



## **Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)**

### **University Transportation Center (UTC)**

3D Printed Smart Permanent Concrete Formwork for Precast  
Structural Component-Structural Performance – Phase 2:  
Large Scale Testing  
LS-24-RP-02

Quarterly Progress Report  
For the performance period ending April 1<sup>st</sup> 2026

**Submitted by:**

Yen-Fang Su, [ysu@lsu.edu](mailto:ysu@lsu.edu)  
Department of Civil & Environmental Engineering  
Louisiana State University and A&M College

**Collaborators / Partners:**

Ayman Okeil, [aokeil@lsu.edu](mailto:aokeil@lsu.edu)  
Department of Civil & Environmental Engineering  
Louisiana State University and A&M College

**Submitted to:**

TRANS-IPIC UTC  
University of Illinois Urbana-Champaign  
Urbana, IL

## TRANS-IPIC Quarterly Progress Report :

### Project Description:

#### 1. Research Plan - Statement of Problem

Tens of thousands of bridges and more than 40% of all the roads and highways in the US are in urgent need of rehabilitation (Azhar et al. 2024). Structural health monitoring (SHM) has gained importance in detecting, measuring the severity, and locating the early damage on the concrete infrastructure. However, issues such durability, material compatibility, and cost challenge the wider adoption of this technology. Tackling these challenges by infusing additional functionalities into precast concrete (PC) will yield enhanced resilience and extended lifespan of the transportation infrastructure. In our previous research, self-sensing cementitious composites (SSCC) demonstrated the capability for producing smart formwork, the fabrication of which depended on the additive manufacturing technology (Taj and Su 2024). In this phase of our research, our aim is to evaluate the structural performance of large-scale 3D printed smart formwork and validate its feasibility in real-world applications.

#### 2. Research Plan - Summary of Project Activities (Tasks)

Task 1: Literature Review and Test Matrix Design

Task 2: Specimen Fabrication

Task 3: Load Testing

Task 4: Data Analysis and Multiphysics Modeling

### Project Progress:

#### 3. Progress for each research task

##### **Task 1: Literature Review and Test Matrix Design [100% completed to date]**

In this part of the research, we conducted a review of studies done on the self-sensing 3D printed large-scale structures. There has been a number of explorations on implementation of self-sensing concrete with the additive manufacturing (AM) technology to produce structural columns, beams, and slabs.

Wang et al. (Wang, Aslani, and Mukherjee 2022), achieved a 3D printable mixture with self-sensing capability by incorporating carbon fiber (CF) that could detect damage and sense strain. They proceeded by utilization of this mortar mix for 3D printing cementitious sensors and embedding them in 1.5 m long beams (Wang and Aslani 2023). They concluded that the 3D printed SSCC sensors were more effective in detecting damage, but not in sensing reversible strain. Next, the idea of fabricating a permanent mold using SSCC through AM process was explored (Atkinson and Aslani 2023; Li and Aslani 2023). To this end, permanent column molds with the dimensions of 24 x 24 x 100 cm were 3D printed and grouted afterwards (Atkinson and Aslani 2023). Noticeable piezoresistivity was achieved for this placement of SSCC, although the results needed improvement in the repeatability aspect. Furthermore, similar investigation on the self-sensing performance of slabs and beams under flexural loading were undertaken (Li and Aslani 2023). The piezoresistive response was recorded for 3.5 m long members were loaded until 80% of the maximum stress. In these cases, although the feasibility of stress and damage detection in large-scale 3D printed structural members were demonstrated, the members were not a monolithic print. Smaller sections for each structure were printed part-by-part and then assembled afterwards. This could be a major cause of concern if the performance was to be compared to the mold-cast members. The occurrence of cold joints between the sections are unavoidable and can have major consequences on the mechanical and piezoresistive performance.

With this in mind, we devised an experimental plan that consists of monolithic additively manufacturing of permanent square and circular column molds. The piezoresistive response will be evaluated for various levels of compressive loading for the columns and loading settings shown in Figure 1.

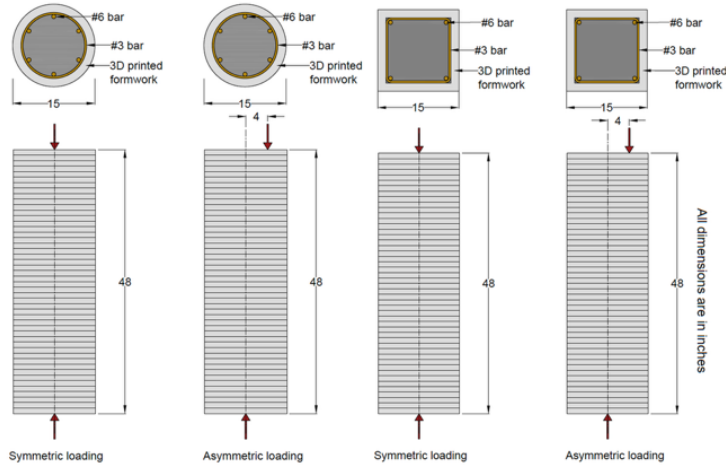


Figure 1. Column types and compressive loading configurations for 3D printed SSCC columns.

