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Integrating Additive Manufacturing with Accelerated Bridge Construction Techniques

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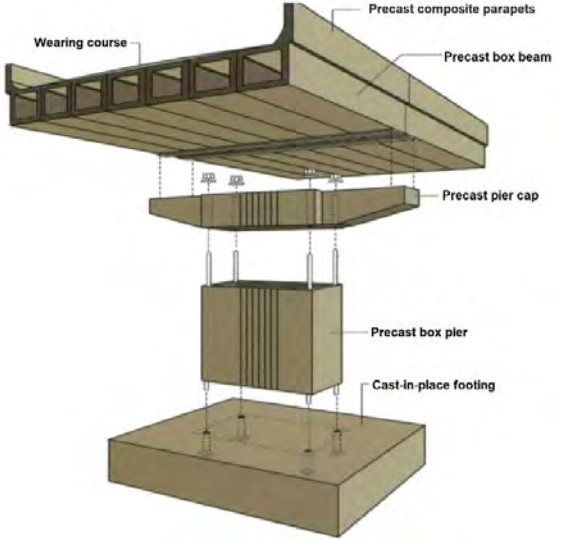
The Research Problem

Modular forms of bridge construction have been of continued interest in prefabricated bridge elements and systems (**PBES**)

The Limitations:

- ➢ High cost for developing modular forms
- ➢ Time consuming and labor intensive
- ➢ Construction safety concerns
- ➢ Limited customizability



The Needs:

Increase the construction quality of PBES

Reduce their construction time and labor cost

Enhance the safety and reliability

Minimize the environmental footprint of the PBES fabrication plants

Produce structural elements with optimized topologies

Enable in-situ repair of existing ABC elements via customizable design

Project Objectives/Deliverables

Objectives:

- Explore the feasibility of integrating additive manufacturing with ABC techniques in Pennsylvania
- Identifying, fabricating and mechanical testing of 3D printable prefabricated bridge elements currently used in ABC projects

Tasks and Deliverables:

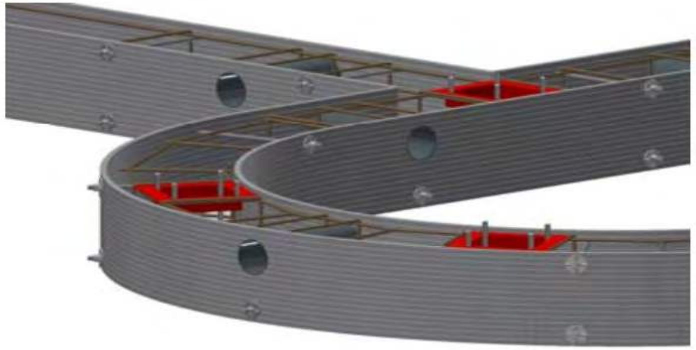
- Task A: Review of the stat-of-the-art of 3D concrete printing research
- Task B: Identifying optimal 3DCP reinforcement
- Task C: 3D printing of prefabricated elements in ABC systems
- Task D: Development of recommendations
- Task E: Final report

Literature Review

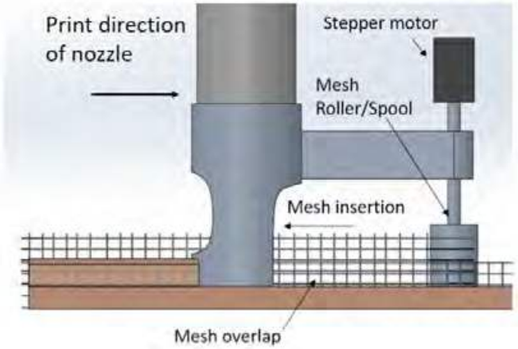
Potential Reinforcement Strategies:


Placing steel reinforcement horizontally between 3d-printed concrete layers


Concrete floor slabs with add-on-printed reinforced ribs


Placing vertical reinforcement in 3D printed formwork


Post-tensioning of steel reinforcement placed in 3D printed conduits



Mesh insertion and embedment using the custom-designed 3D printing nozzle

Concrete Beam 3D Printing

Without Reinforcement

Printed Formwork

Printed Entire Sample

With Reinforcement

Printed Formwork with Reinforcement

Printed Entire Sample with Reinforcement

Concrete Beam 3D Printing

Without Reinforcement

Printed Studs Formwork

With Reinforcement

Printed Studs Formwork with Reinforcement

Sikacrete^{R} -752 3D micro-concrete

Compressive strength[1]	**1st day**	**~2,900 psi**
	7th day	~5800 psi
	28th day	~7,250 psi
Flexural strength[2]	~1,000 psi	
Water penetration under pressure[3]	~0.8 inch	
Service temperature	Under 212 °F	

