Semi-Annual Progress Report

Project Number and Title: Project 2.4 - Thermoplastic Composites by 3D Printing and Automated Manufacturing to Extend the Life of Transportation Facilities
Research Area: 2 - New Materials for Longevity and Constructability
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Co-PI(s): *James Anderson, Douglas Gardner and Yousoo Han, University of Maine*
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Overview:

Introduction

This project aims to extend the life of transportation facilities by using 3D printed molds to manufacture thermoplastic composite molds that can be used as formworks for precast concrete. This project addresses the need to develop durable and cost-effective forms and tooling for precast concrete parts used in transportation. This need has been identified in our meetings with representatives from the Precast/Prestressed Concrete Institute (PCI). As an alternative to wooden tooling, Gate Precast has found that 3D printed forms fabricated using large-scale additive manufacturing are more durable and better suited for supporting large projects [1]. Recent advances in large-scale 3D printing and thermoplastic composite materials with bio-based fillers and reinforcements have great potential for expanding the possibilities of making forms for precast concrete structures. For example, polylactic acid (PLA) that is a biodegradable thermoplastic derived from natural resources can be reinforced with cellulose nano fibers and/or wood fillers to enhance mechanical properties and reduced material cost.

We have discussed the application of additive manufacturing for making forms with researchers from Oak Ridge National Lab that is the leading place in the country in large-scale 3D printing. We also discussed applications of 3D printed forms with PCI New England. One important question asked by precasters is if 3D printed forms can be recycled and reused. The recycling process can be simplified by adapting the additive manufacturing equipment to use ground material, rather than pelletized material. The impact of mold release and concrete residue on the performance of the recycled material will also need to be investigated.

Background

Based on our discussions with MaineDOT and precasters, we decided to precast a box culvert using 3D printed forms. Culverts are short-span transverse and fully enclosed structures that provides passage for water across the roadways. It is difficult to make wooden forms for skewed sections for arches or boxes in the culvert. The skewed tongue and groove joints that connect the culvert sections and other intricate features are especially difficult to precast using conventional wooden forms. 3D printed forms would be useful in casting such skewed or arched sections.

A 3D model for a culvert was designed based on sketches received from MaineDOT. Figure 1 shows the 3D model of the box culvert. The box culvert is designed as an assembly of eighteen parts. The central eight parts are identical and can be cast using a single set of forms. Eight outer open-sectioned parts are similar and require four different forms. A total of seven different sets of 3D printed forms will be necessary to precast these parts.

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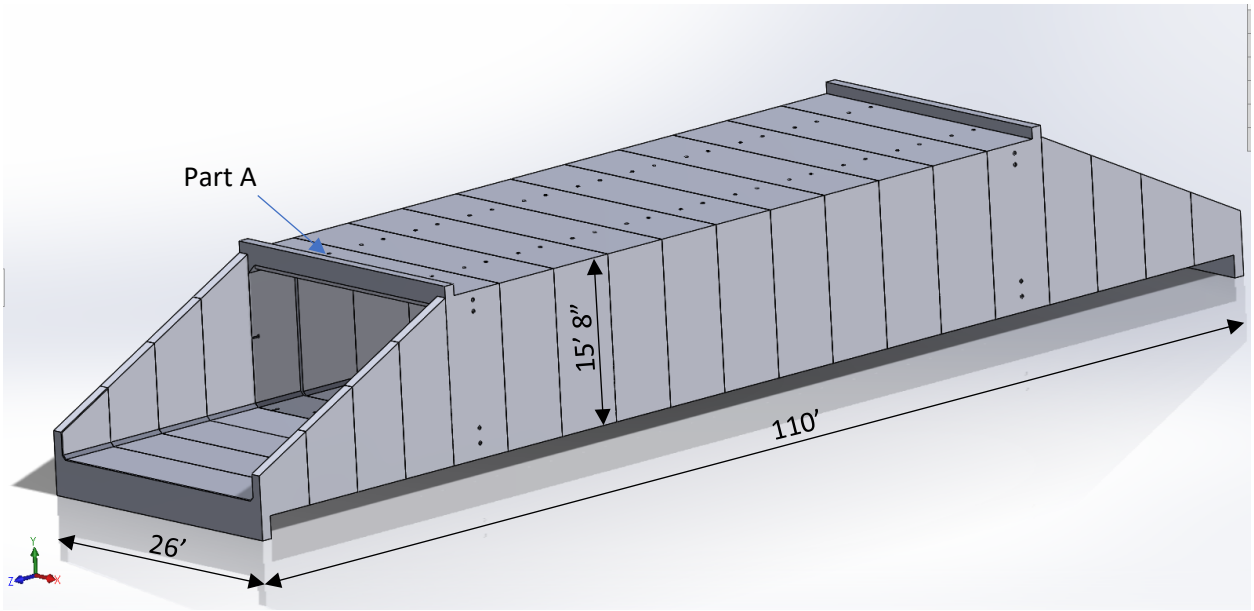


Figure 1: 3D model of the box culvert.

Part A marked in Figure 1 and shown in Figure 2 was selected for initial prototyping and testing. Out of all the parts in the assembly, part A poses highest difficultly to create precasting forms. The part has irregular features like chamfers, internal features, and tongue and groove joint. These features make forms difficult to remove once the concrete is cast.