**Task 2: Specimen Fabrication [10% completed to date]**

The preliminary trials on printing large-scale permanent molds have already begun. The SSCC mixture designed in the first phase of this project is selected for AM. The material proportions of this mixture are shown in Table 1. Following the 3D printing of mCF05 mixture, the permanent molds will be grouted with reference mixture.

Table 1. Weight-based mix design ratios

Mix	OPC	Silica Fume	Sand	W/C	Filler Type	Superplasticizer	Filler Dosage*
Reference	0.8	0.2	1	0.40	-	PCE derivative	-
mCF05					Milled Carbon Fiber		0.005

In these trials, printing the column molds with high print quality achieved by optimizing the extrudability, printability, and buildability was intended. The secondary objective was to achieve the intended maximum height without the structure collapsing (elastic buckling).

In this study, a house-developed assembly of a robotic arm-based 3D concrete printing system was used. The hardware of this 3D printer consisted of 3 main parts: the robotic arm, the concrete pump, and the Extruder (Figure 2). The robotic arm is a KUKA model KR 70 R2100 with 6 degrees of freedom, allowing for rotation and translation in 3D space. It has a maximum reach and payload of 2101 mm and 85 kg, respectively. A portable screw pump that can provide a concrete flow from 0.3 to 14 liters/min was used. A 15 m long hose with an internal ID of 19 mm was connected to the outlet of the pump on one end and to the print head on the other. The print consisted of an inlet for the material, a rotary motor, a nozzle, and the connections in between.

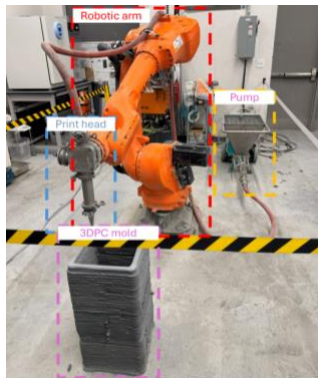


Figure 2. 3D printing setup with Kuka robotic arm, concrete pump, and print head.

The 3D printing of square column molds with different nozzle sizes has been undertaken. To maintain comparable cross-sectional area ratios of infill/shell, two different nozzles (8 mm ID and 16 mm ID) were used for printing the molds with cross sections of 150 mm x 150 mm and 300 mm x 300 mm, respectively. The nozzle and print parameters for these two nozzle sizes are presented in Table 2.

*Table 2. Nozzle dimensions and print parameters.*

Parameter	Nozzle 1	Nozzle 2
Nozzle ID (mm)	8	16
Layer width (mm)	15	30
Layer height (mm)	7.5	15
Robot speed (m/s)	0.2	0.2
Pump speed (RPM)	8	12

4. Percent of research project completed

Task 1: Literature Review and Test Matrix Design [100%]

Task 2: Specimen Fabrication [10%]

Task 3: Load Testing [0%]

Task 4: Data Analysis and Multiphysics Modeling [0%]

5. Expected progress for next quarter

In the next quarter, the completion of the fabrication of all the specimens are aimed. Additionally, the loading both symmetrically and asymmetrically at upper thresholds of 10%, 20%, and 40% will be performed.

6. Educational outreach and workforce development

To maximize the educational impact of this project, we actively extend our reach to K-12 education through participation in the Science Research Mentorship (SRM) program. The SRM program launched in 2012 and connects Kenilworth Middle School students with university faculty members and graduate students to conduct experiments that lead to science fair projects. During this program, the faculty work with graduate student mentored a middle school student with a parent present. From their observations, a presentation for a regional science fair was prepared and presented by the middle school student.

This calendar year, Amy Lopez, a middle schooler from Kenilworth Academy, was mentored by the graduate student Khalilullah Taj. She participated in the Louisiana Science and Engineering Fair held at Louisiana State University on March 3<sup>rd</sup>, 2026. She was able to secure the 3<sup>rd</sup> place in this competition. Below are a few pictures from this event Figure 3.

