14th Advances in Cement-Based Materials

Assessment of High-volume Harvested Fly Ash Blends for Use in Precast Construction

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My **Background**

Assistant Professor of Civil Engineering
& Director of the Concrete Materials and Structures Laboratory
Department of Civil, Architectural and Environmental Engineering
Illinois Institute of Technology (Chicago, IL)
2019 - Present

PhD in Structural Engineering
Lehigh University
2019

MS in Structural Engineering
Lehigh University
2016

BS in Civil Engineering
Minor in Engineering Mechanics
Penn State University
2014

Research Areas
- Behavior and mechanics of concrete structures
- Innovative precast concrete components
- Innovative cementitious materials
- Experimental methods
- *Blast design and analysis methodologies*
- *Progressive collapse mitigation*

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Highlights of **IIT Concrete Materials & Structures Laboratory**

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Highlights of **IIT Concrete Materials & Structures Laboratory**

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Presentation **Outline**

+ Overview/Review of precast concrete
+ Development of high-volume harvested fly ash (HV-HFA) binder formulations
+ Performance testing of HV-HFA concrete mixtures
+ Design, fabrication, and larger-scale experimental testing
+ Implications for design guidelines and standards

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Precast Concrete → The process of fabricating concrete components in a location other than their final position.

Tilt-Up (site prefabricated)

Factory Precast

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HVFA use is more feasible in cast-in-place (CIP) concrete construction than **precast** concrete due to specialty **structural performance requirements**.

Development of **high early strength** is crucial for precast components

Maximizes operational efficiency of the facility by turning over casting beds rapidly

Components often stripped from formwork within ~24 hours of fresh concrete placement

Second photo source: "QUIKLIFT™ DTA Installation to Stripping (Precast Double Tee) by ALP Supply (formerly Patterson)" https://www.youtube.com/watch?v=sBCznhGwfFY&ab_channel=ALPSupply

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Research **Objectives** and Expected **Outcomes**

1) Increase fly ash beneficial use by at least 15% in the precast concrete industry

2) Maintain or exceed stringent structural property requirements
(e.g., compressive strength at initial prestress, modulus of rupture, etc.)
Ex: 3500 psi compressive strength typical at initial prestress (~24 hrs.)

3) Exhibit little or no additional cost relative to conventional mixtures

4) Facilitate harvesting of large fly ash quantities from landfills

5) Influence new design guidelines and code provisions for sustainability requirements for concrete mix designs

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Development of **Optimized HV-HFA Binders**

Evaluating mainly **compressive strength** and **flow**

Binary Binders
→ HV-HFA & Type III Portland Cement w/ additional optimization

Ternary Binders
→ HV-HFA, Type III Portland Cement, [additional material] (w/ additional optimization)
→ Ex: CSA, slag, calcined clay, etc.

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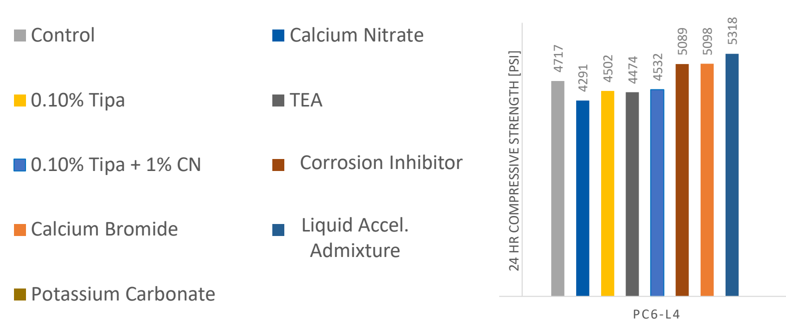
Evaluation of HV-HFA ***[binary]*** **binders**

→ **GOAL:** ~4000 psi compressive strength of mortar samples at 24 hrs.

→ <u>NOTE</u>: Slightly different than the overall goal of 3500 psi for concrete (discrepancy between mortar and concrete)



<u>Successful Accelerators:</u>
1- Calcium Bromide
2- Tipa (Triisopropanolamine) + CN (Calcium nitrate)
3- Sika Set NC (Calcium Nitrate, Sodium Thiocyanate)
4- Sika CNI (Calcium Nitrite)

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Gypsum optimization

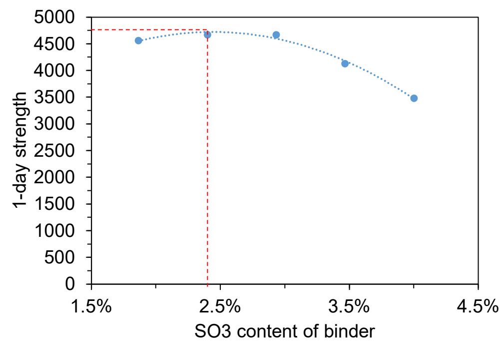
Determine SO_3 Content of Binder

Material	SO_3 (XRF)
Type III	2.80%
Class F	2.20%
Class C	2.00%
Landfilled	0.46%
Gypsum	46.5%

ASTM - C563: Standard Guide For Approximation of Optimum SO_3 in Hydraulic Cement.