1) Tested at +77 °F, w/c=17% (1.10-gallon water per 55 lb bag) (ASTM C109)

2) Tested at +77 °F, w/c=17% (1.10-gallon water per 55 lb bag) (ASTM C348)

3) Tested at +77 °F, w/c=17% (1.10-gallon water per 55 lb bag)

Printed Entire Sample with Staples

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Concrete Beam Tests

Cast

Printed Entire Sample

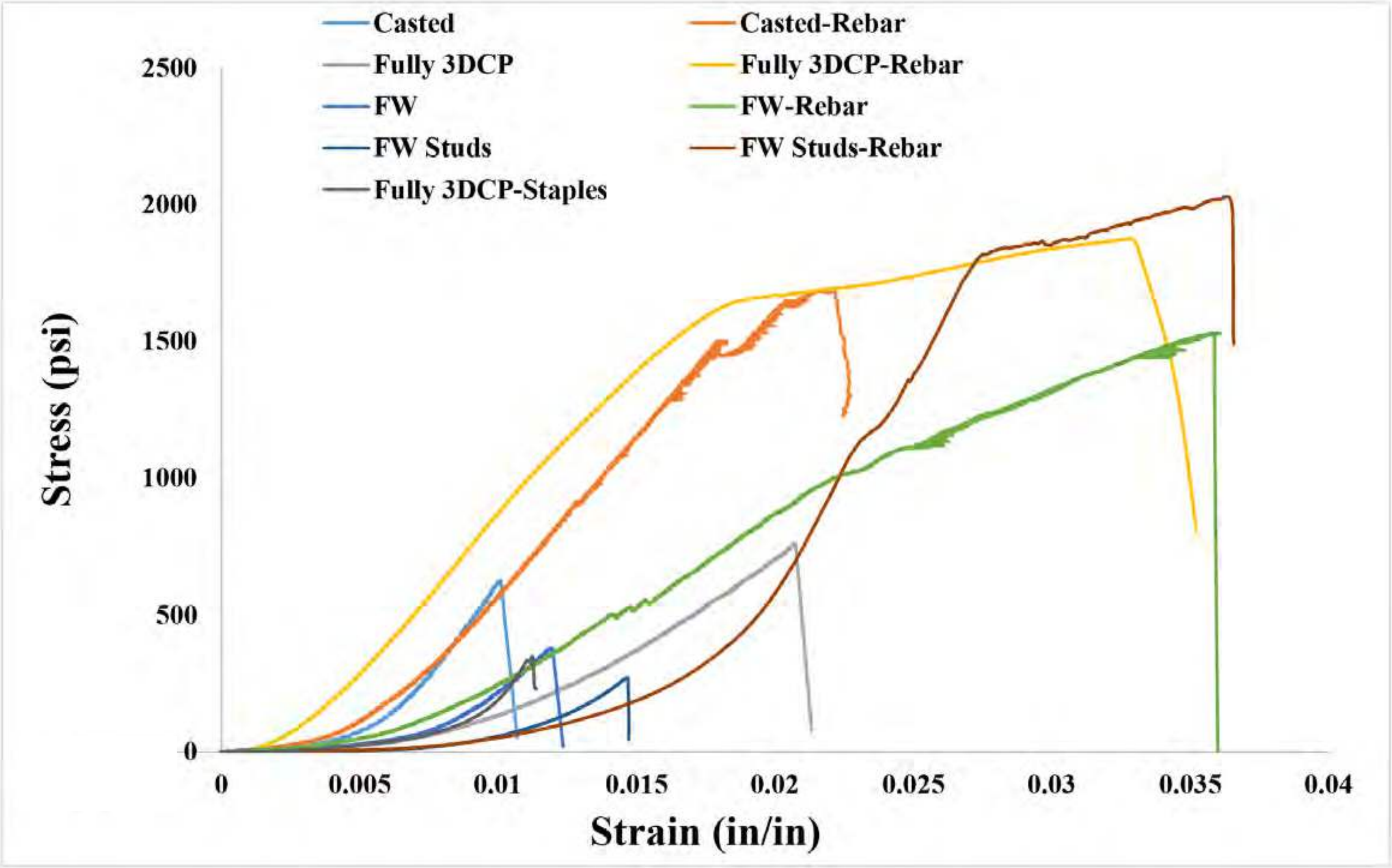
Printed Formwork

Concrete Beam Tests

Cast with Reinforcement

Printed Formwork with Reinforcement

Concrete Beam Test Results



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Concrete Beam Test Results

Casted-Plain

Beam Width	6	in
Beam Height	6	in
Max Load	5.17	kips
Max Stress	646.33	psi

3DP-Walls-Plain

Beam Width	8	in
Beam Height	6	in
Max Load	4.20	kips
Max Stress	393.45	psi