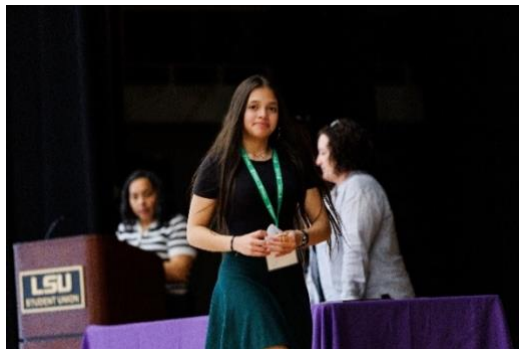




Figure 3. Shots from 2026 SRM Regional Science Fair held at Louisiana State University

7. Technology Transfer  
None

### **Research Contribution:**

8. Papers that include TRANS-IPIC UTC in the acknowledgments section:  
(G: Graduate Student, UG: Undergraduate Student)
- (1) K. Taj<sup>G</sup>, Y.-F. Su\*, V. Gopu, T. Rupnow, "Impedance-Based Characterization and Equivalent Circuit Modeling of Recycled Carbon Fiber-Enabled Self-Sensing Cementitious Composites" *Construction and Building Materials*, 2026 (Revision under review)
  - (2) K. Taj<sup>G</sup>, L. Reid<sup>UG</sup>, Y.-F. Su\*, "Environmental influence on the smart self-sensing 3D-printed concrete column", *Proceedings of SPIE. 2026 (Accepted)*
9. Presentations and Posters of TRANS-IPIC funded research:
- (1) K. Taj<sup>G</sup>, L. Reid<sup>UG</sup>, Y.-F. Su\*, "Environmental influence on the smart self-sensing 3D-printed concrete column", *SPIE Smart Structures + Nondestructive Evolution*, Vancouver, B.C., Canada, March 16-19, 2026
10. Please list any other events or activities that highlights the work of TRANS-IPIC occurring at your university  
None

### **References:**

- Atkinson, Cynthia D., and Farhad Aslani. 2023. "Performance of 3D Printed Columns Using Self-Sensing Cementitious Composites." *Construction and Building Materials* 375 (130961): 130961.
- Azhar, Anis Shafiqah, Sakhiah Abdul Kudus, Adiza Jamadin, Nur Kamaliah Mustaffa, and Kunitomo Sugiura. 2024. "Recent Vibration-Based Structural Health Monitoring on Steel Bridges: Systematic Literature Review." *Ain Shams Engineering Journal* 15 (3): 102501.
- Li, Zhuming, and Farhad Aslani. 2023. "Performance of 3D-Printed Beams and Slabs Using Self-Sensing Cementitious Composites and DIC Method." *Sensors (Basel, Switzerland)* 23 (20). <https://doi.org/10.3390/s23208486>.
- Taj, Khalilullah, and Yen-Fang Su. 2024. "Development of Durable Self-Sensing Cementitious Composites (SSC) for Transportation Infrastructures Rehabilitation and Monitoring." FHWA/LA.24/24-4TIRE. <https://trid.trb.org/View/2427607>.
- Wang, Lining, and Farhad Aslani. 2023. "Structural Performance of Reinforced Concrete Beams with 3D Printed Cement-Based Sensor Embedded and Self-Sensing Cementitious Composites." *Engineering Structures* 275 (115266): 115266.
- Wang, Lining, Farhad Aslani, and Abhijit Mukherjee. 2022. "Development of 3D Printable Self-Sensing Cementitious Composites." *Construction and Building Materials* 337 (127601): 127601.

**Appendix 1: Research Activities, leadership, and awards (cumulative, since the start of the project)**

- A. Number of presentations at academic and industry conferences and workshops of UTC findings
  - No. = 1
- B. Number of peer-reviewed publications submitted based on outcomes of UTC funded projects
  - No. = 1
- C. Number of peer-reviewed journal articles published by faculty.
  - No. = 0
- D. Number of peer-reviewed conference papers published by faculty.
  - No. = 1
- E. Number of TRANS-IPIC sponsored thesis or dissertations at the MS and PhD levels.
  - No. MS thesis = 0
  - No. PhD dissertations =0
  - No. citations of each of the above =0
- F. Number of research tools (lab equipment, models, software, test processes, etc.) developed as part of TRANS-IPIC sponsored research
  - Research Tool #1 (3D printing extruder, extruder for large scale concrete printing, and Figure 4) =1
  - Research Tool #2 (Name, description, and link to tool) =0
  - Research Tool #3 (Name, description, and link to tool) =0
- G. Number of transportation-related professional and service organization committees that TRANS-IPIC faculty researchers participate in or lead.
  - Professional societies
    - No. participated in =1
    - No. lead =0
  - Advisory committees (No. participated in & No. led)
    - No. participated in =0
    - No. lead =0
  - Conference Organizing Committees (No. participated in & No. led)
    - No. participated in =0
    - No. lead =0
  - Editorial board of journals (No. participated in & No. led)
    - No. participated in =0
    - No. lead =0
  - TRB committees (No. participated in & No. led)
    - No. participated in =1
    - No. lead =0
- H. Number of relevant awards received during the grant year
  - No. awards received = 0
- I. Number of transportation related classes developed or modified as a result of TRANS-IPIC funding.
  - No. Undergraduate =0
  - No. Graduate = 0
- J. Number of internships and full-time positions secured in the industry and government during the grant year.

- No. of internships =1
- No. of full-time positions =0