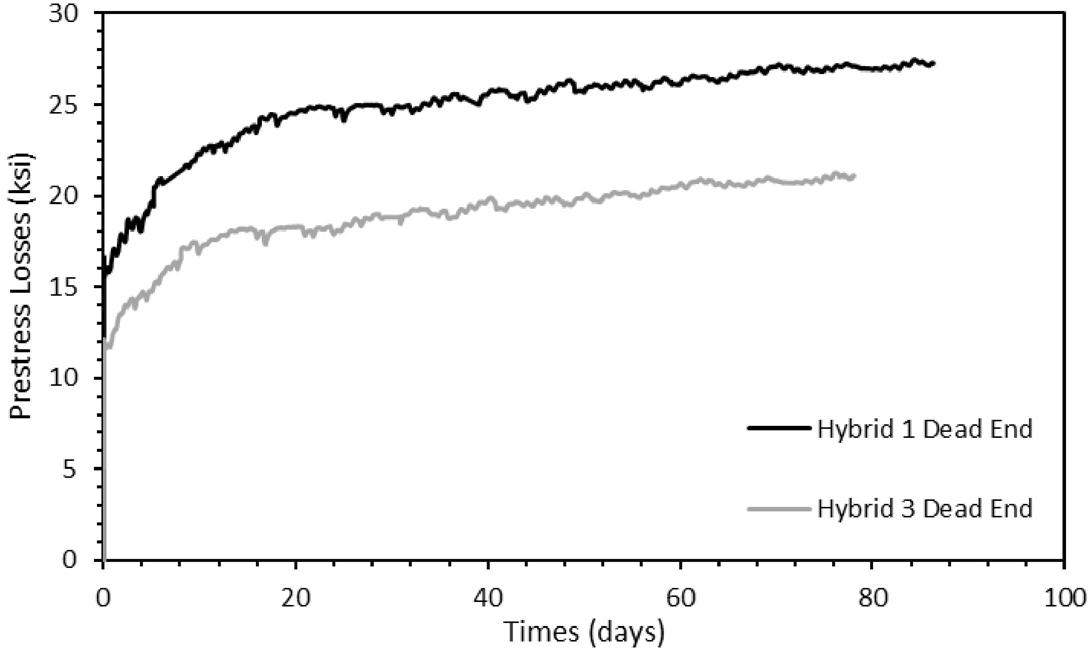
Measured Prestress Losses Over Time for one Hybrid and one UHPC Girder at Midspan

Overall Behavior

- H-UHPC-SCC 1 vs H-UHPC-SCC 3
  - Less prestress losses with 202.5 ksi prestressing stress



Measured Prestress Losses Over Time for one Hybrid Girder with 180 ksi Prestress and one with 202.5 ksi Prestress at Midspan



Measured Prestress Losses Over Time for one Hybrid Girder with 180 ksi Prestress and one with 202.5 ksi Prestress at the SCC End

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Conclusion

- The stay-in-place trial specimens showed good bonding between UHPC and SCC for both interface conditions.
- The placement of the hybrid prestressed girders with the Bi-fluid interface was successful.
- The UHPC end regions for all the hybrid prestressed girders followed the same trend, achieving higher stress compared to the SCC end regions.
- The midspan behavior of the hybrid prestressed girders was similar to that of the SCC prestressed girder.
- The length of the UHPC section in the hybrid prestressed girders did not appear to have an effect on the prestress loss behavior at midspan for those tested

Future Work

- The formwork of the UHPC concrete shells are currently under construction. Two girder specimens will be cast with different interfaces between the UHPC and SCC.

- Two full UHPC girders with 202.5 ksi prestressing stress will be constructed to investigate the prestress losses with higher prestressing stress and to evaluate different end region detailing.

- Deck placement will be done on all the girders, then they will be tested in shear to evaluate the performance and continuity of the composite girders. The shear testing will be conducted after taking the required time-dependent prestress losses measurements.

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Thank you!

Questions?