More Choices for Connecting Prefabricated Bridge Deck Elements

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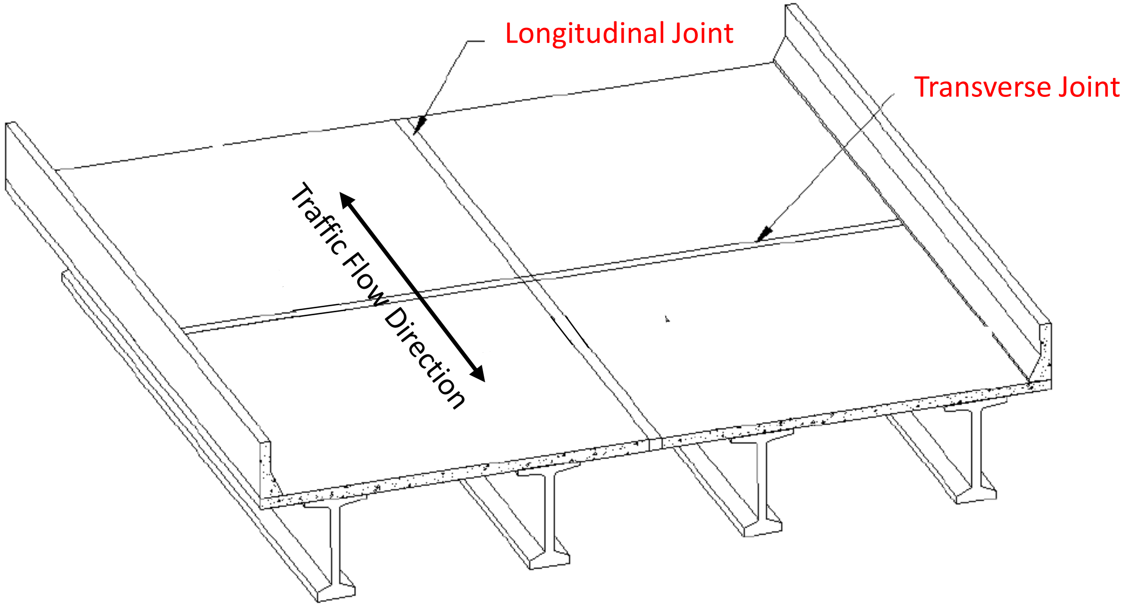
Outline

- Introduction
- Literature
- Experimental Program
- Results of Transverse Specimens
- Results of Longitudinal Specimens
- Conclusions

Introduction

- Prefabricating bridge elements and systems (PBES) → major time savings, cost savings, safety advantages, convenience for travelers
- Innovative PBES connections evolved and many of these connections use advanced materials (e.g. ultra-high performance concrete UHPC)
- Why advanced materials?

  1. Simplified reinforcement configurations
  2. Smaller joints
  3. Better joint interface bonding
  4. Better long-term durability



- One popular application

  → bridge deck field joints

Introduction

UHPC works for bridge deck joints, but…

- High material cost and limited availability
- Mixing and curing process complexity
- High early shrinkage
- Quality control for early strength characterization
- Special heat curing required for low temperatures
- Superior mechanical properties that may not be needed or critical in some applications, e.g. field joints in bridge decks

↓

Identify and proof-test potential alternatives to UHPC
(for precast bridge deck field joints)

Objectives

1. Explore alternative materials with less cost and high availability to replace UHPC for deck field joints (e.g. polymer concrete).
2. Characterize the material and mechanical properties of the selected alternative.
3. Conduct large-scale testing to study the response of the alternative material in the transverse and longitudinal field joints in precast bridge decks.

Literature

1. Alternative materials to replace UHPC

- Different materials have been searched as potential alternatives such as advanced grouts, Engineered Cementitious Composites (ECC) and polymer concrete (PC).
- Wide choices between different types of polymer concrete lead to use of a robust construction material named Poly methyl methacrylate polymer concrete (PMMA-PC)

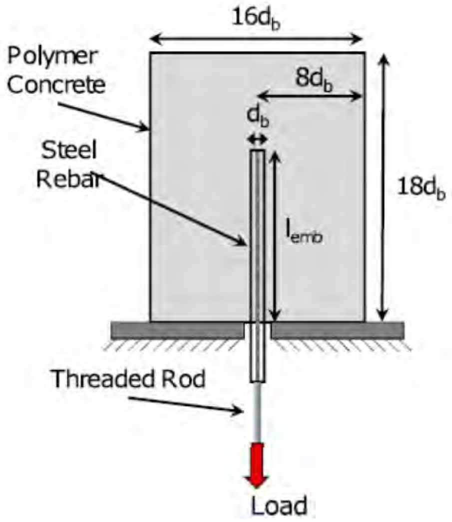
Compressive Strength	8000 – 9000 psi (55 – 62 MPa)	ASTM C579 Method B
Flexural Strength	1800 – 2500 psi (13-17 MPa)	ASTM D790
Linear Shrinkage	<0.2%	DuPont
Tensile Strength	1000 – 1200 psi (6.90-8.25 MPa)	ASTM D638 Type I
Compressive Modulus	1.1-1.2 x 10^6 (7.50-8.50 GPa)	ASTM C579 Method B
Tensile Adhesion (pull-off concrete)	>250 psi (>1.7 MPa)	ACI 503R

Literature

Polymer concrete (PC):

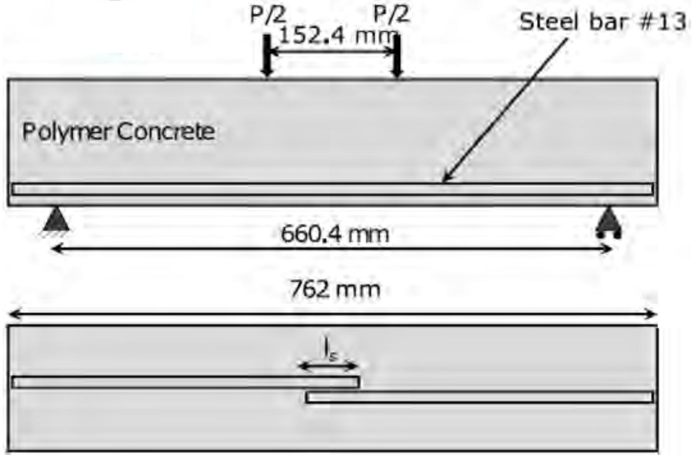
- High bond strength, high early strength, high shear strength, and adequate flowability.
- High durability with respect to cycles of freezing and thawing.
- Corrosion resistant, fast curing, very low permeability and superior cracking resistance.
- PMMA-PC beams have better fatigue strength than Portland cement concrete beams.

PMMA-PC: Mantawy et al. (2019)



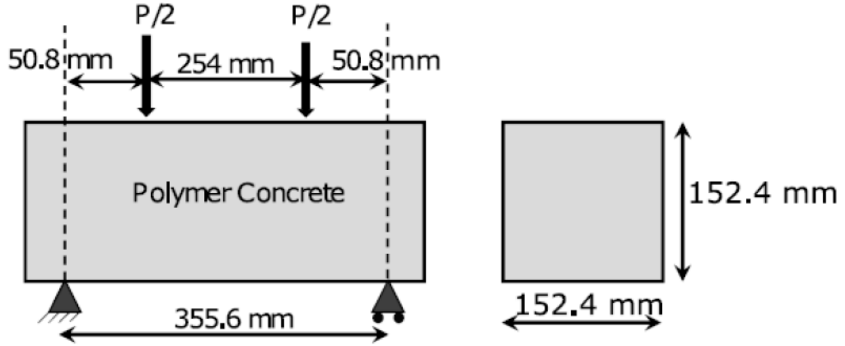
$L_{development}$ (PMMA-PC) = 3.6 to 4.1 d_b

$L_{development}$ (PMMA-PC) $\simeq$ ½ $L_{development}$ (UHPC)



L_{splice} (PMMA-PC) = 4.1 d_b

L_{splice} (PMMA-PC) < L_{splice} (UHPC)



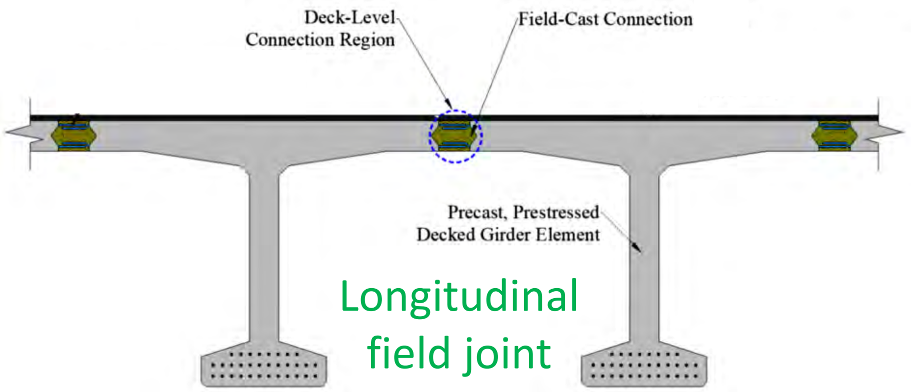
Shear strength (PMMA-PC) = 2 x shear strength (UHPC)

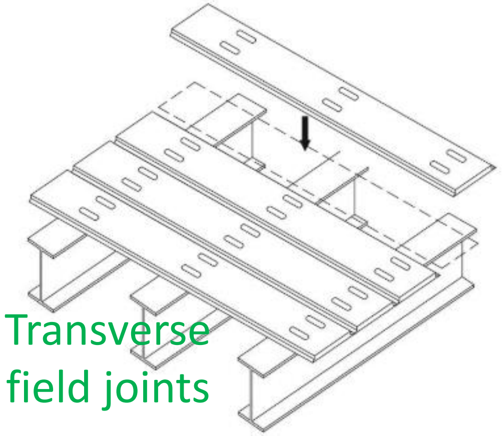
The overall cost of the PMMA-PC is only one-half that of the UHPC

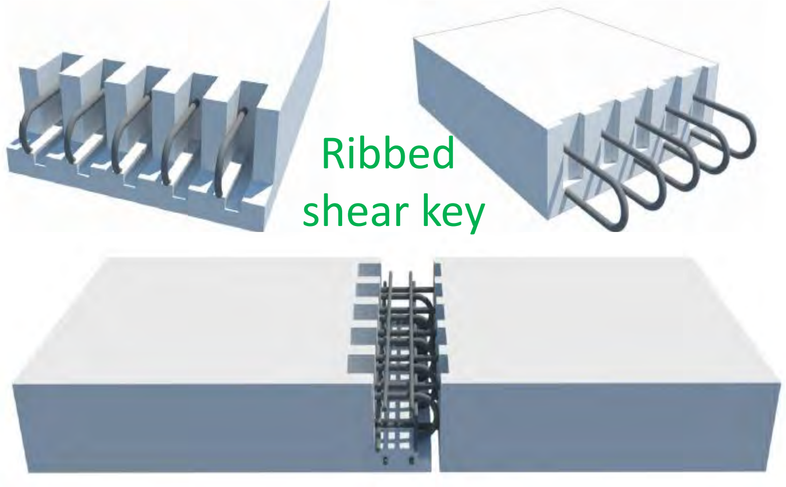
Literature

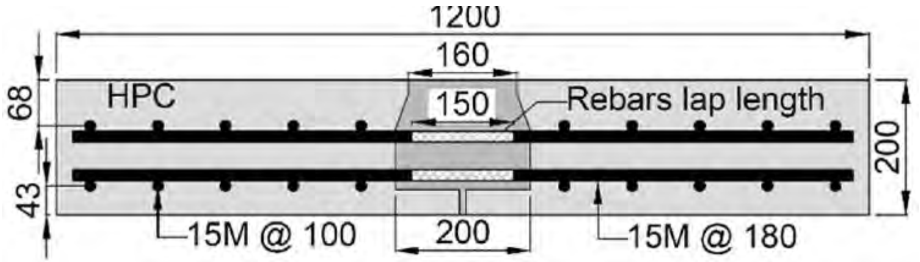
2. Experimental testing of field joints in precast bridge decks

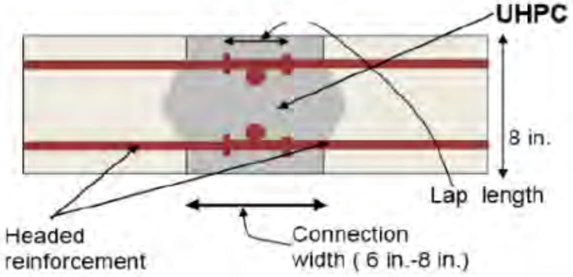
- Types of field joints (Transverse & Longitudinal joints)
- Shear key shape (straight, ribbed & diamond shape)
- Reinforcement splice type (Straight, loop & headed bar splice)
- Type of Loading (static & cyclic)











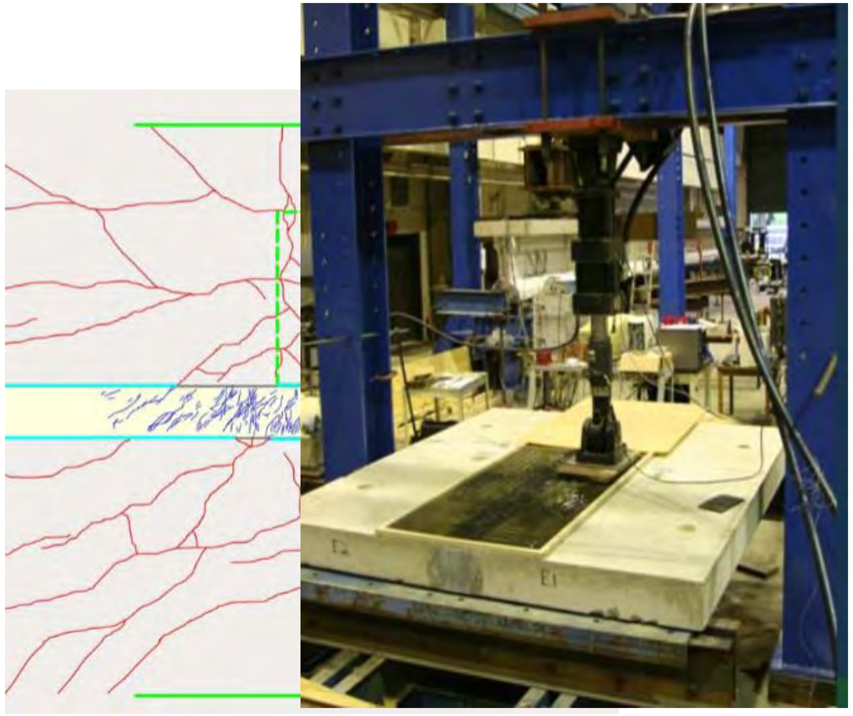
Literature

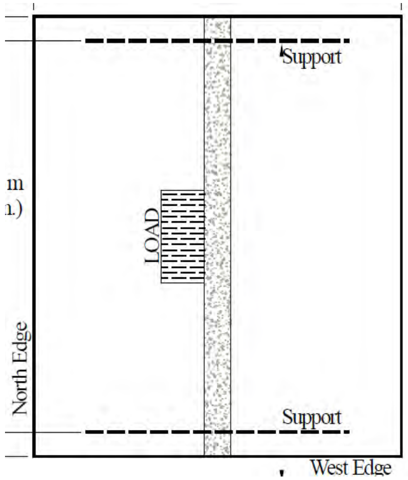
One example: Graybeal (2010)

- UHPC in field joints of precast bridge decks
- Tested full scale field joints (4 transverse, 2 longitudinal)
- Tested under cyclic then static loading up to failure

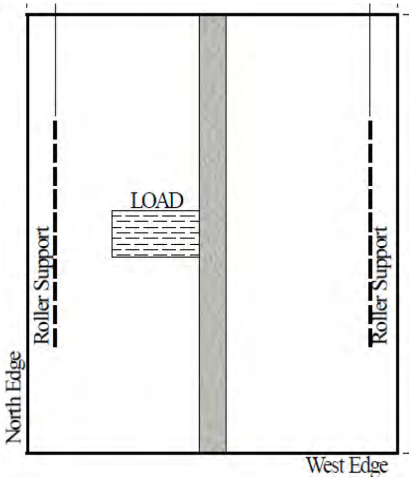
Desired features as demonstrated by UHPC:

1. The field-cast UHPC joints provided a limited additional amount of strength and stiffness
2. No evidence of bar or joint interface de-bonding was observed
3. Load distribution capability was maintained
4. Tensile cracking behavior is much better (One wide crack in precast slab = hundreds of micro cracks in UHPC)