3DP-Stud-Plain

Beam Width	8	in
Beam Height	7	in
Max Load	4.82	kips
Max Stress	331.69	psi

Fully Printed-Plain

Beam Width	8	in
Beam Height	6	in
Max Load	8.26	kips
Max Stress	774.31	psi

Casted-Rebar

Beam Width	6	in
Beam Height	6	in
Max Load	13.64	kips
Max Stress	1704.90	psi

3DP Wall-Rebar

Beam Width	9.5	in
Beam Height	6	in
Max Load	19.63	kips
Max Stress	1549.43	psi

3DP-Stud-Rebar

Beam Width	7	in
Beam Height	7	in
Max Load	29.46	kips
Max Stress	2319.04	psi

Fully Printed-Rebar

Beam Width	10	in
Beam Height	7	in
Max Load	34.06	kips
Max Stress	1876.64	psi

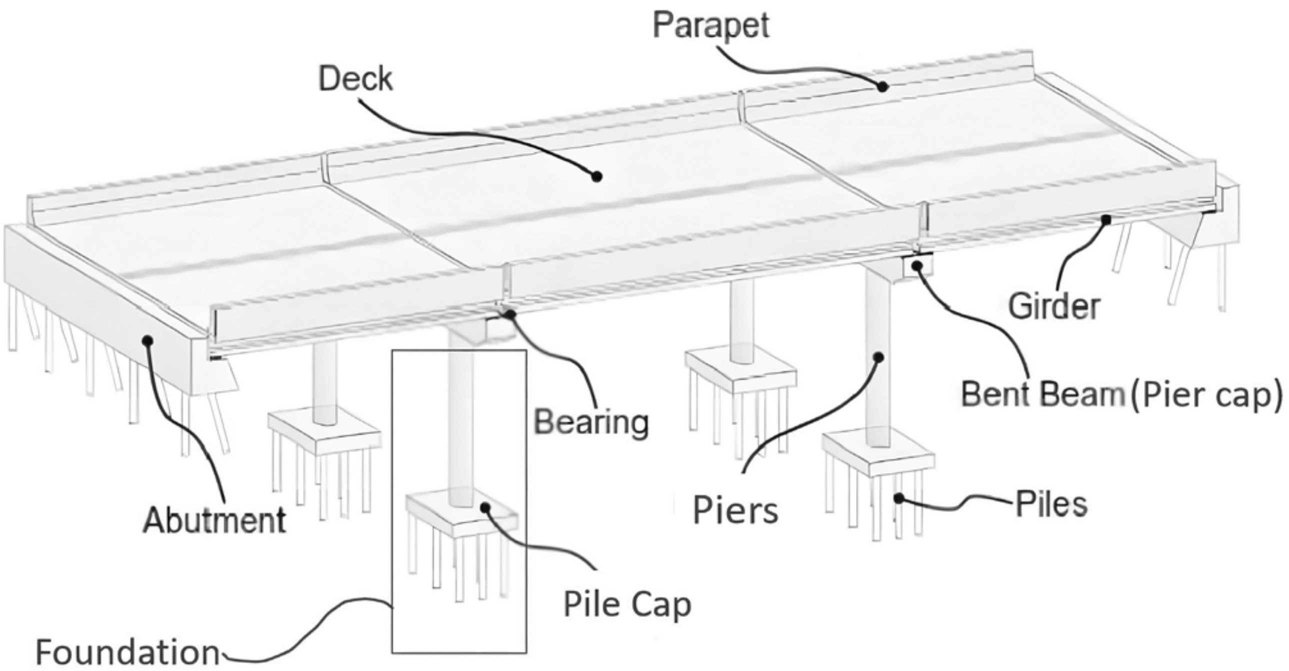
Fully Printed- Staple

Beam Width	8	in
Beam Height	6	in
Max Load	5.07	kips
Max Stress	474.94	psi

Bridge Component Selection

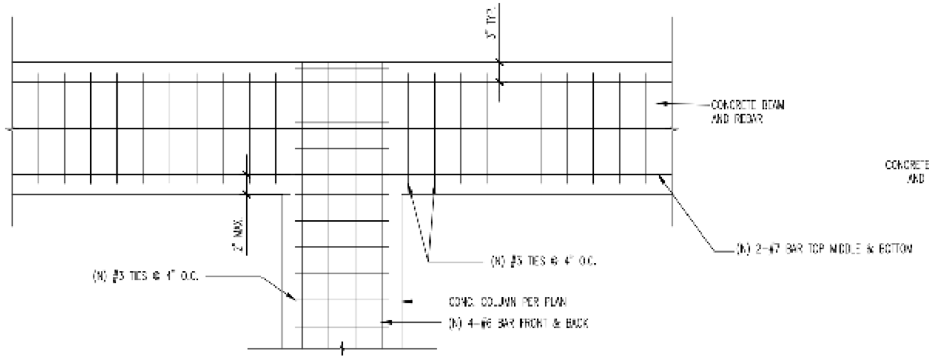
Main Components:

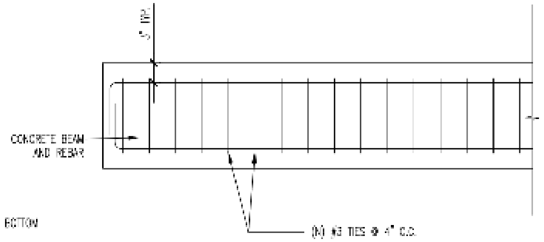
- Abutment
- Girder
- Bent Beam
- Piers

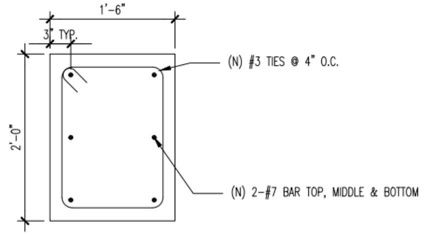


Final Decision: Pier cap

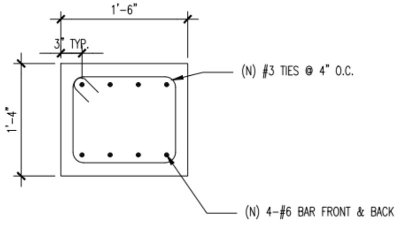
Pier Cap Design Details







CONC. BEAM CROSS SECTION



CONC. COL. CROSS SECTION

Micro-concrete

Compressive Strength	1 day	7 days	28 days
	~2900 psi	~5800 psi	~7250 psi
Flexural Strength	~1000 psi (28 days, 77 °F, 17% w/c ratio)		

Standard Concrete

Compressive Strength	28 days
	4000-10000 psi
Flexural Strength	800~1200 psi

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Pier Cap Design and 3D Printing

Conventionally Cast Reinforced Pier Cap

3DCP of Pier Cap Formwork

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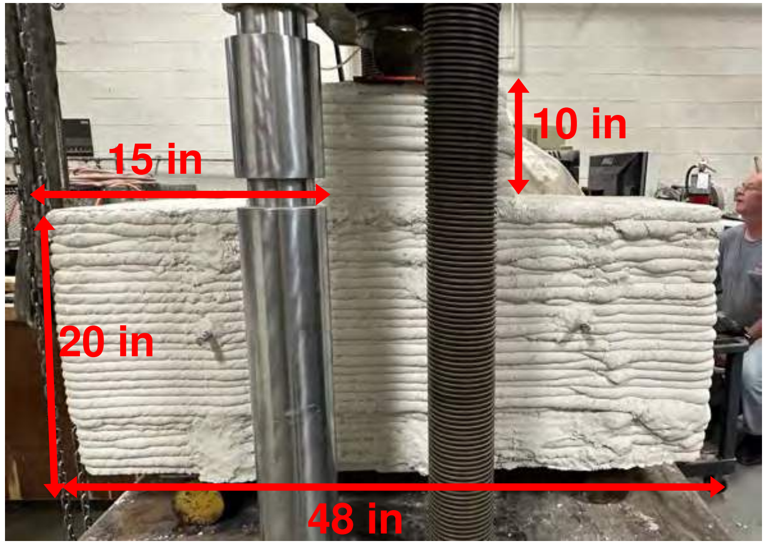
Pier Cap Test Results