ASTM- C595: Standard Specification for Blended Hydraulic Cements determines the maximum sulfate reported as SO_3 as **"4%"**

Mix	SO_3 Content	1 day strength
L-G0	1.86%	4563
L-G1	2.40%	4670
L-G2	2.93%	4671
L-G3	3.47%	4131
L-G4	4.00%	3483



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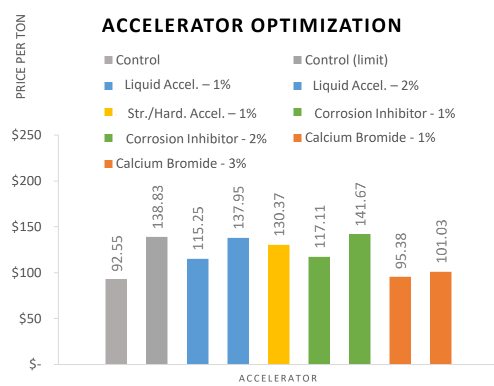
Accelerator [admixture] optimization

→ **GOAL:** Balancing of optimized cost and 24-hour strength performance



	Corrosion Inhibitor	Liquid Accel. Admixture	Calcium Bromide	Strength/Hardening Accel. Admixture
Optimal %	1%	1%	1.50%	0.50%
Strength	5476	5269	5554	5134

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Scaling to **HV-HFA Concrete**

Optimization of 1) aggregate packing, 2) admixture dosage, and 3) w/c ratio was used to scale most promising binders to HV-HFA concretes

→ **Compressive** and **flexural strength** evaluated at several points during early-age period

(e.g., within ~12-24 hours & also at 28 days)

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HV-HFA **Compressive Strength** Results

Minimum Goal
3500 psi comp. strength
@ 24 hours

	Mix ID	12 hr.	16 hr.	18 hr.	20 hr.	24 hr.	28 days
		Compressive Strength (psi)					
Type III	L40-Control		2540		3120	3510	8889
Type III	L40-G		2184		3120	3510	8889
Type III	L40-G-NCA		3455		4064	4545	12150
Type III	L40-G-CI		3069		3674	3880	10216
Type III	L40-G-SHA		3224		3584	3912	9361
Type IL	L40-IL-G-NCA-SEA		3784		4405	4946	12311

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HV-HFA **Flexural Strength** Results

	Mix ID	12 hr.	16 hr.	18 hr.	20 hr.	24 hr.	28 days
		Flexural Strength, MOR (psi)					
Type III	L40-Control		473		542	566	895
Type III	L40-G		413		470	548	947
Type III	L40-G-NCA		551		589	632	1089
Type III	L40-G-CI		538		560	616	938
Type III	L40-G-SHA		538		587	634	935
Type IL	L40-IL-G-NCA-SEA		570		647	648	1173

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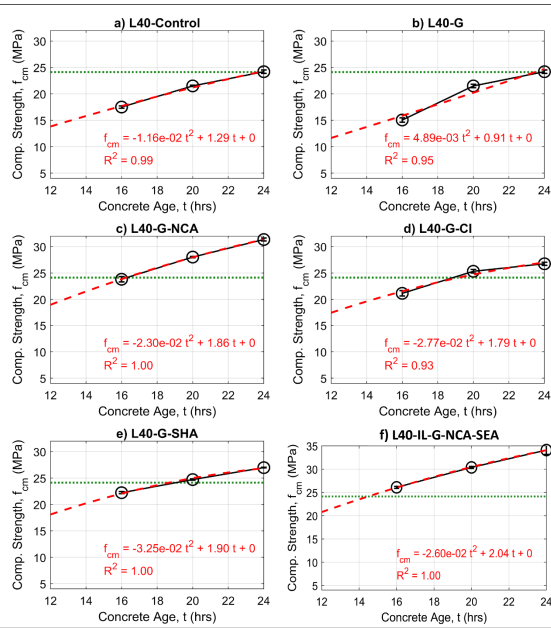
Characterizing **HV-HFA Compressive Strength** Development



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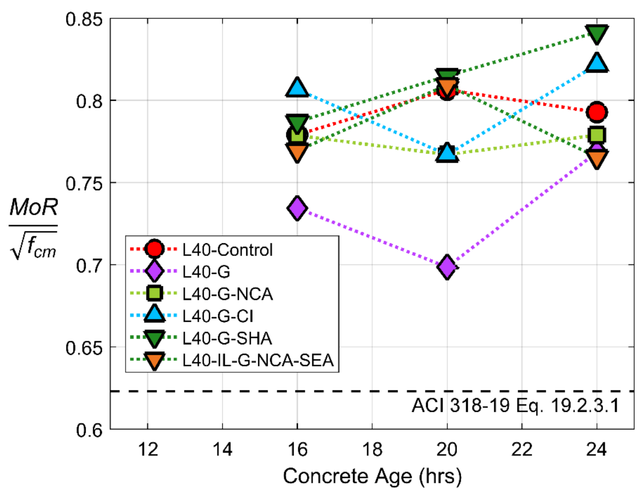
Characterizing **HV-HFA Flexural Strength** Development