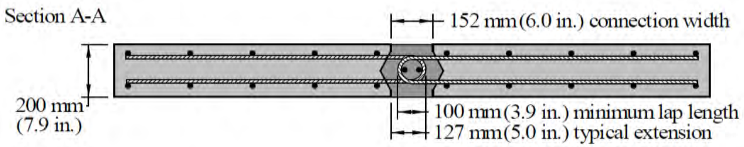


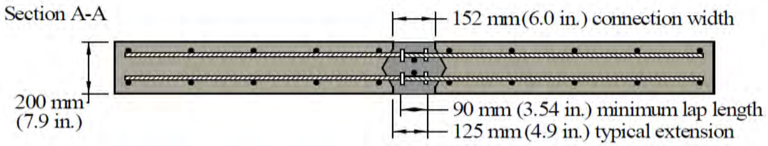


Transverse Specimen



Longitudinal Specimen

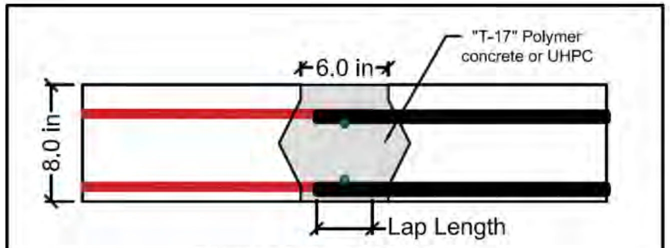




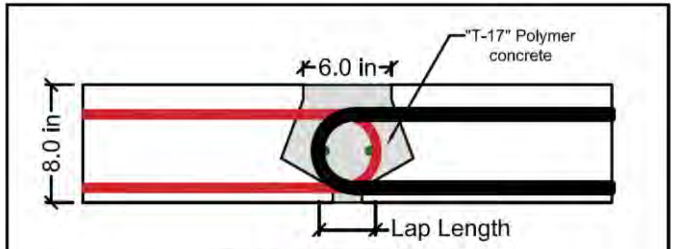
Experimental Program

- <u>Specimens details:</u>

Specimen Name	Joint Orientation	Specimen Dimensions (L × W × thickness)	Closure material	Lap splice type	Joint width	Lap splice length
S1-T-UHPC	Transverse	9'x 8' x 8''	UHPC	Straight	6''	5''
S2-T-PMMA	Transverse	9'x 8' x 8''	PMMA-PC	Straight	6''	5''
S3-T-PMMA-Loop	Transverse	9'x 8' x 8''	PMMA-PC	Loop	6''	4.5''
S4-L-UHPC	Longitudinal	8'x 7' x 6''	UHPC	Straight	6''	5''
S5-L-PMMA	Longitudinal	8'x 7' x 6''	PMMA-PC	Straight	6''	5''



Diamond shaped field joint - straight bar splice



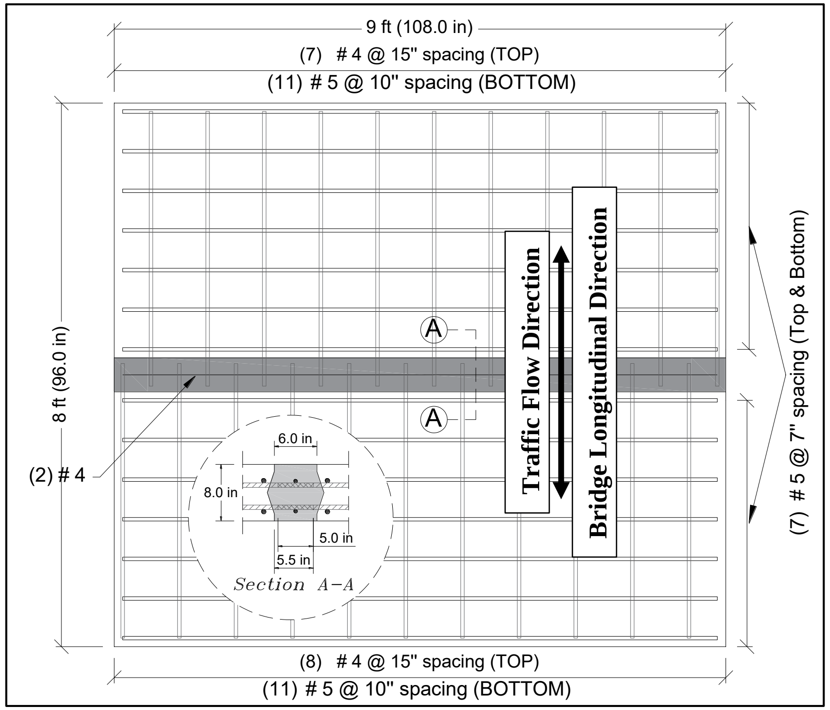
Diamond shaped field joint - U-bar splice


Backer rod for S3

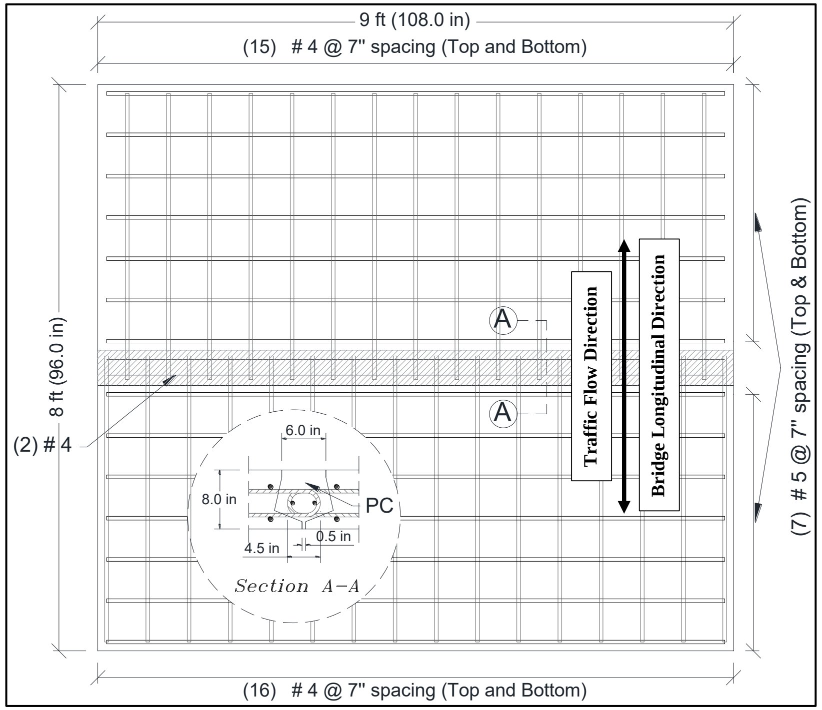
Experimental Program

- Specimens design:

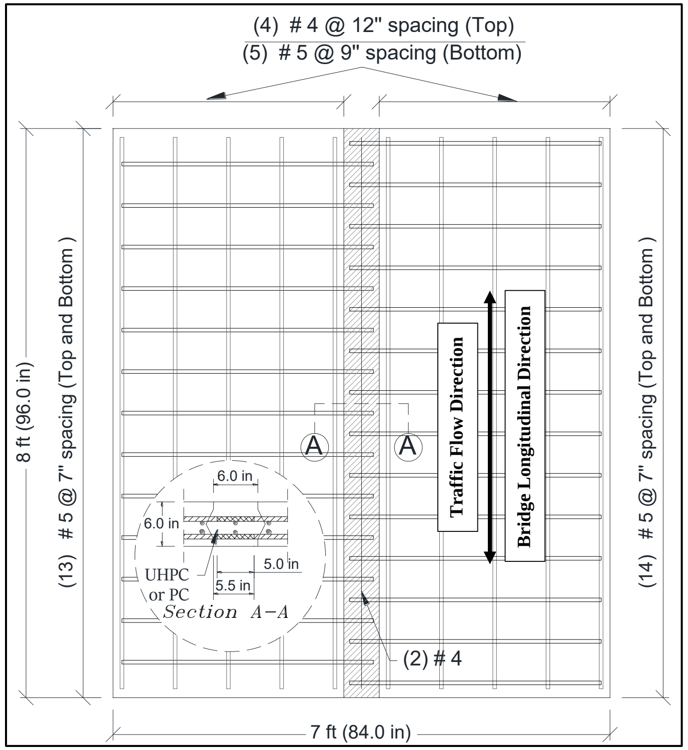
- Design of the specimens was done according to the AASHTO LRFD Bridge Design Specification
- Positive and negative design moments were determined based on the AASHTO Equivalent strip method



S1 & S2 Transverse specimens

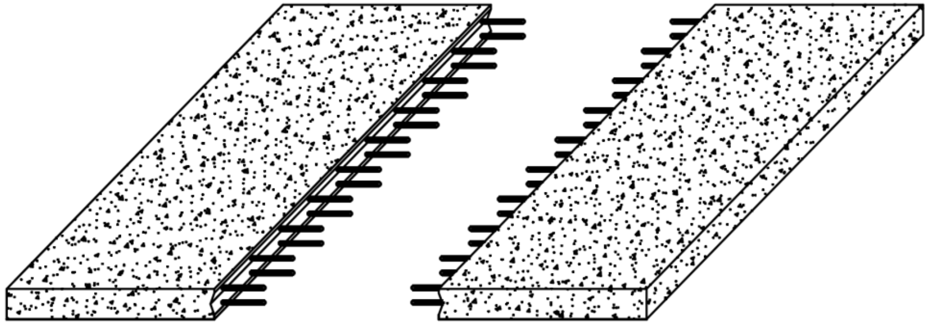


S3 Transverse specimen

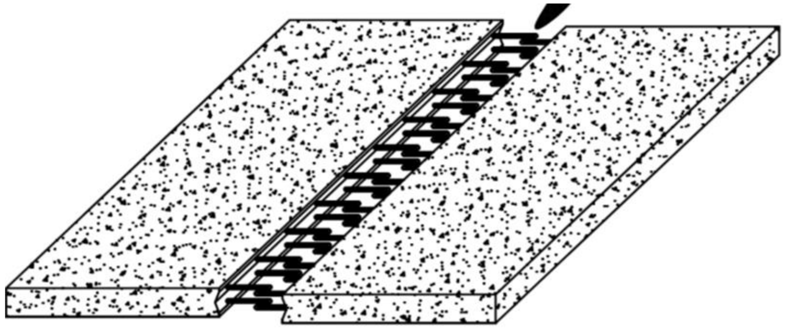


S4 & S5 Longitudinal specimens

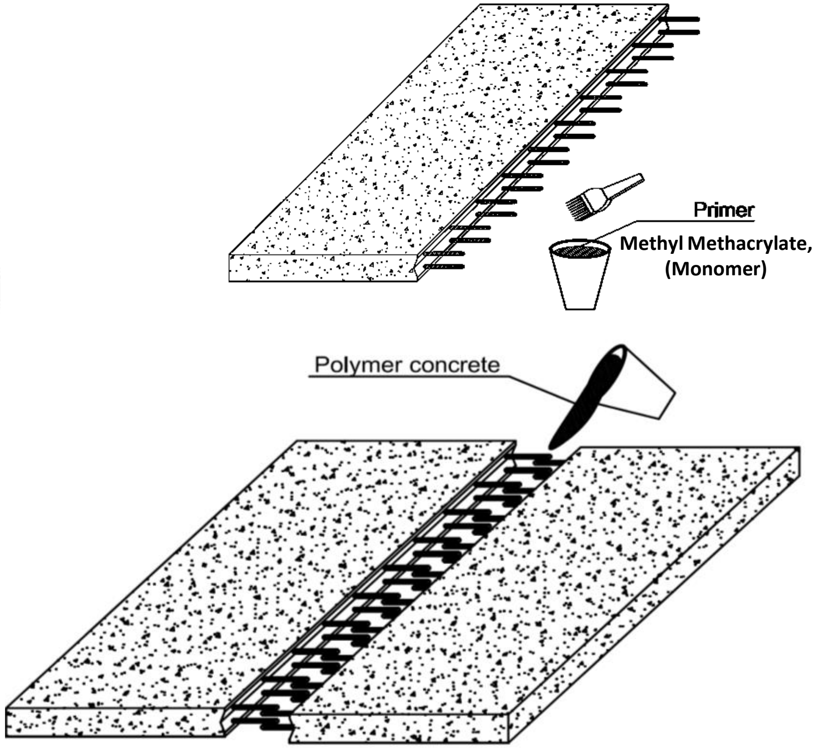
Stages of Construction



Stage 1: Fabrication of precast panels using conventional concrete with specified compressive strength of 5 ksi



Stage 2: Align the precast panels together



Stage 3: Apply an MMA Primer resin to the joint surface for the PMMA-PC only, then pour the PMMA-PC and UHPC in the joints

Stages of Construction

Stage 1: Construction of the precast deck panel parts





Stages of Construction

Stage 1: Construction of the precast deck panel parts





Stages of Construction

<u>Stage 2:</u> Precast panels alignment

Stages of Construction

Stage 3: Pouring UHPC in the joints

Stages of Construction

<u>Stage 3:</u> Pouring PMMA-PC

Material Properties

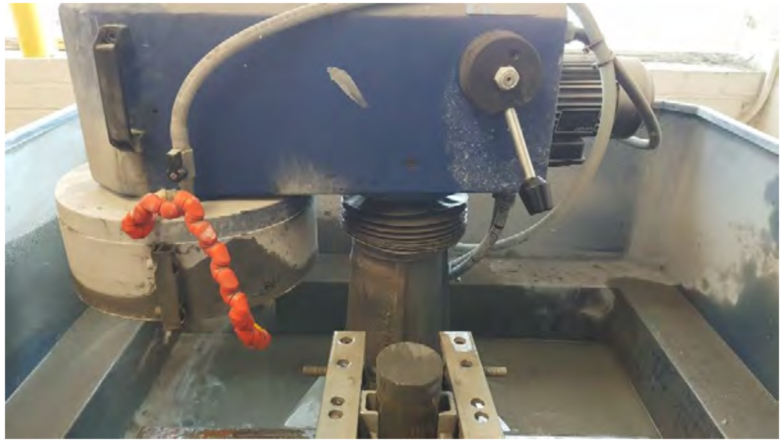
PMMA-PC polymer concrete

- Potential: used in airports as a fast permanent repair to runways and taxiways, because it can be cured to full hardness in less than 45 minutes.
- Features and advantages:
  - Wide Application Temperature Range (14-100° F)
  - Fast Setting (45 minutes at 70° F)
  - High Early Strength (Compressive strength of 2,500 psi @2hrs and 8,000-9,000 psi @24hrs)
  - Strong Chemical Bond
  - Freeze-Thaw Resistant
  - High tensile strength (1.2 Ksi)