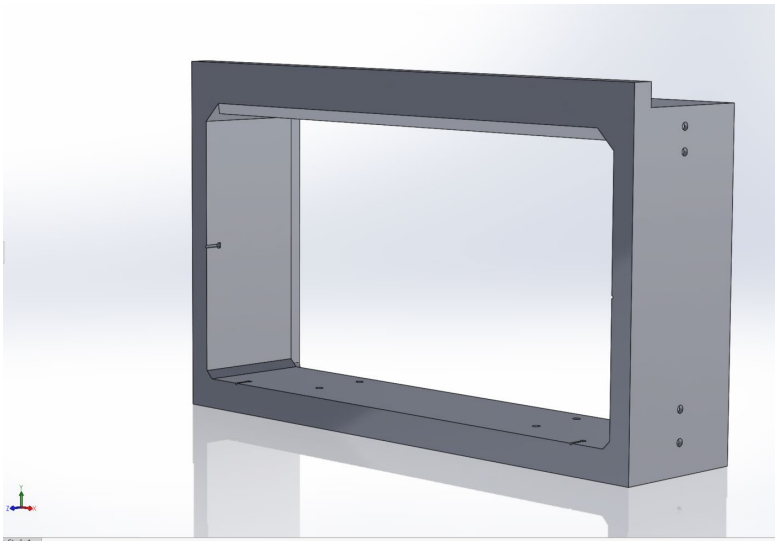
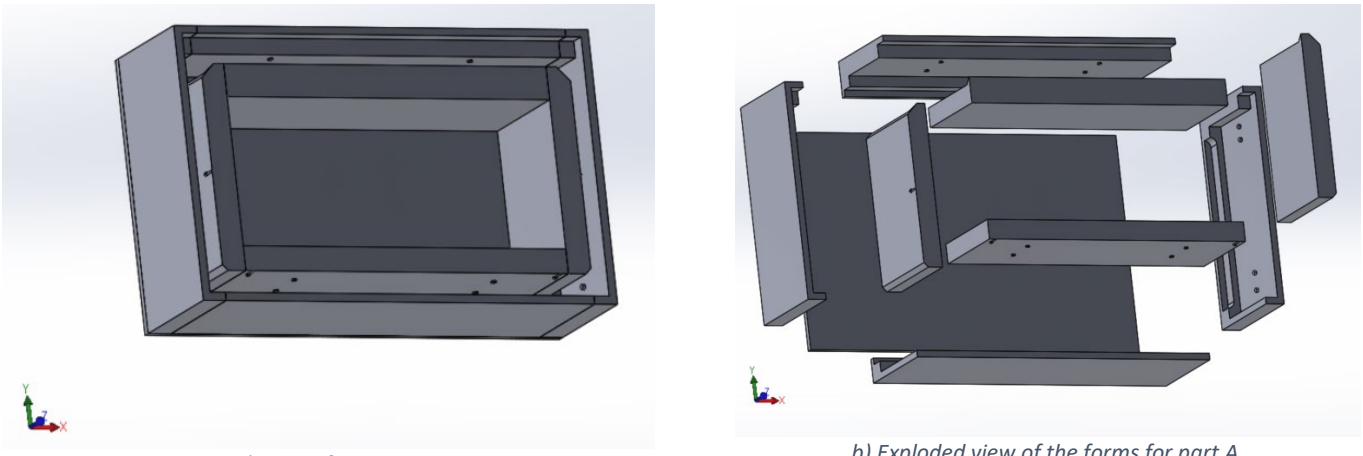


Figure 2: Part A of the culvert assembly.

Figure 3 shows the forms designed for part A of the culvert assembly. The molds are designed to reduce usage of the 3D printing material and to facilitate easy demolding process. Some research works have shown that thin 3D printed sections can be used as form as long as they can support the weight of the wet concrete[1]. The forms will be shored during casting to support the weight of the wet concrete.



a) Forms for part A.

b) Exploded view of the forms for part A.

Figure 3: The designed forms for part A.

We decided to use HPC (high-performance concrete) instead of UHPC (ultra-high-performance concrete) due to unavailability of generic UHPC mix, lack of contractors and facilities well equipped for large volume UPHC manufacture in the region, and shrinkage and heating related issues during large volume casting.

Participants and Collaborators:

- Individuals who have worked on the project: Roberto Lopez-Anido, James Anderson, Douglas Gardner and Yousoo Han, University of Maine
- Students who have participated in the project:
  Sunil Bhandari, Ph.D. student, Civil Engineering
  Anthony Salafia, Undergraduate Student, Civil Engineering
- Organizations that have been involved as partners on this project: PCI – New England, McInnis Cement, MaineDOT.
- Other collaborators or contacts been involved: Oak Ridge National Lab

Changes:

Based on recommendations from MaineDOT, the design part changed from bridge diaphragm to culvert. The intended material for precasting has been changed from UHPC to HPC.

Planned Activities:

We will test the compatibility of 3D printing polymers with concrete to ensure easy demolding. We will cast prototype part A using 3D printed forms.

References:

[1] R. Naboni, L. Breseghello, Fused Deposition Modelling Formworks for Complex Concrete Constructions, (2018) 700-707.