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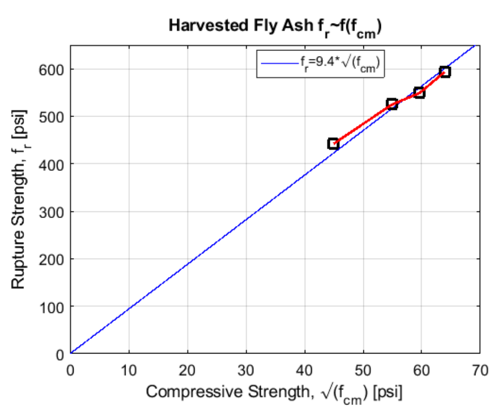
Scaling Up to **HV-HFA Concrete Structures**

- Conduct ASTM C39 (f_{cm} from cylinders) & ASTM C78 (f_r from small beams) simultaneously
- Plot f_r vs. √(f_{cm})
  - → very similar to approach to get HVFA strength development curves but done under ambient conditions to reflect fabrication of larger-scale components (such as beams)



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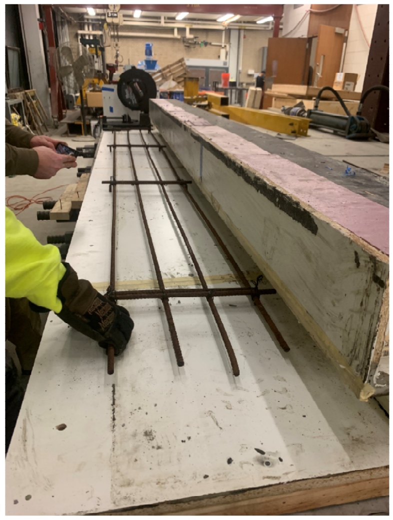
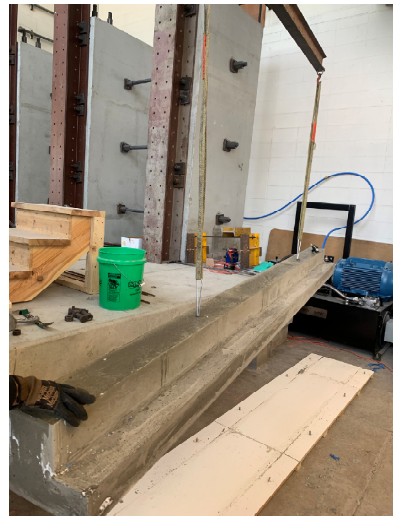
Larger-Scale Beam Testing

Three main demonstrations:

1) Scale up HV-HFA concrete technology in an environment that closely resembles a precast plant (IIT CM&S Lab)
2) Proof-of-concept early-age lifting/handling tests
3) Tension-driven analysis framework validation (i.e., calculating M_{cr})





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Larger-Scale Beam Testing (cont…)

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Larger-Scale Beam Testing (cont…)

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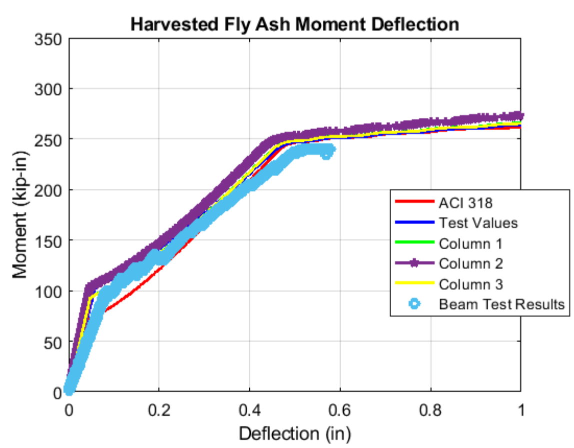
Scaling Up to HVFA Concrete Structures cont… (Task 5)

Framework Validation via Early-Age HV-HFA Beam Testing

→ Demonstration of lifting/handling

→ Validation of calculating M_{cr}



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Conclusions

Objective 1: **Increase fly ash beneficial use by at least 15% in the precast concrete industry**
Outcome: **Several HV-HFA mix designs with 40% fly ash (increase of 15% relative to traditional max. of 25%) were designed for use in precast operations and tested for pertinent limit states/criteria.**

Objective 2: **Maintain or exceed stringent structural property requirements**
Outcome: **All HV-HFA mixes in this study exhibited satisfactory early-age performance (i.e., >= 3500 psi comp. strength within 24 hours). Many mixes greatly exceeded this metric.**

Objective 3: **Exhibit little or no additional cost relative to conventional mixtures**
Outcome: **HV-HFA binders (and concrete mixes) were optimized to ultimately facilitate and balance structural performance (high-early strength) and cost.**

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Questions ?

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Thank You!