Material Properties

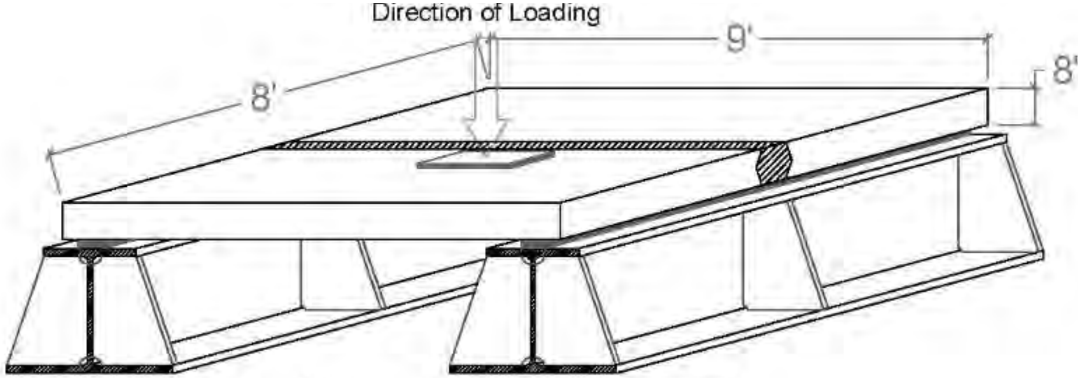
- <u>Compressive strength:</u>

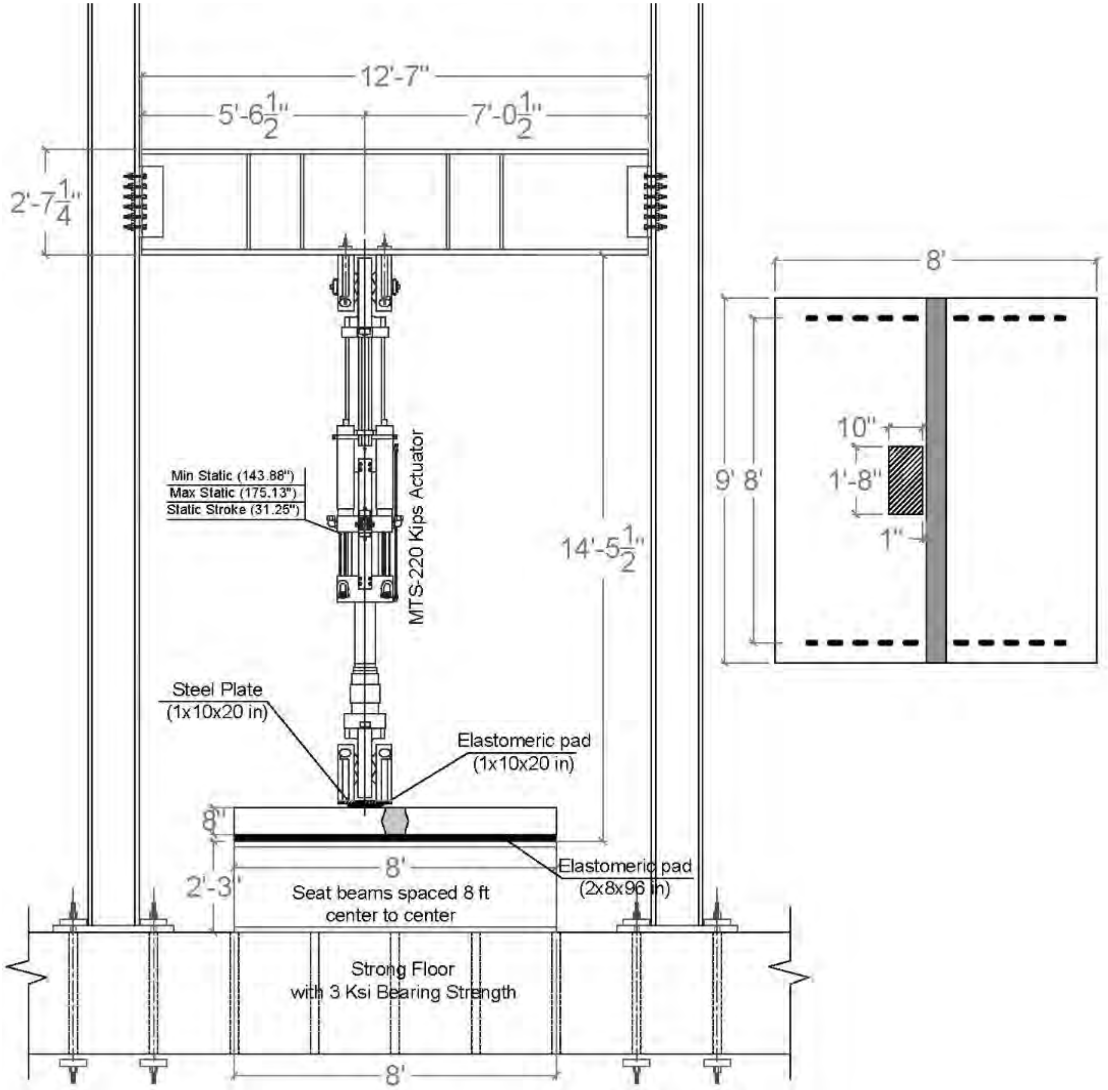
Type of Concrete	ASTM Test Type	Specimen Dimensions	Age	Average Strength (ksi)
Conventional concrete	ASTM – C39	6”×12” cylinders	7 days	2.93
	ASTM – C39	6”×12” cylinders	28 days	4.32
	ASTM – C39	6”×12” cylinders	test day	5.20
UHPC	ASTM – C39	3”×6” cylinders	28 days	24.80
	ASTM – C39	3”×6” cylinders	test day	27.80
PMMA-PC	ASTM – C579/B	2”×2”×2” cubes	2 days	11.90
	ASTM – C579/B	2”×2”×2” cubes	7 days	12.10
	ASTM – C579/B	2”×2”×2” cubes	28 days	10.60
	ASTM – C579/B	2”×2”×2” cubes	test day	10.70
PMMA-PC	ASTM – C469	3”×6” cylinders	9 days	10.60
	ASTM – C469	3”×6” cylinders	28 days	8.56
	ASTM – C469	3”×6” cylinders	test day	9.03



Test Setup

- Transverse Specimens Test Setup:



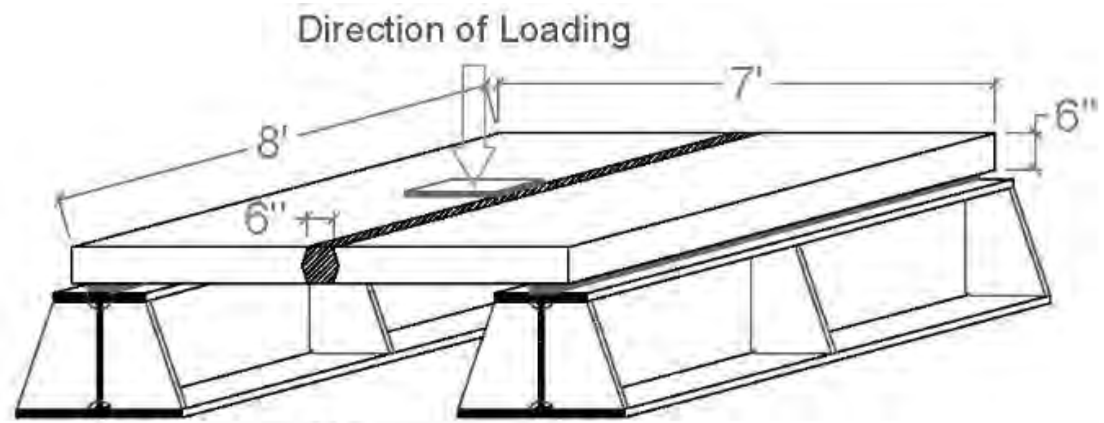


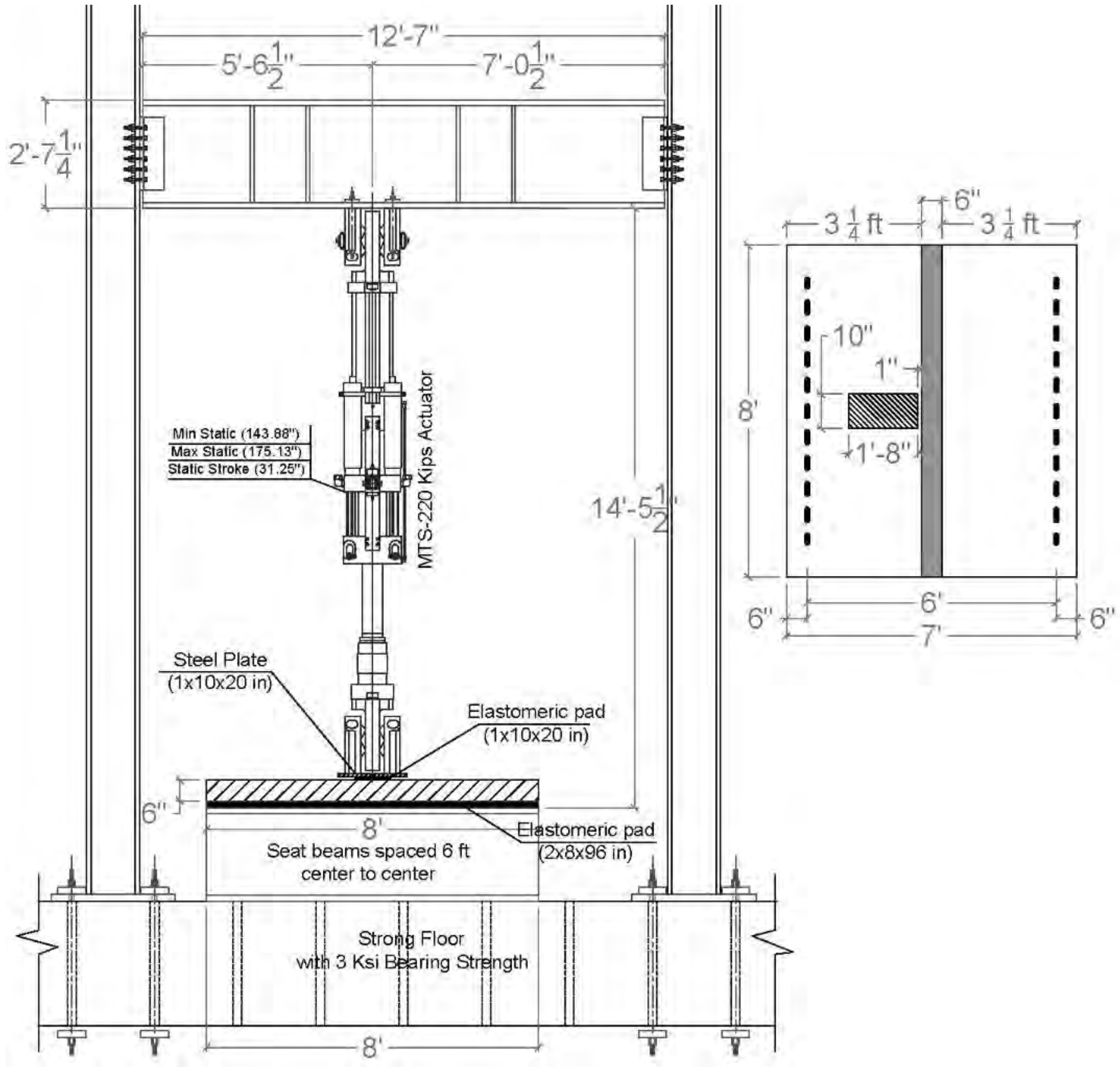
Test Setup

- Transverse Specimens Test Setup:

Test Setup

- Longitudinal Specimens Test Setup:

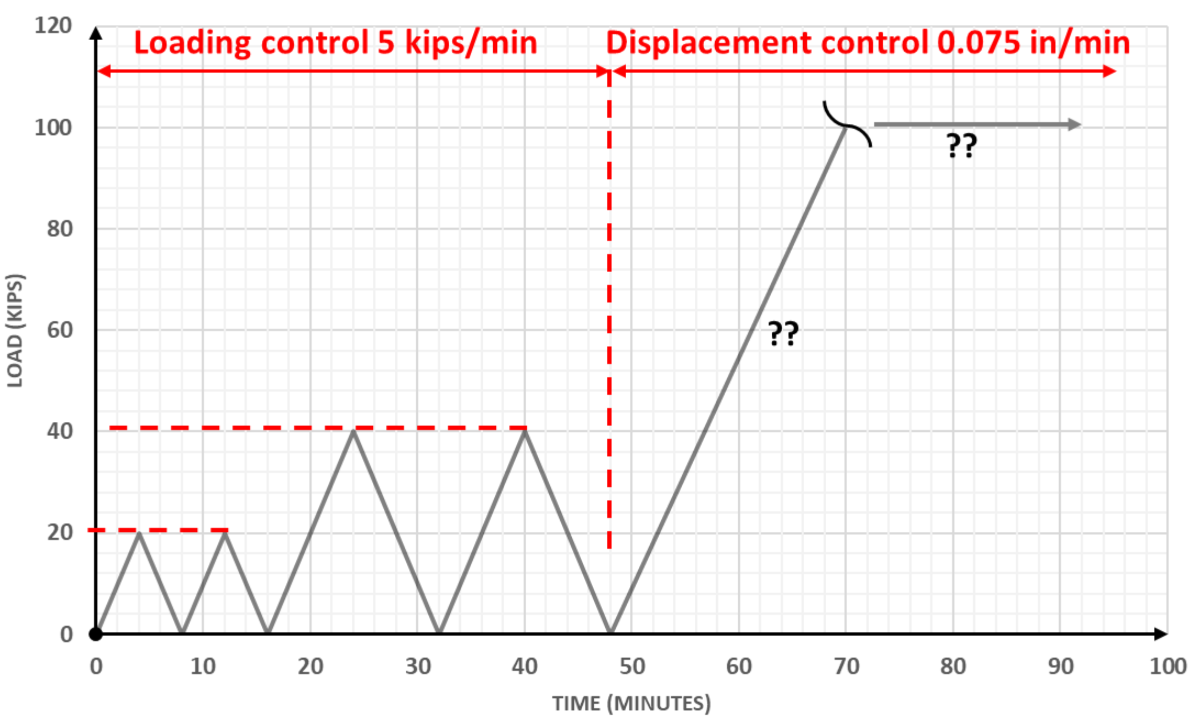




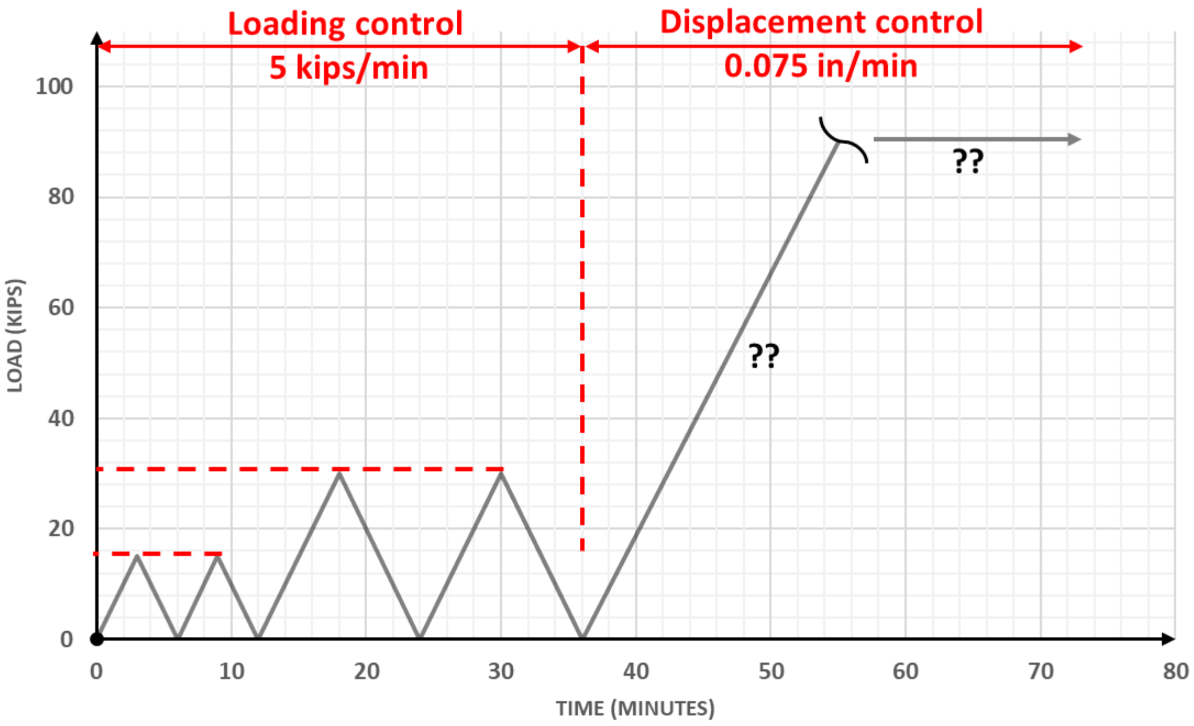
Test Setup

- Longitudinal Specimens Test Setup:

Loading Protocol



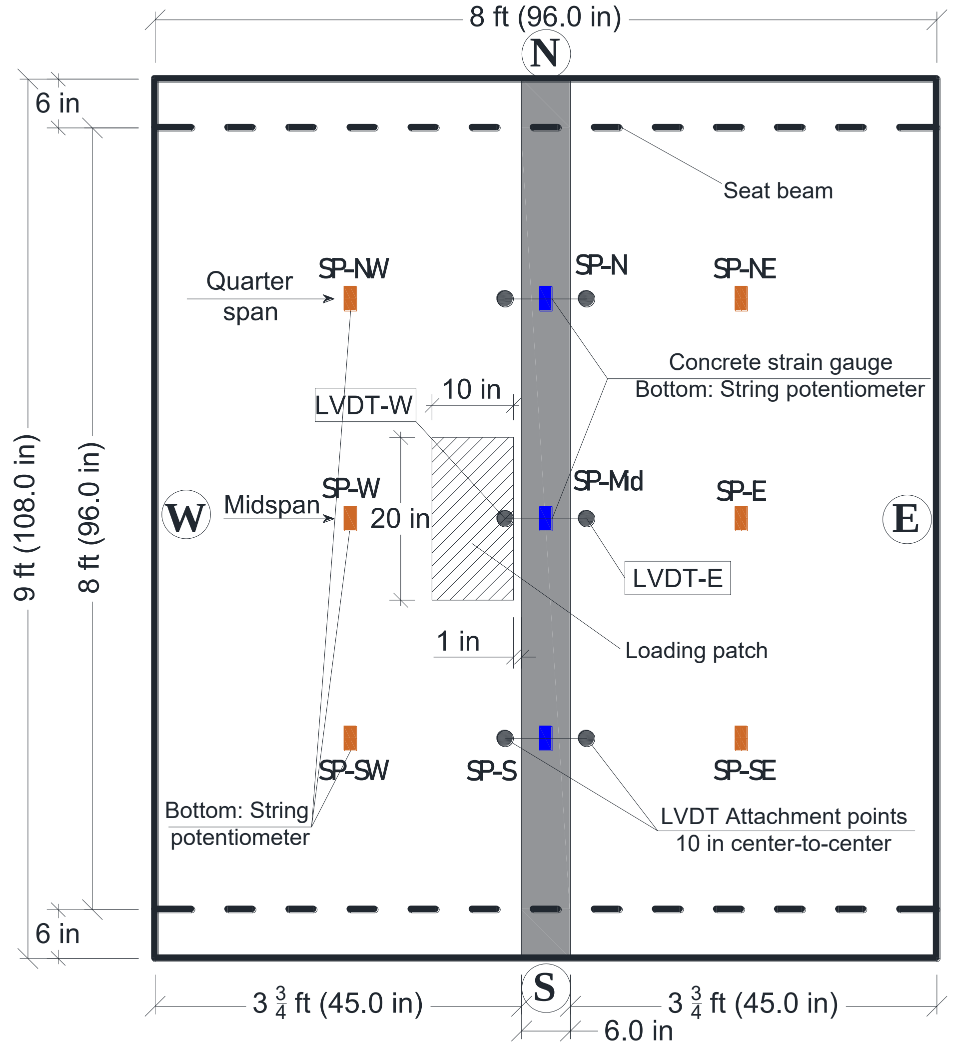
Loading protocol for transverse specimens

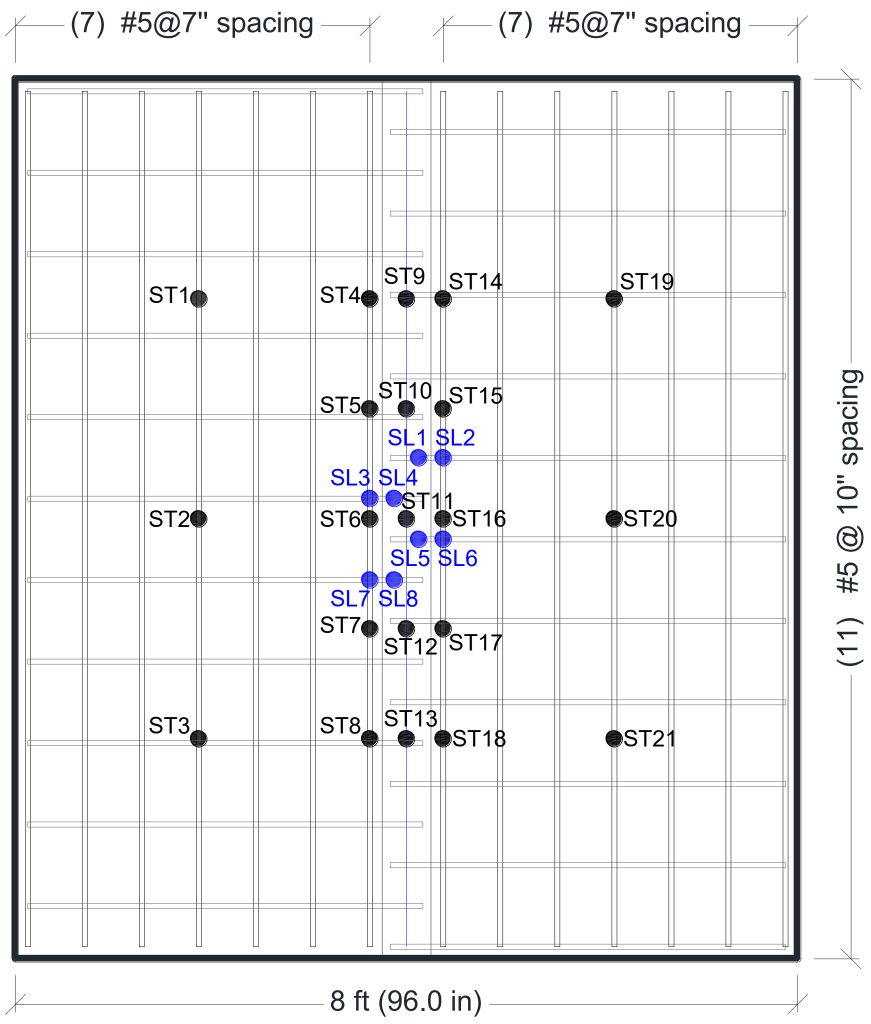


Loading protocol for longitudinal specimens

Instrumentation Plan

- S1 & S2 Transverse specimens



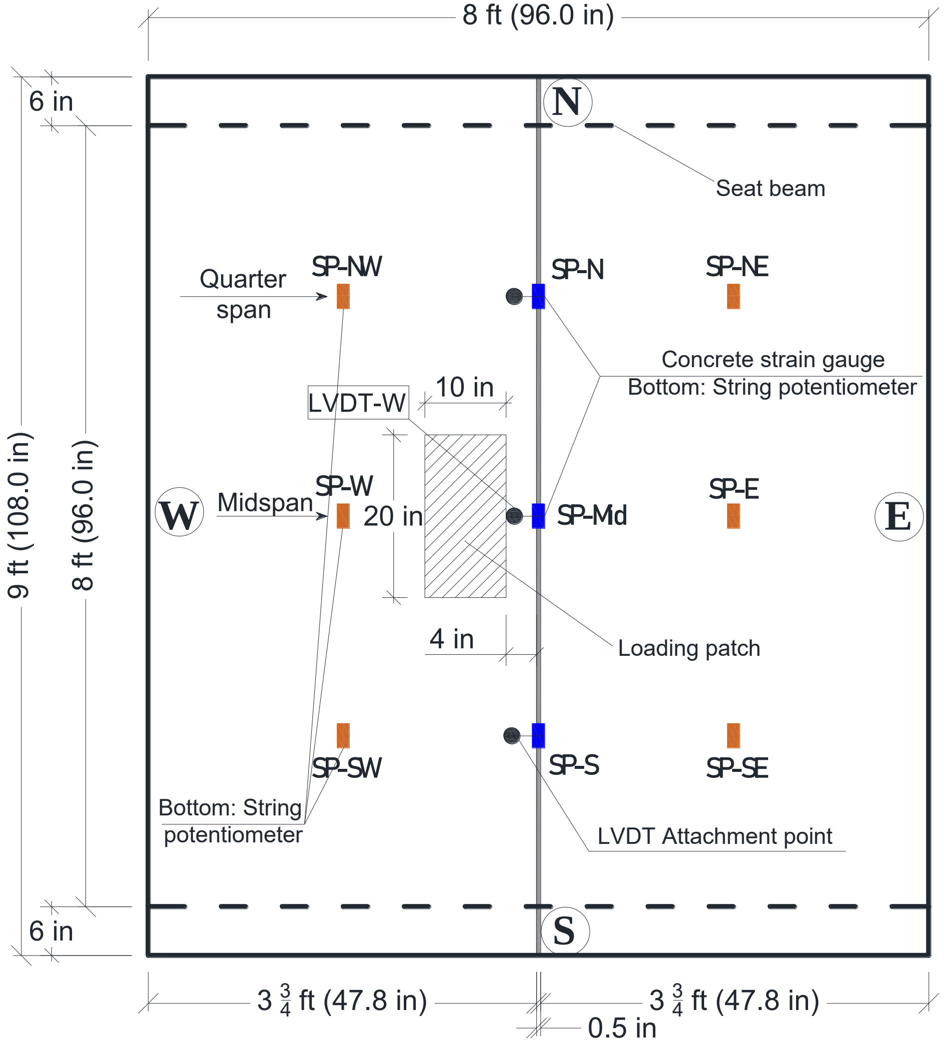


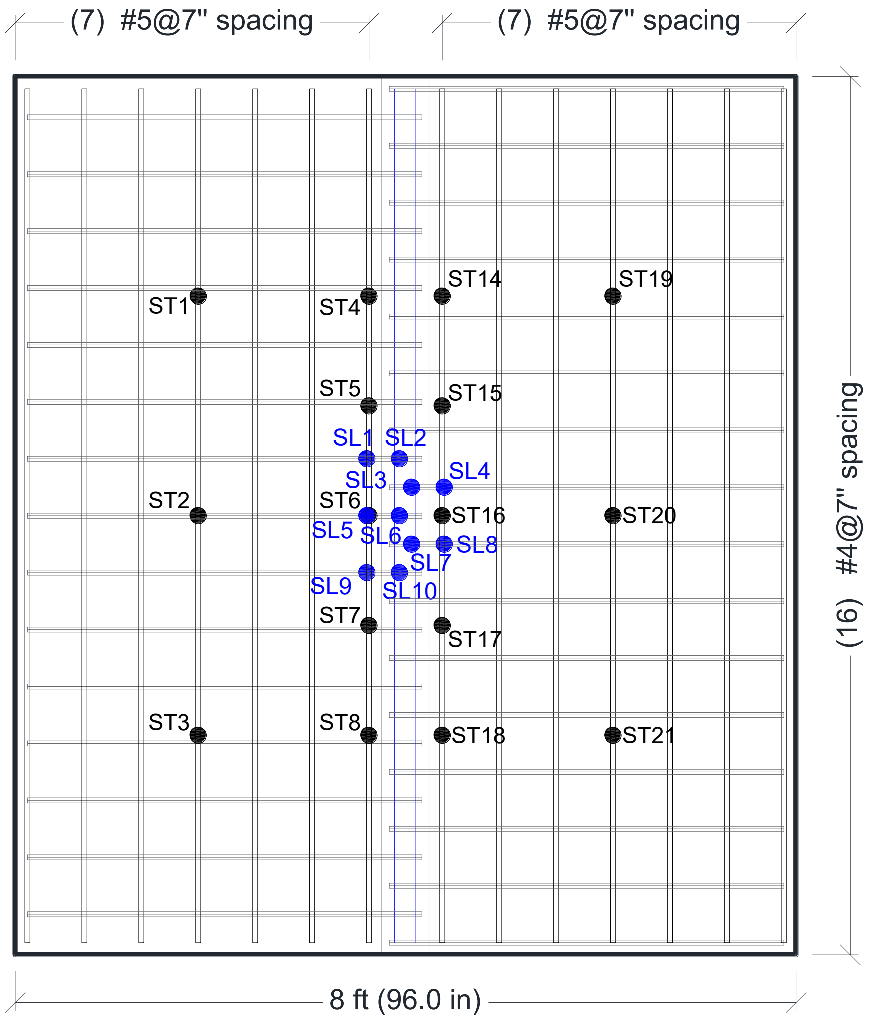
Instrumentations:

- Number of reinforcement strain gages (ST & SL): 44
- Number of concrete strain gages: 3
- Number of string potentiometers (SP): 9
- Number of displacement transducers (LVDTs): 6

Instrumentation Plan

- S3 Transverse specimen





Instrumentations:

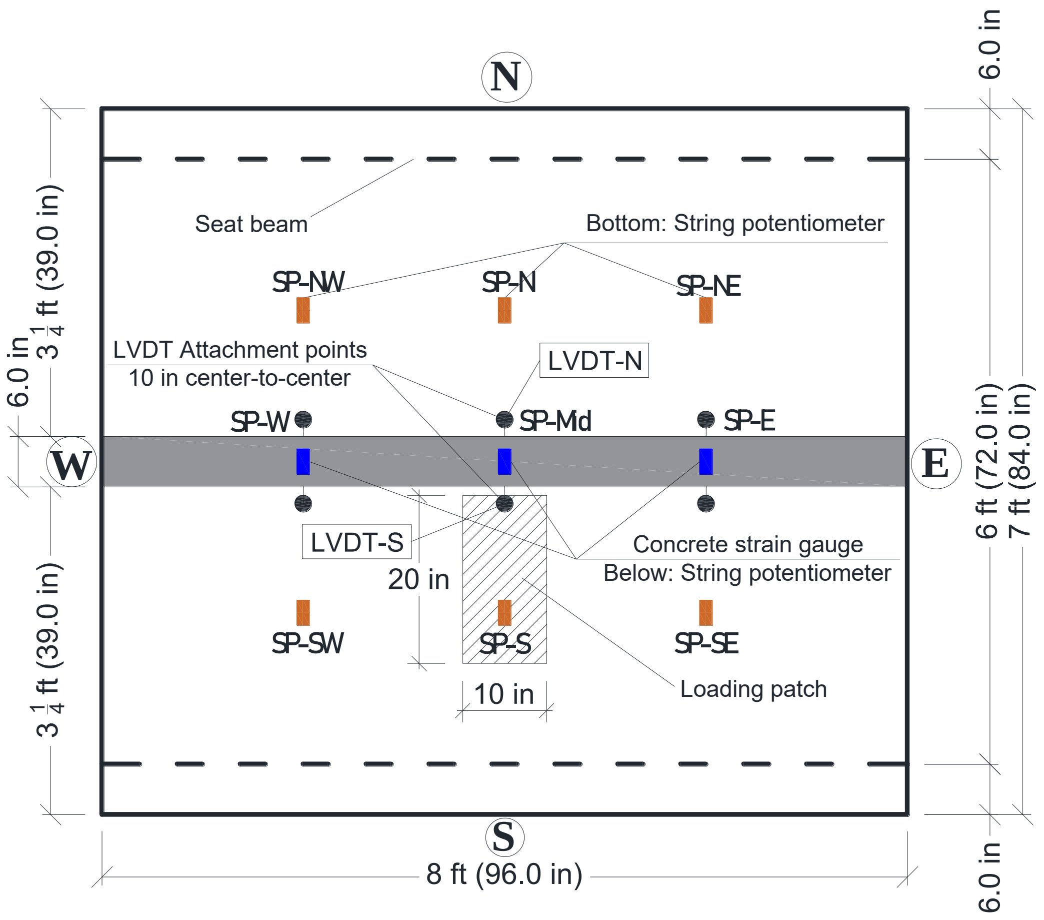
- Number of reinforcement strain gages (ST & SL): 46
- Number of concrete strain gages: 3
- Number of string potentiometers (SP): 9
- Number of displacement transducers (LVDTs): 3