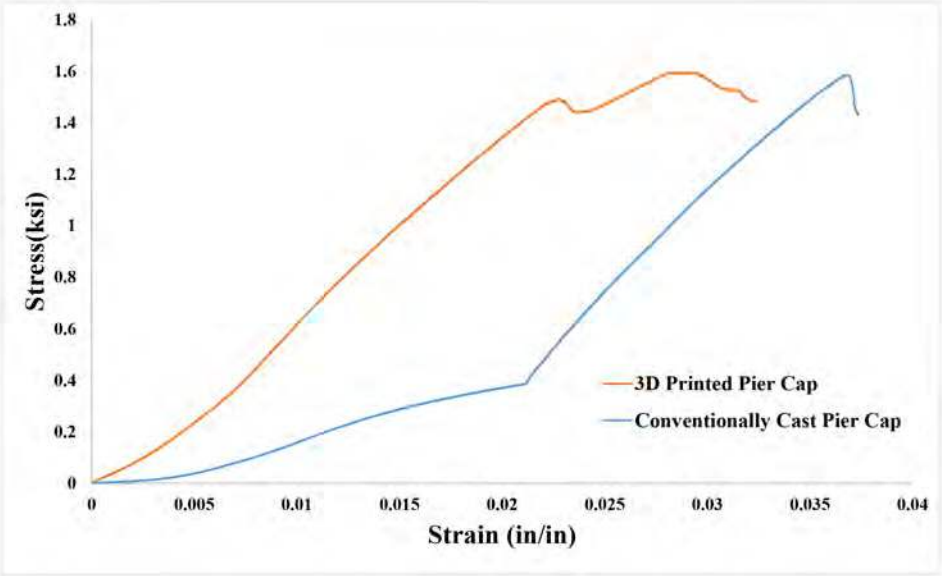


Shear Failure of Pier Caps

Conventionally Cast

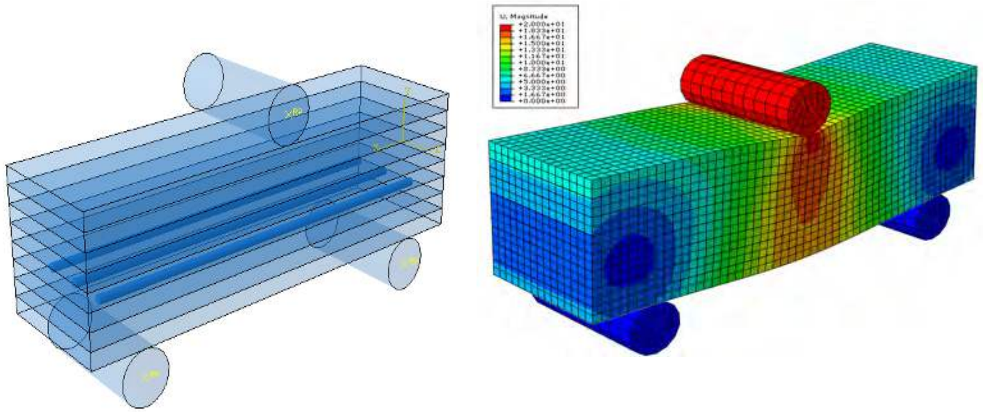
3DCP

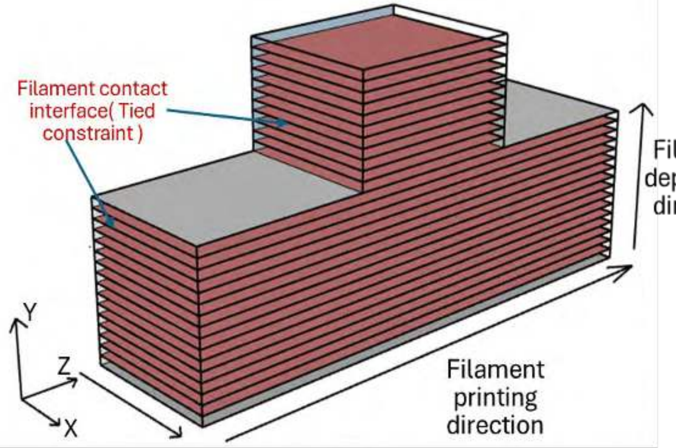
Stress-strain curves

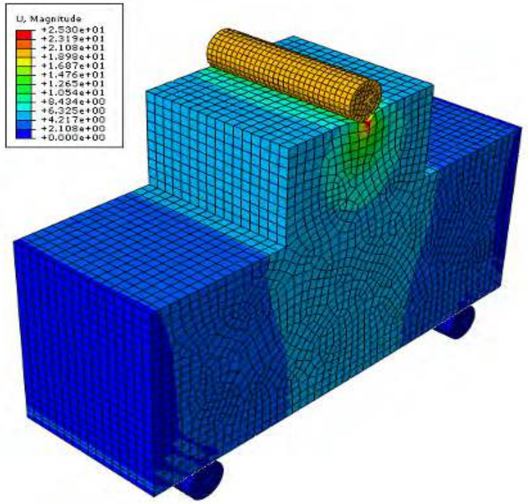


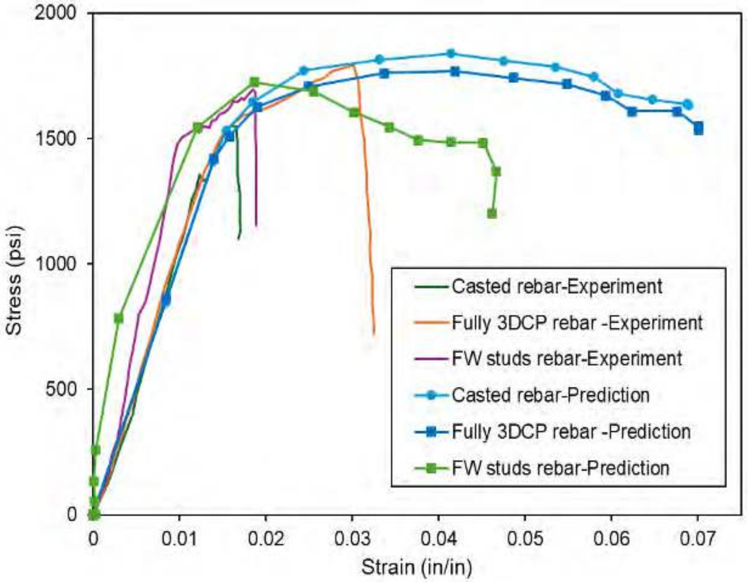
Pier Cap Test Results

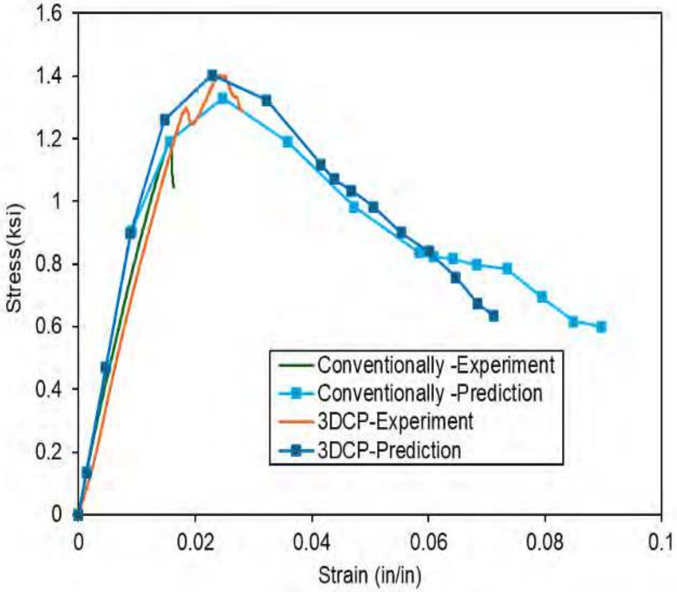
Numerical Simulations











Summary

- Feasibility of using additive manufacturing for developing PBES for ABC
- 3DCP beams without refinement demonstrated acceptable strength results compared to the conventionally cast samples
- Reinforced 3D printing formwork with studs showed higher strength than other samples
- Conventionally cast pier cap provided a similar strength to the cap with reinforced 3DCP formwork with studs
- The 3D printed pier cap exhibited higher stiffness

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Further Considerations

- **Exploring the stapling reinforcement method (e.g. understanding how overlaps influence strength)**
- **Investigating the integration of smart technologies, such as sensors and monitoring systems, into 3DCP prefabricated elements**
- **Material discrepancies: The divergence in materials between 3DCP and traditional concrete introduces a challenge**
- **Durability and long-term performance**

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Acknowledgement

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Thank you

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