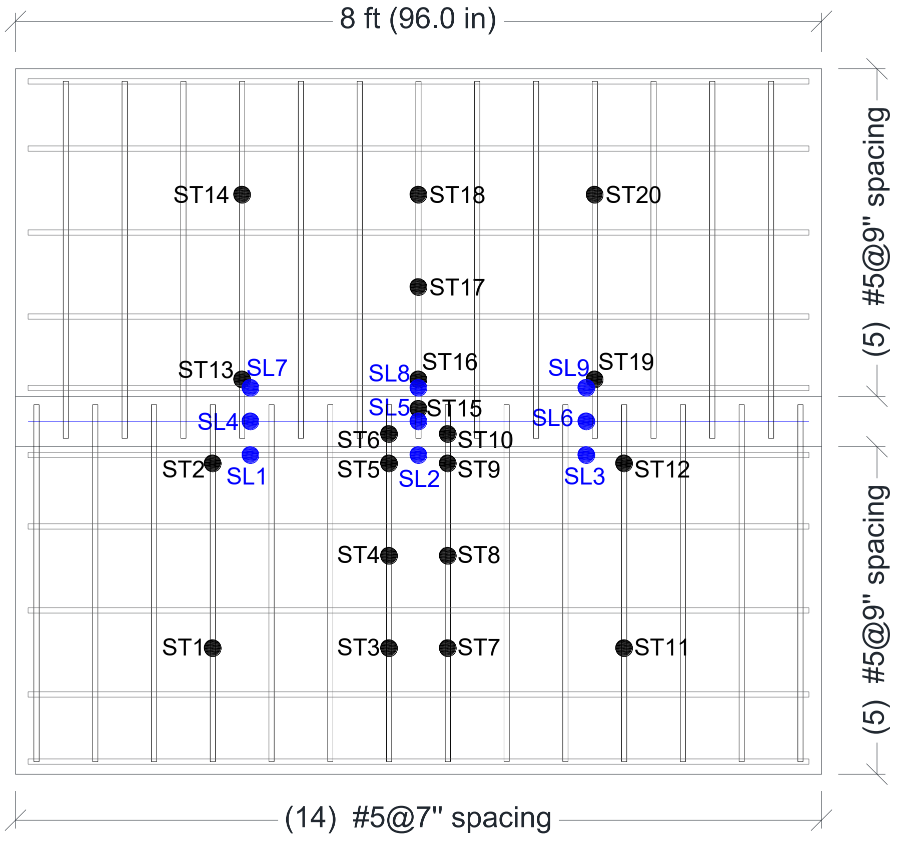
Instrumentation Plan

- <u>S4 & S5 Longitudinal specimens</u>

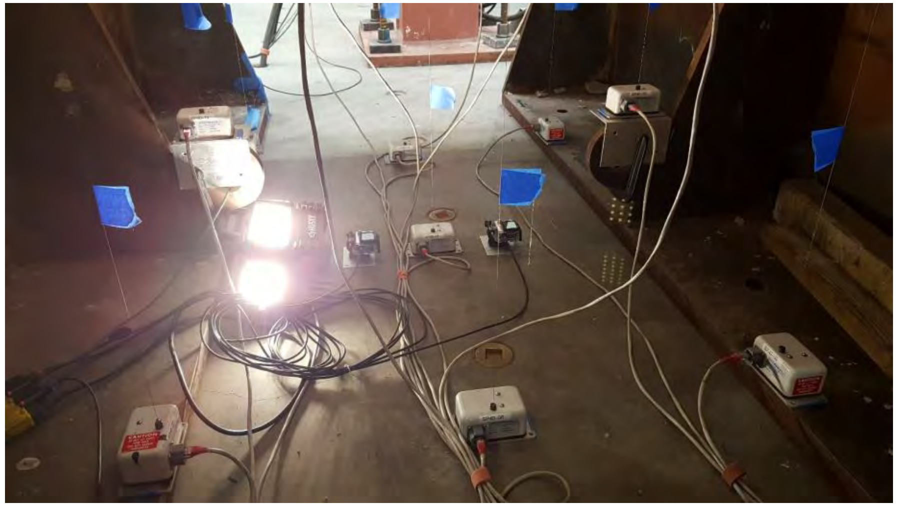
Instrumentations:

- Number of reinforcement strain gages (ST & SL): 41
- Number of string potentiometers (SP): 9
- Number of concrete strain gages: 3
- Number of displacement transducers (LVDTs): 6





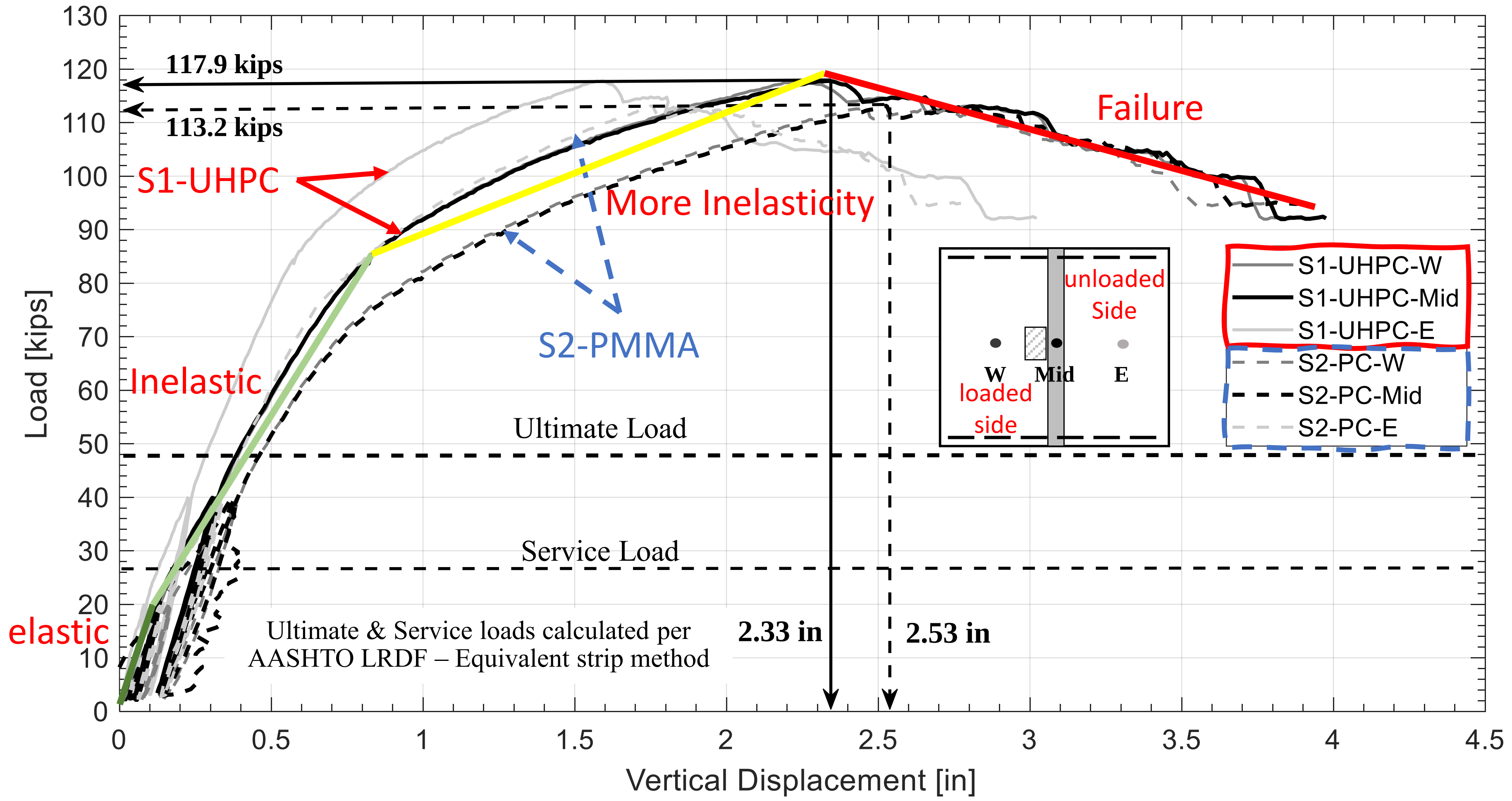
Instrumentation Plan



Results of Transverse Specimens

Load-deflection relationship

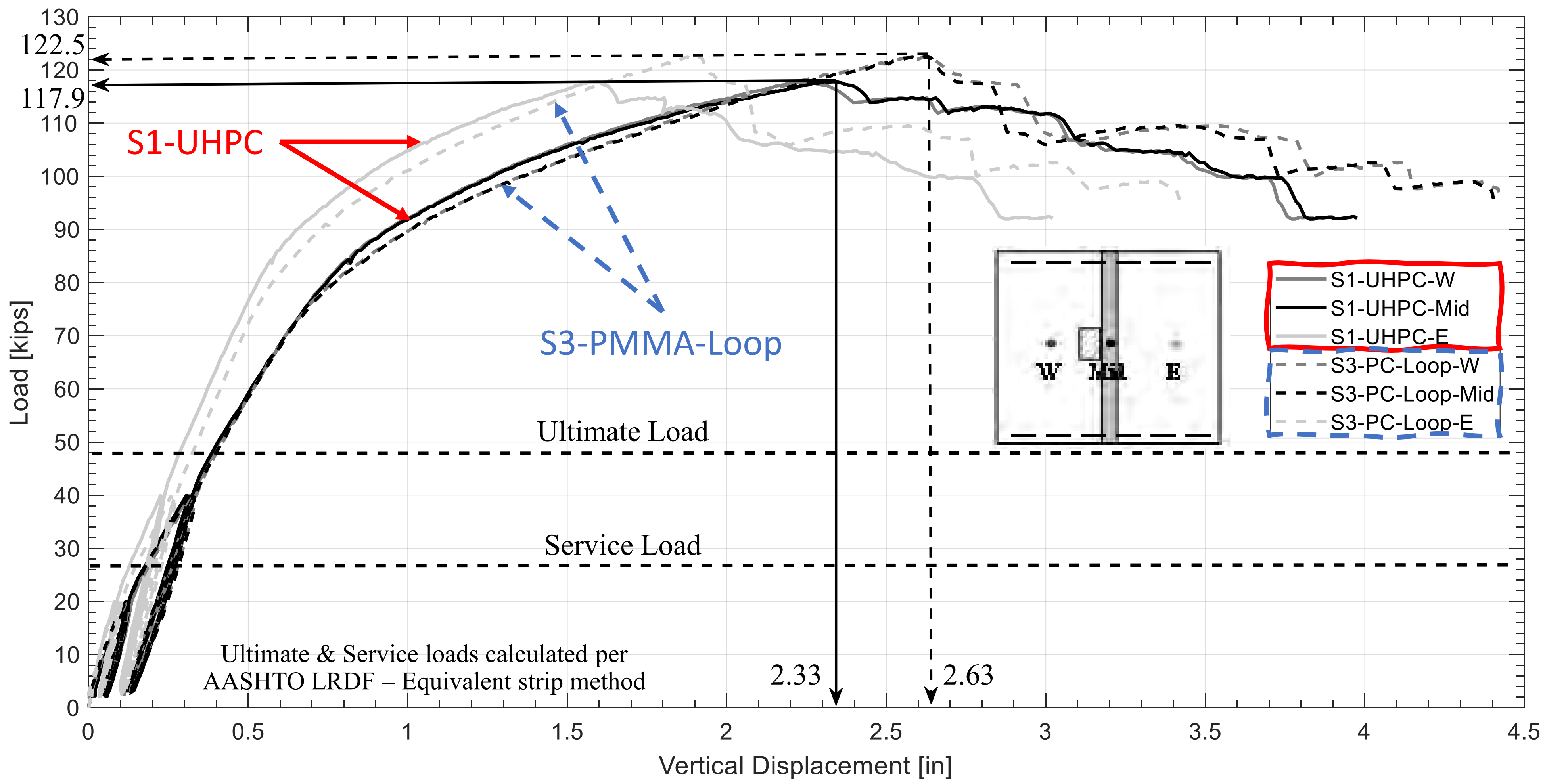
- *"S1-T-UHPC" vs "S2-T-PMMA":*



Results of Transverse Specimens

Load-deflection relationship

- *"S1-T-UHPC" vs "S3-T-PC-Loop":*



Results of Transverse Specimens

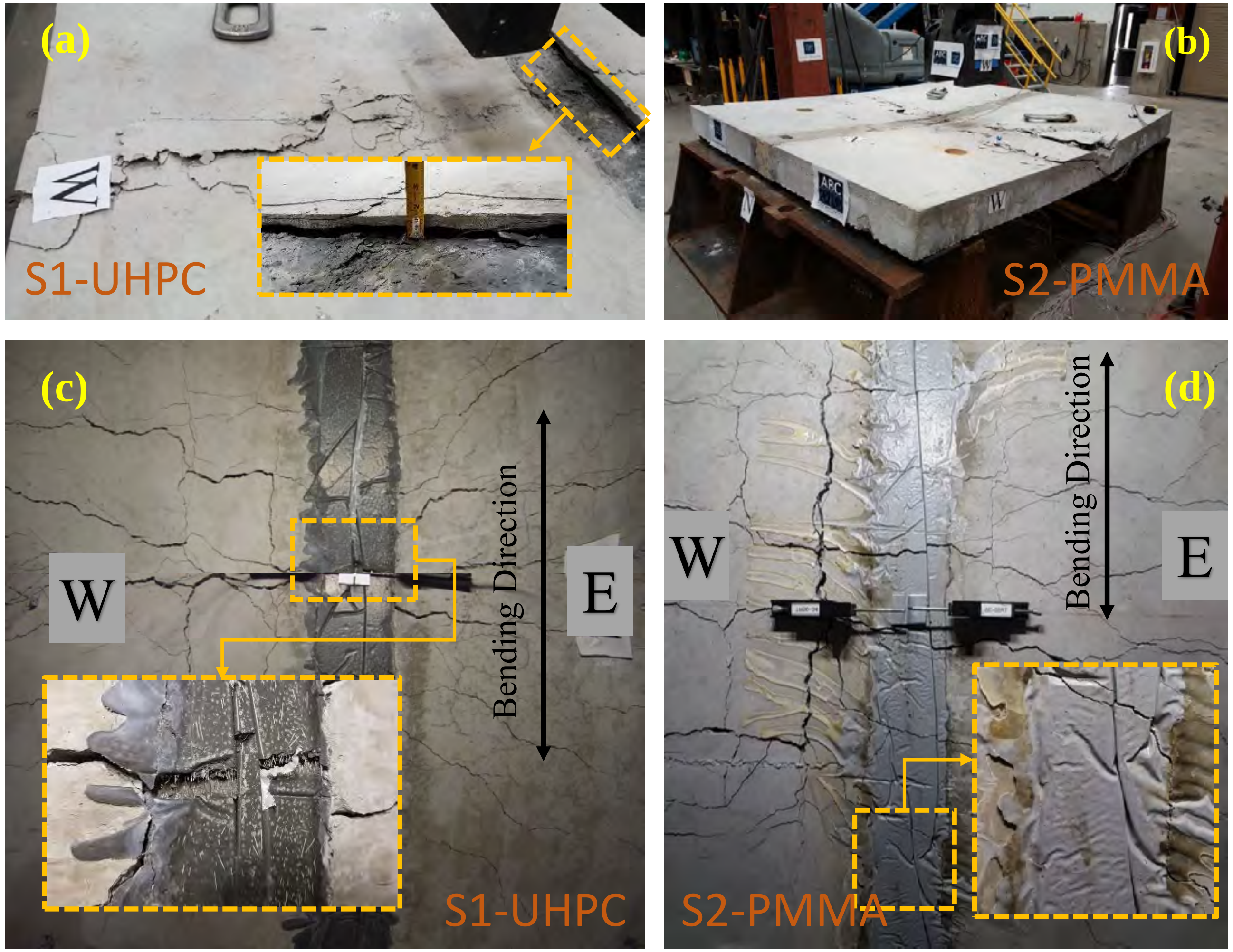
Summary of Results:

Specimen Name	Peak Load (kips)	Mid-span Deflection at Peak Load (in)	Mid-span Deflection at Service Load (in)	Mid-span Deflection at Ultimate Load (in)	Initial Stiffness (kips/in)
S1-T-UHPC	117.9	2.33	0.175	0.384	240
S2-T-PMMA	113.2	2.53	0.205	0.460	190
S3-T-PMMA-Loop	122.5	2.63	0.177	0.397	220

Results of Transverse Specimens

Damage progression and mode of failure

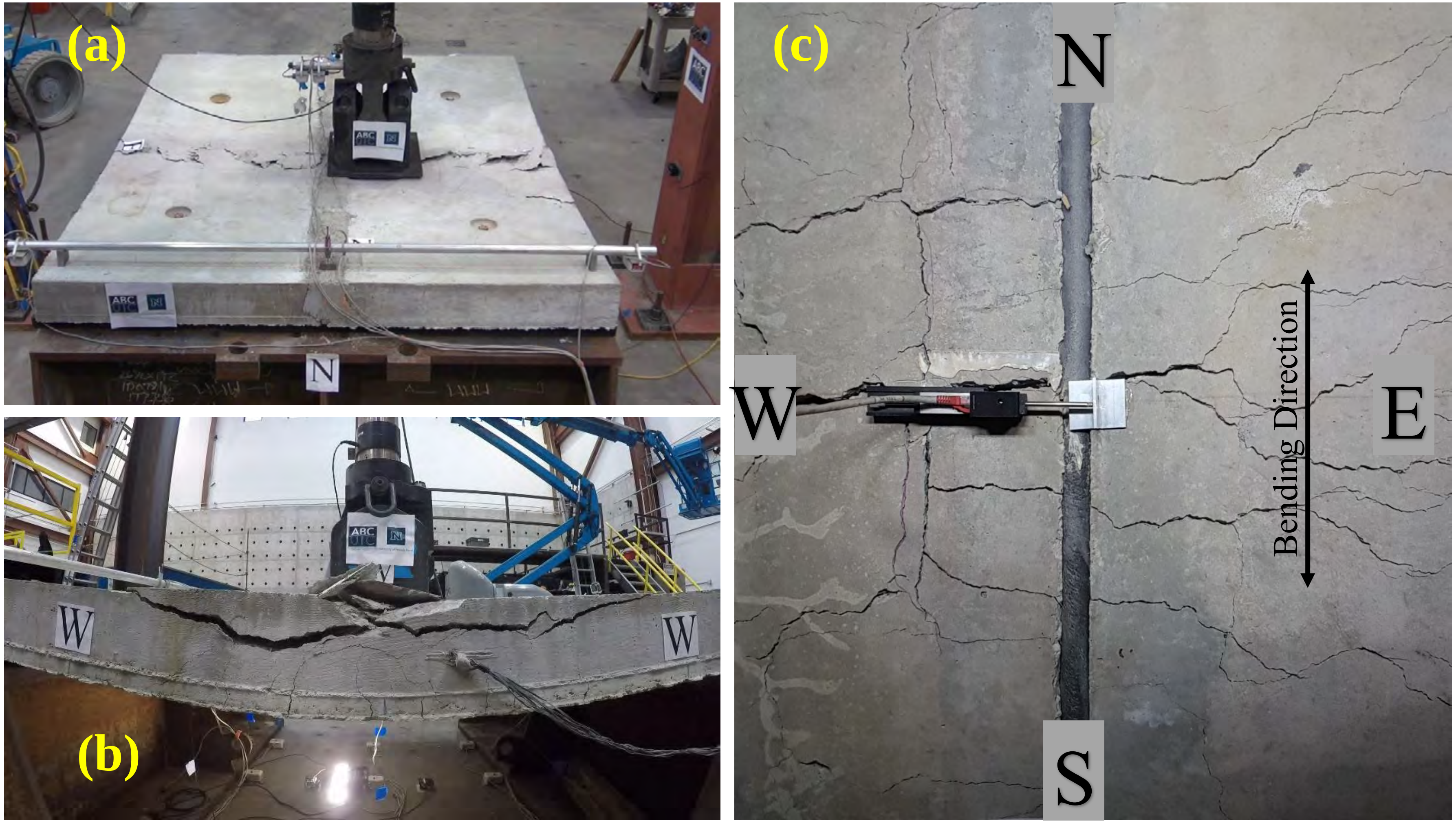
- *"S1-T-UHPC" vs "S2-T-PMMA":*



Results of Transverse Specimens

Damage progression and mode of failure

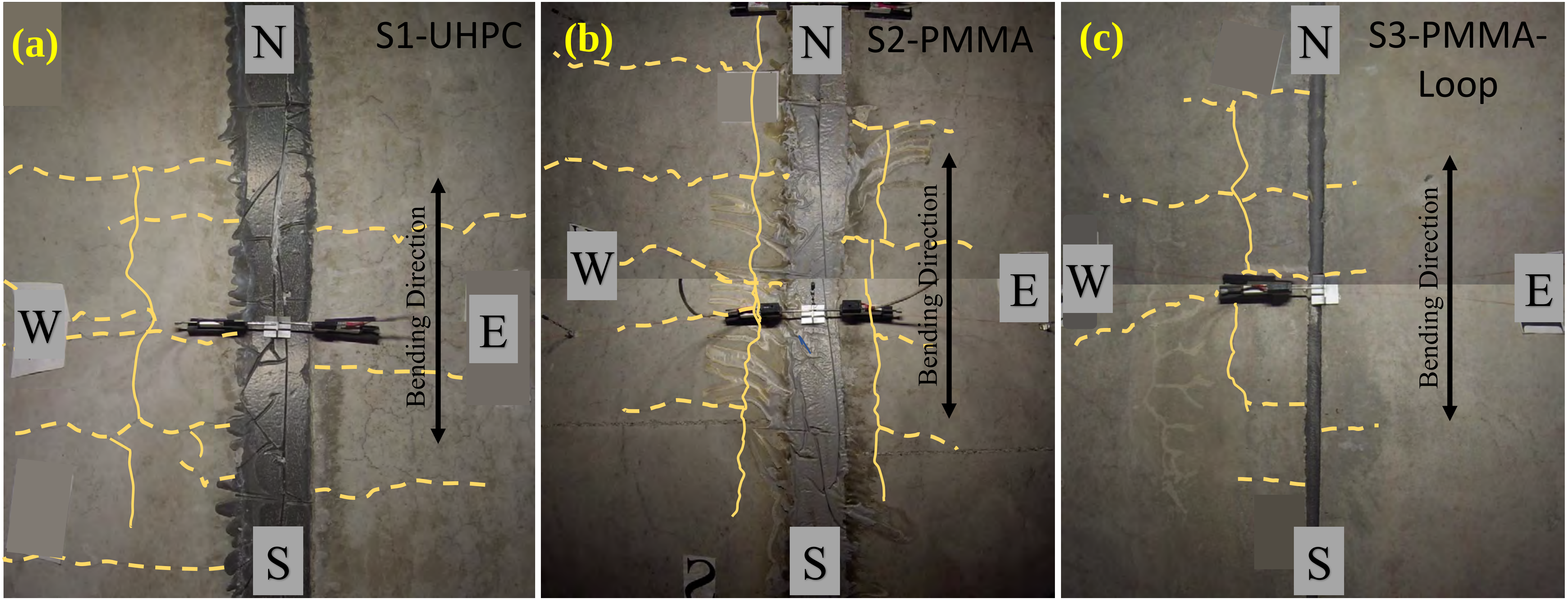
- *"S3-T-PMMA-Loop":*



Results of Transverse Specimens

Crack pattern at the AASHTO ultimate load

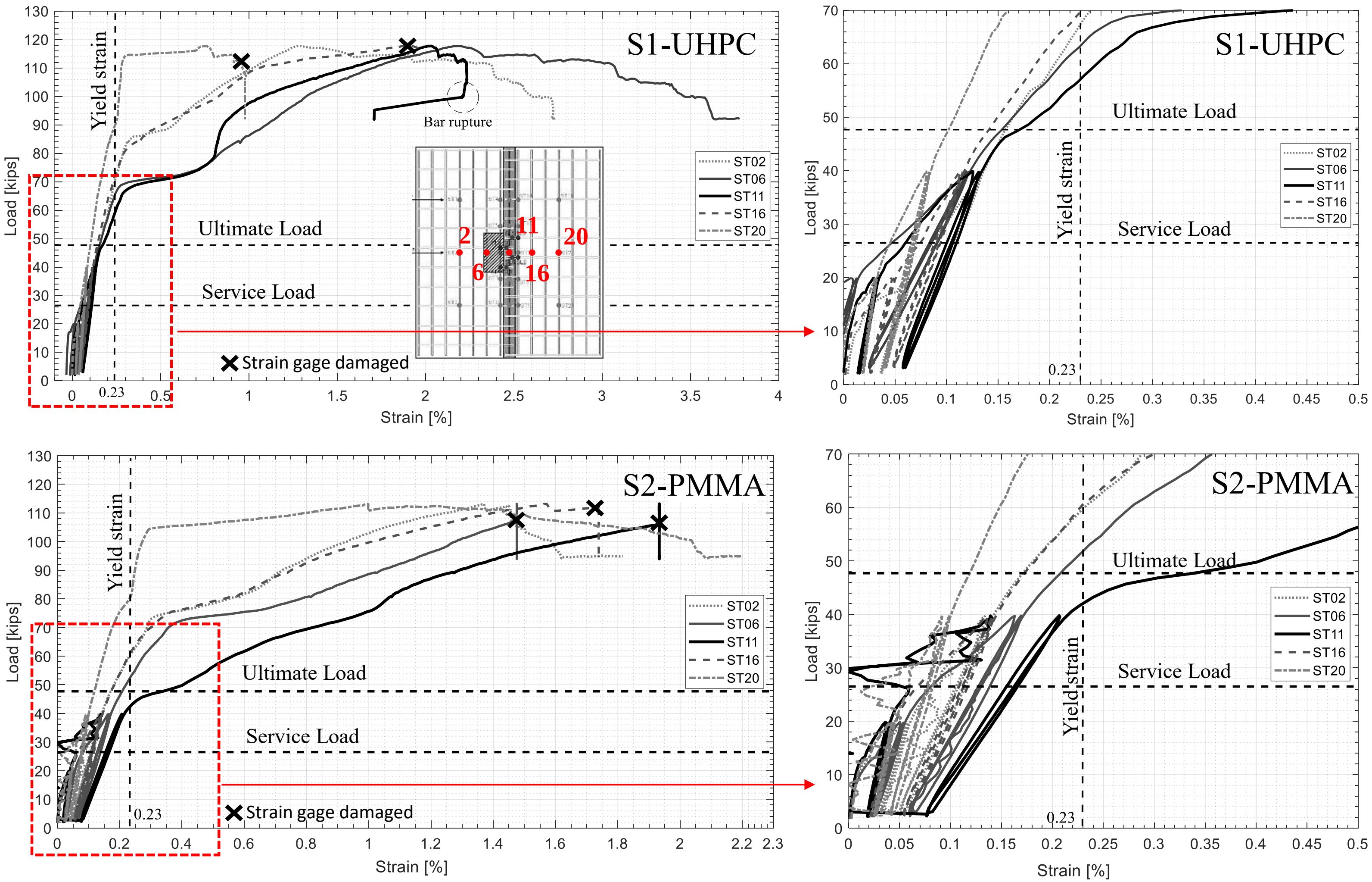
- *“S1-T-UHPC” vs “S2-T-PMMA” vs “S3-T-PMMA-Loop”:*



Results of Transverse Specimens

Load-strain relationship

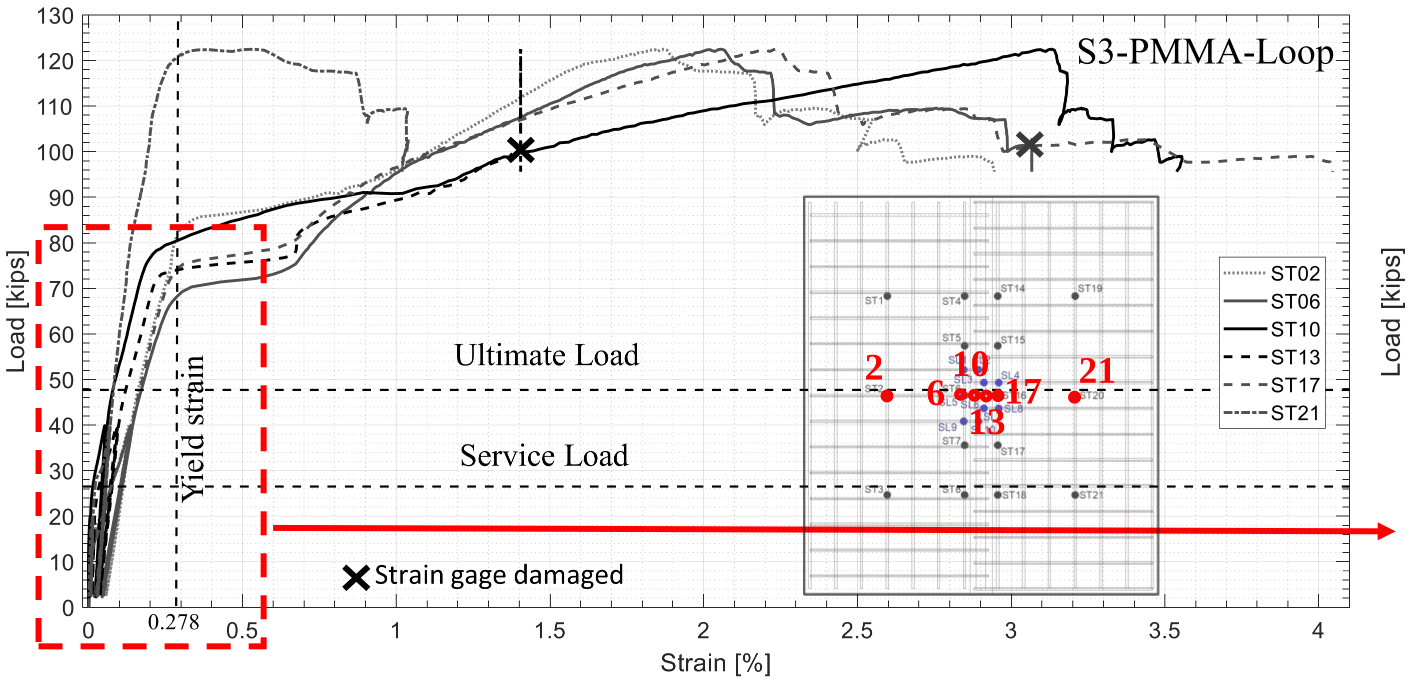
- *“S1-T-UHPC” vs “S2-T-PMMA”:*

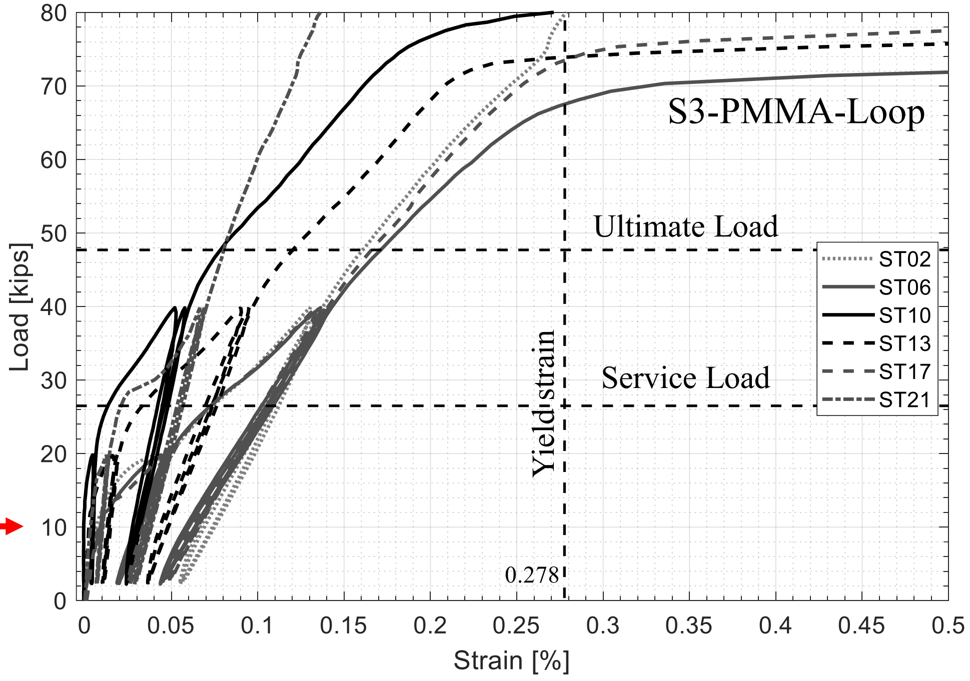


Results of Transverse Specimens

Load-strain relationship

- *“S3-T-PC-Loop”:*

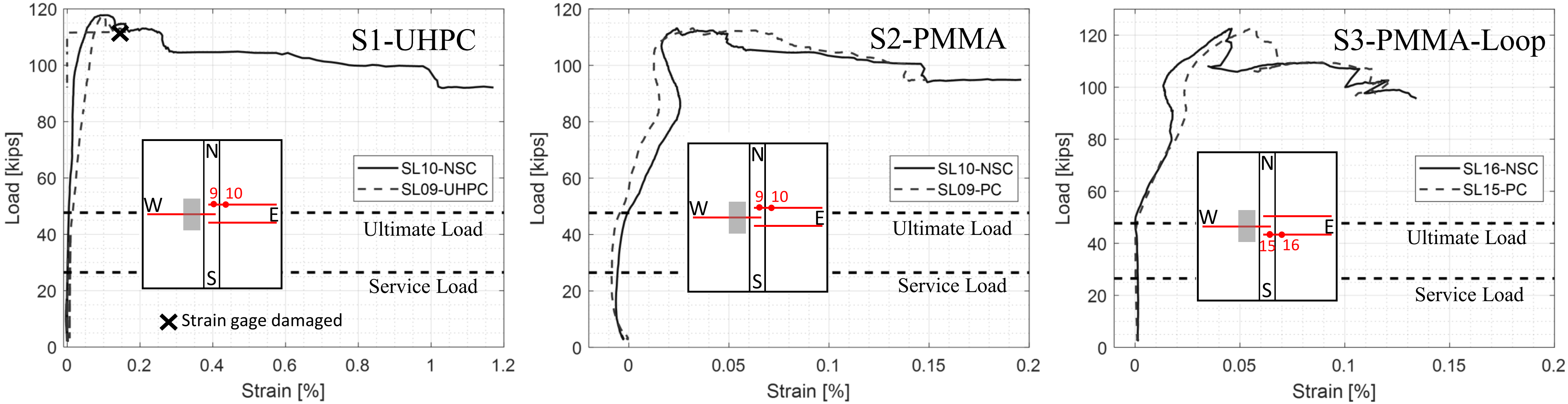




Results of Transverse Specimens

Load-strain relationship

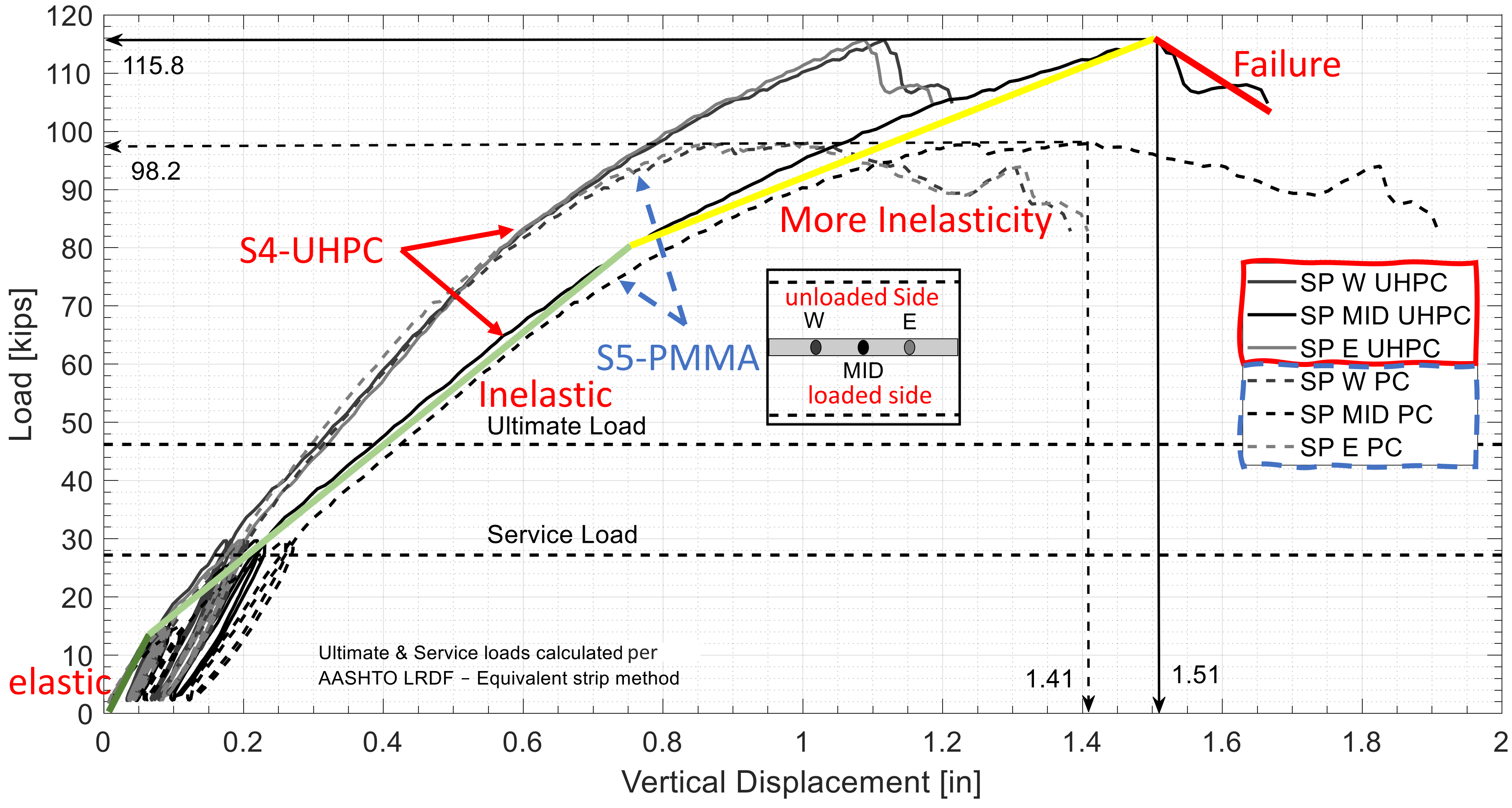
- *“S1-T-UHPC” vs “S2-T-PMMA” vs “S3-T-PMMA-Loop”:*



Results of Longitudinal Specimens

Load-deflection relationship

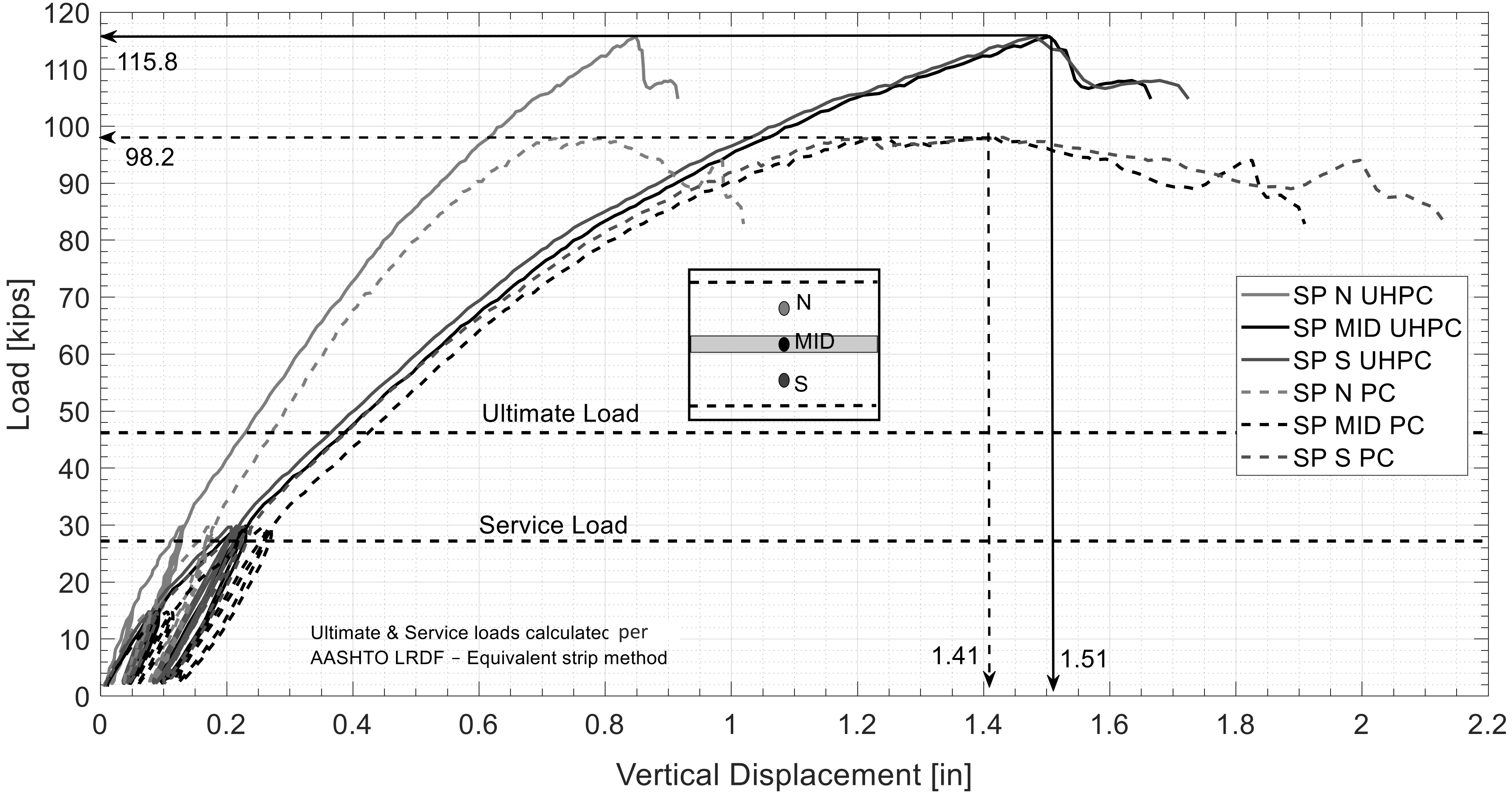
- *“S4-L-UHPC” vs “S5-L-PMMA”:*



Results of Longitudinal Specimens

Load-deflection relationship

- *“S4-L-UHPC” vs “S5-L-PMMA”:*



Results of Longitudinal Specimens

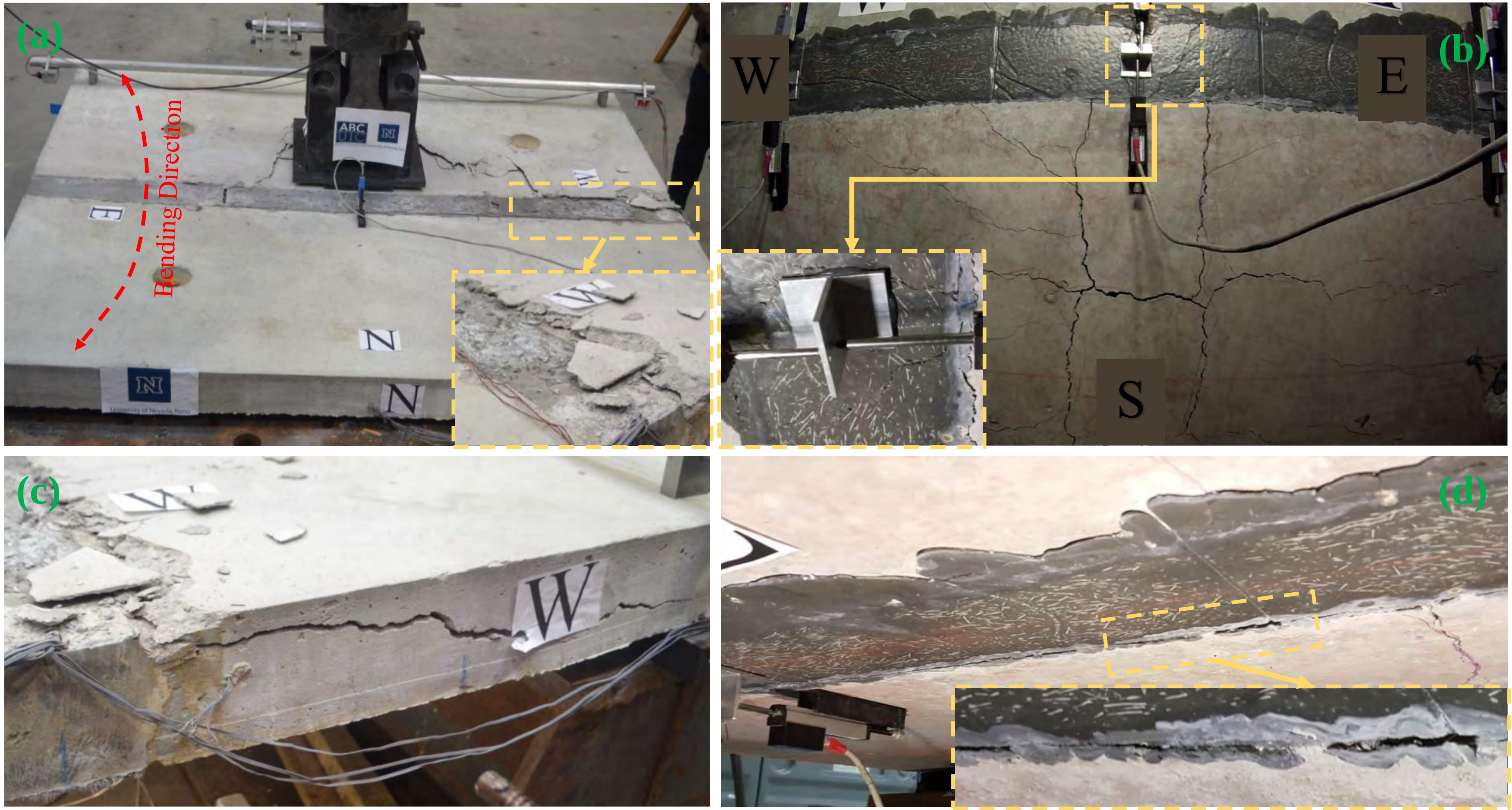
Summary of Results:

Specimen Name	Peak Load (kips)	Mid-span Deflection at Peak Load (in)	Mid-span Deflection at Service Load (in)	Mid-span Deflection at Ultimate Load (in)	Initial Stiffness (kips/in)
S4-L-UHPC	115.8	1.51	0.193	0.387	240
S5-L-PMMA	98.2	1.41	0.231	0.424	210

Results of Longitudinal Specimens

Damage progression and mode of failure

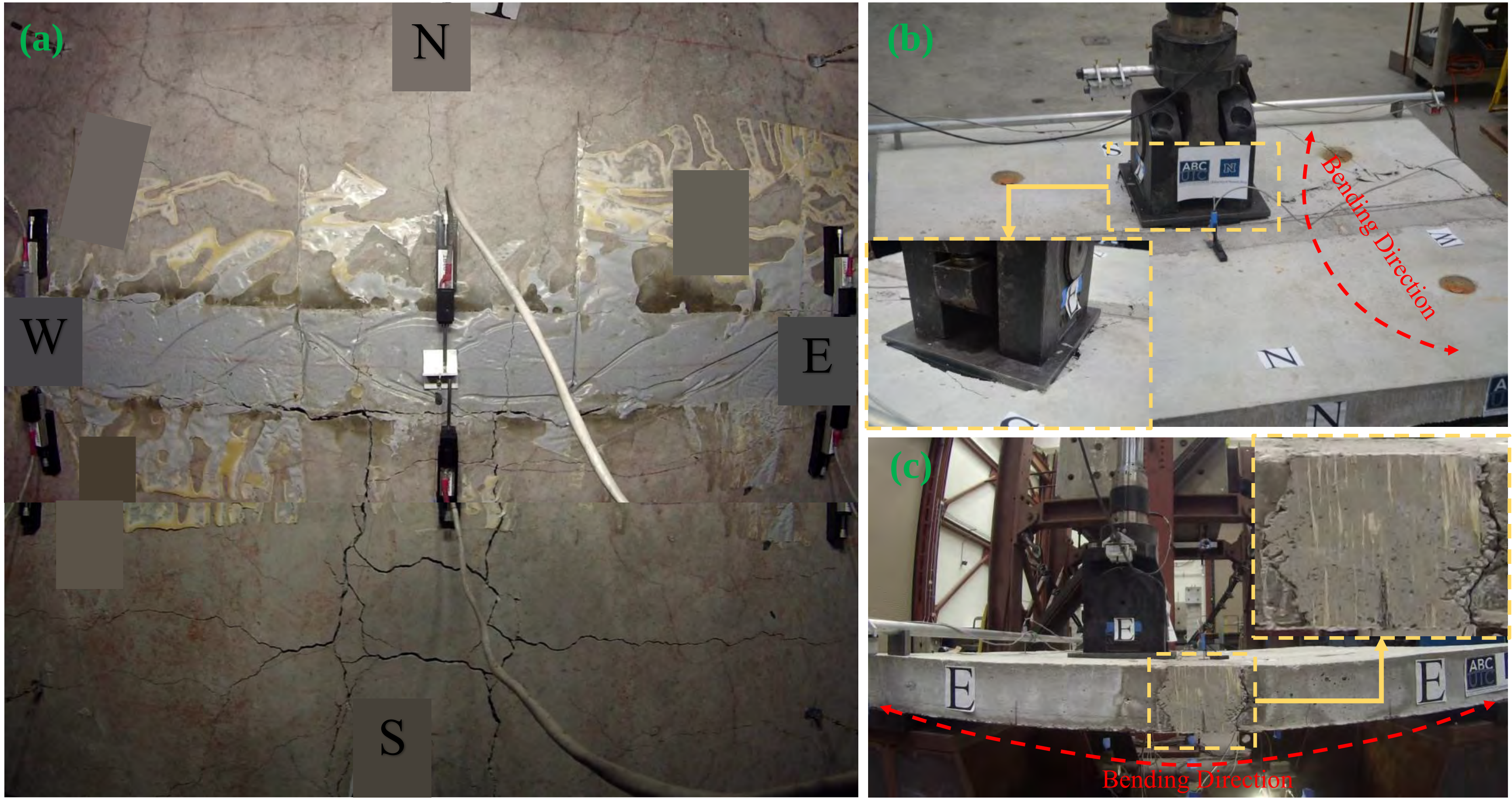
- *"S4-L-UHPC":*



Results of Longitudinal Specimens

Damage progression and mode of failure

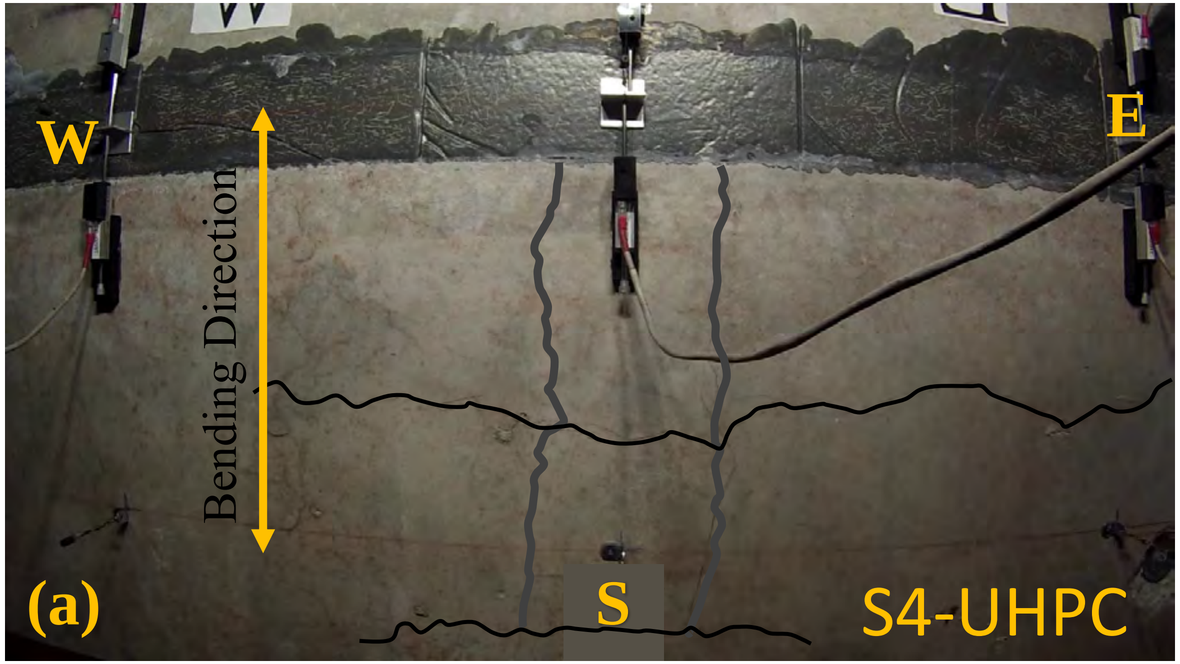
- *"S5-L-PMMA":*

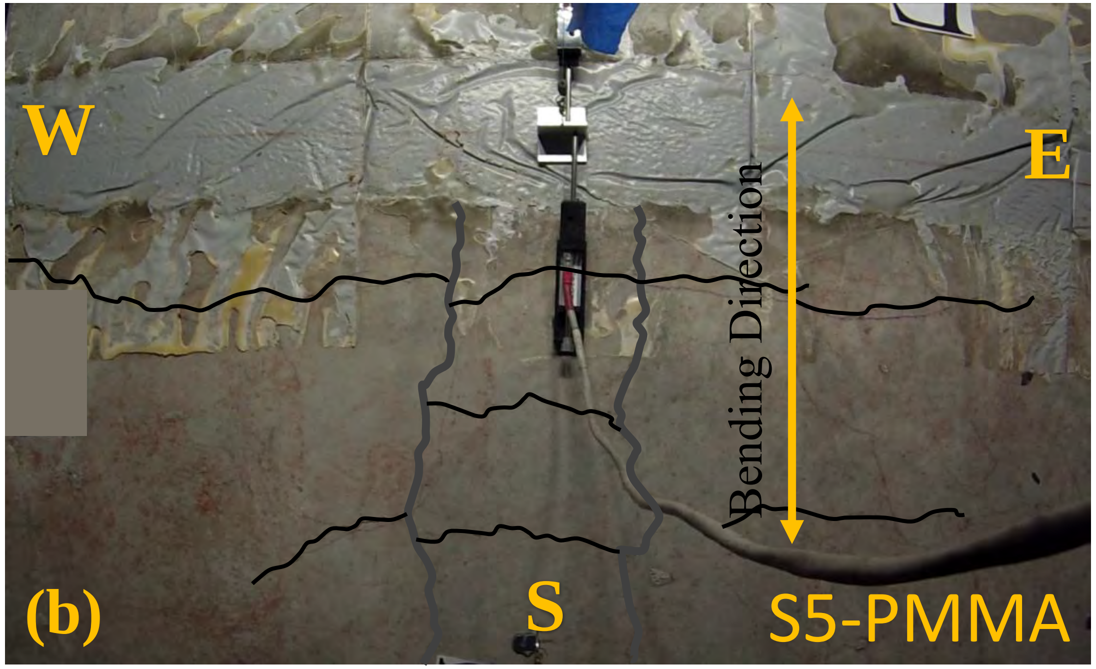


Results of Longitudinal Specimens

Crack pattern at the AASHTO ultimate load

- *“S4-L-UHPC” vs “S5-L-PMMA”:*

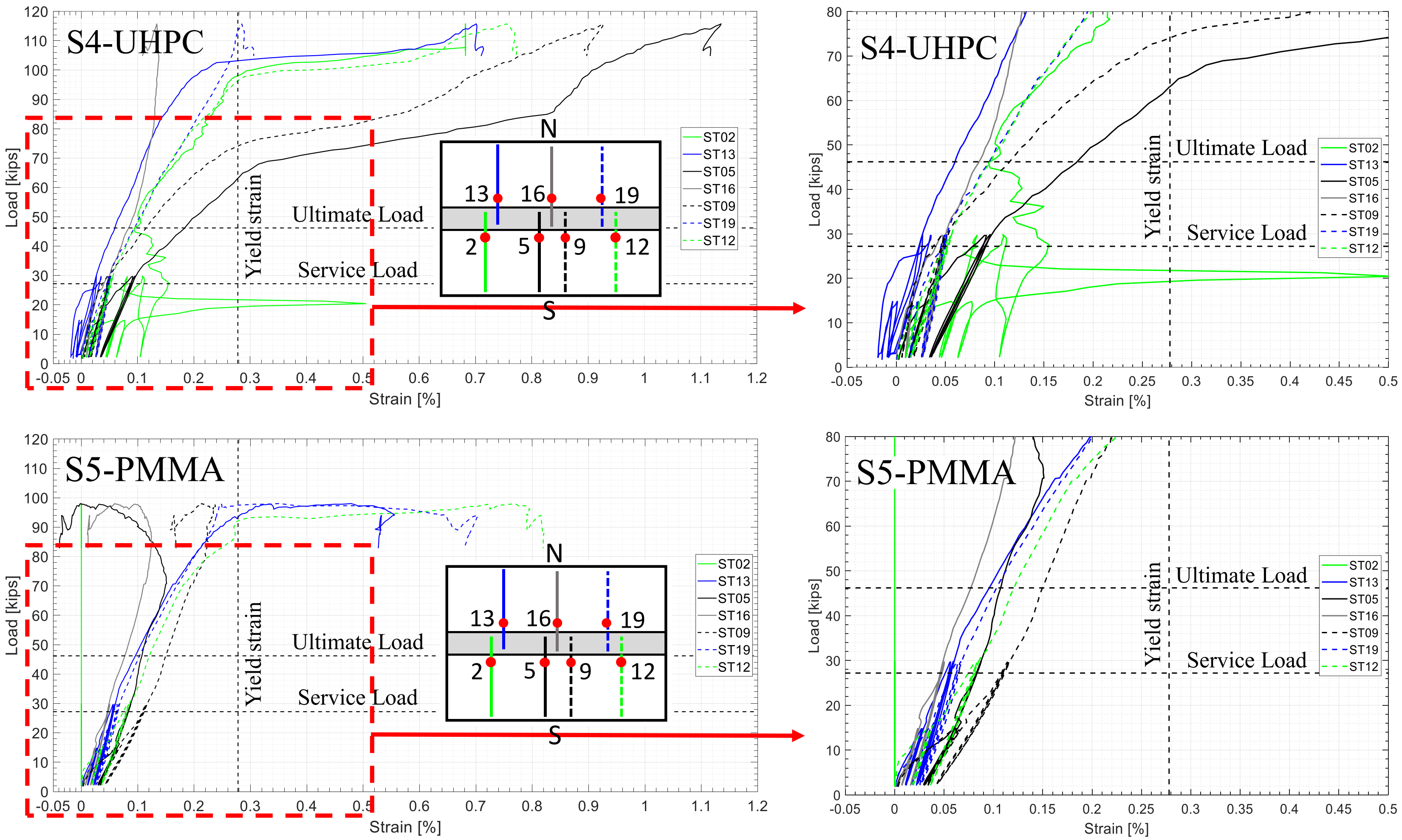




Results of Longitudinal Specimens

Load-strain relationship

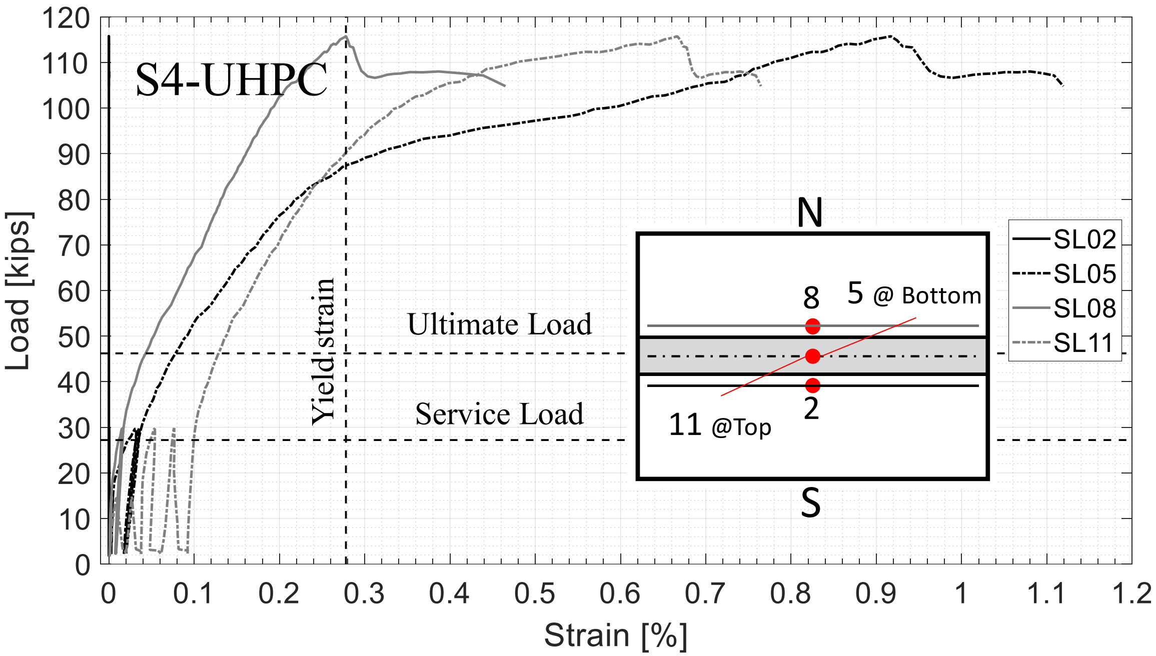
- *"S4-L-UHPC" vs "S5-L-PMMA":*

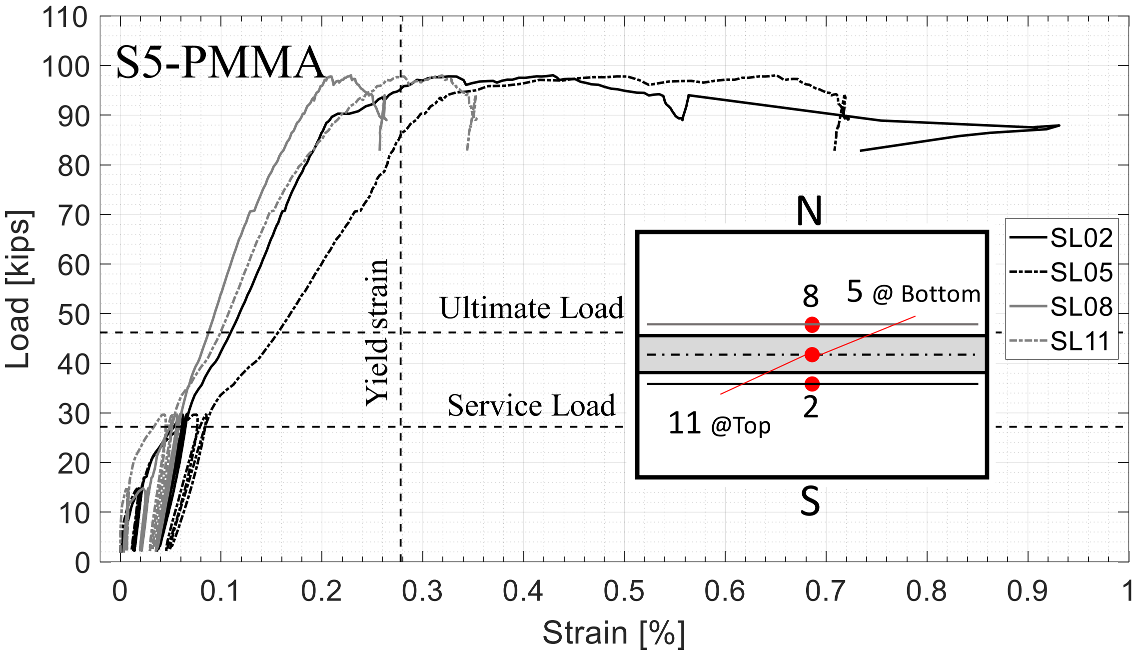


Results of Longitudinal Specimens

Load-strain relationship

- *"S4-L-UHPC" vs "S5-L-PMMA":*





Concluding Remarks

- The PMMA-PC field joints results in a very comparable performance to the currently accepted practice of UHPC field joints in terms of service performance as well as load and deflection capacities.
- Both UHPC and PMMA-PC field joints adequately satisfy the specified AASHTO LRFD service and ultimate load requirements, where deck systems should remain elastic without any major flexural or interface cracking in the joint or any bar slippage.
- No flexural or interface cracks were observed in the UHPC or the PMMA-PC joints up to the AASHTO LRFD ultimate load level, which could be attributed to the higher tensile and bond properties of both materials compared to high strength grouts or conventional concrete.

Concluding Remarks

- Initial stiffness of the deck system with UHPC joint was found to be higher than that of the system with PMMA-PC joint, which is attributed to the higher mechanical properties, mainly modulus of elasticity, of UHPC. However, the slightly lower stiffness from PMMA-PC joints did not lead to any excessive deflections or deficiency in meeting code requirements.
- Both UHPC and PMMA-PC systems showed adequate load distribution capabilities all the way through failure without any shear failure or significant interface debonding.
- The proposed PMMA-PC field joint with a new shear key shape and shorter loop splice length was successfully validated as another viable alternative. This detail provided more strength and ductility in addition to better load distribution across the precast panels than UHPC or PMMA-PC joints with straight lap splice.

Concluding Remarks

- The flexural capacity of the longitudinal UHPC specimen was found to be higher than the PMMA-PC longitudinal specimen. Nonetheless, both specimens had comparable behavior in terms of loads, deflections, and field joint performance at the AASHTO ultimate load level, which is the more relevant limit state.
- The structural performance of DBT girder flanges/slabs with full-depth longitudinal PMMA-PC field joints is demonstrated to be a viable alternative for ABC.
- PMMA-PC can be effectively used inside full-depth bridge deck field joints without any need for post-tensioning or mechanical splicing. This indirectly also confirms that the 6 in field joint width, typically used for UHPC, is also sufficient for PMMA-PC to provide emulative, i.e., monolithic-equivalent, bridge deck systems in terms of load distribution.

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Reference

- Mohamed Abokifa, Mohamed A. Moustafa. “Experimental behavior of poly methyl methacrylate polymer concrete for bridge deck bulb tee girders longitudinal field joints”, Construction and Building Materials, Volume 270, 2021, ISSN 0950-0618. (http://www.sciencedirect.com/science/article/pii/S0950061820338447).

Thank You! Questions?