TIDC Transportation Infrastructure Durability Center AT THE UNIVERSITY OF MAINE

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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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. One potential application that we have investigated is making forms for precast concrete bridge diaphragms. 3D printing of the form allows for design optimization of the precast concrete element since the tooling complexity is no longer a limitation.

Background

Diaphragms are structural elements used to transmit lateral loads across structural elements (See Figure 1). In steel bridges with I-girders, during construction, diaphragms act as brace points to stabilize the compression flanges. During service, the cross bracing members resist and transfer lateral forces to the bearings and distribute vertical live load and dead load across the girders. In bridges with girders that exhibit composite action with decks, the deck provides some lateral restraint and can effectively transmit the loads to the girders. The two most commonly used cross-bracing structural members are cross-frames and diaphragms. Cross frames, are truss systems that resist and transfer loads axially. Diaphragms are usually either a steel plate or an I-section made up of non-composite web with top and bottom flanges. Diaphragms, in addition to resisting lateral loads, are designed to resist bending and shear forces.

One of the major problems with steel components used in bridges is corrosion. Corrosion leads to loss of effective material and reduction in steel thickness resulting in decrease of the stiffness and increase of the structural deformation. This creates additional maintenance cost and reduces the service life of the bridge superstructure.


Figure 1: Cross frames on the left and concrete diaphragm on the right.

Reinforced concrete diaphragms are less susceptible to corrosion related problems and are better-suited materials to exposed conditions from durability point of view. However, weight to strength ratio for reinforced concrete is higher compared to steel. The extra dead load increases the stresses on the bridge structure and reduces the live load capacity.

Semi-Annual Progress Report

Traditionally, concrete diaphragms are cast with regular geometry based on available formwork. 3D printed formwork allows creating optimized concrete structures with more complex geometry without additional manufacturing cost. 3D printed formwork would enable the design of tailored concrete diaphragms to accommodate the bridge girder type and geometry (depth, spacing, skew).

3D printed stay-in-place formworks have been used for casting topologically optimized concrete slabs for buildings [2]. Figure 2 shows a prototype topology optimized precast concrete slab formed used 3D printed formwork. The optimized structure is lightweight but structurally sound at resisting the prescribed loads. Large formworks have been 3D printed using large format 3D printers at Oakridge National Lab [3]. The size of the formworks can be further increased by splitting the mold into sections and printing the sections separately.

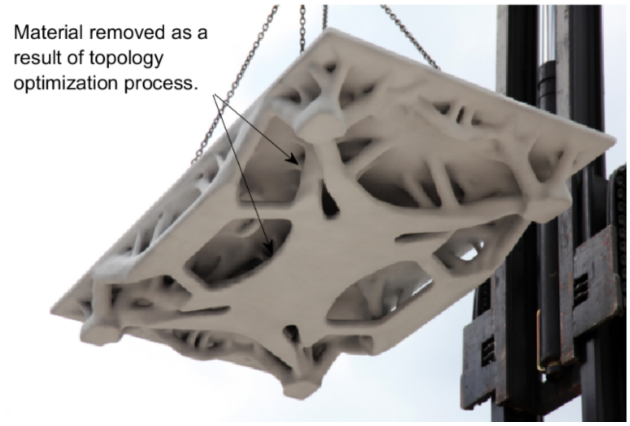

Figure 2: Topologically optimized slab cast using 3D printed formwork being placed [2]

3D printed forms for bridge diaphragms

The geometry of diaphragms is not limited to traditionally used regular shapes. 3D printed formwork will enable the design of concrete bridge diaphragms with optimized geometry that will be more durable. Shape optimization, and topology optimization techniques can be used to get such optimized geometry. Such optimized geometry would reduce the weight of concrete diaphragms while maintaining the required stiffness and strength.
Hence, 3D printed formwork can help in replacing steel diaphragms with more durable concrete diaphragms.

A possible concern for such concrete diaphragms is connection with the steel girders. Steel plates can be embedded into the concrete while casting. Such plates can be used for creating a welded or bolted joint with steel girder. Although 3D printed formwork can be used for both precast concrete or cast-in-place concrete diaphragms, the first option seems to be more practical for bridge construction. The potential of using 3D printed forms for new bridge construction and bridge rehabilitation will be investigated.

A preliminary topology optimized geometry is obtained by using Abaqus is shown in Figure 3. Certain considerations have to be taken into account when casting a concrete part based on the topology optimized geometry. The regions where steel reinforcement needs to be placed should have enough area for steel reinforcement and concrete cover. The curvature of the optimized geometry should allow for convenient placement of steel rebars.

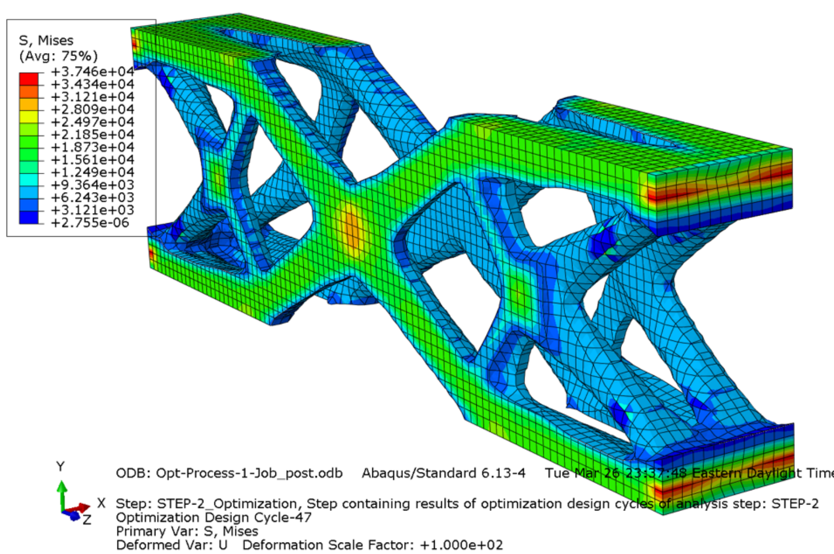

Figure 3: Topology optimized geometry obtained after 50 iterations

A prismatic diaphragm has been optimized using Abaqus Tosca. Loading and initial geometry has been shown in Figure 4 [4].

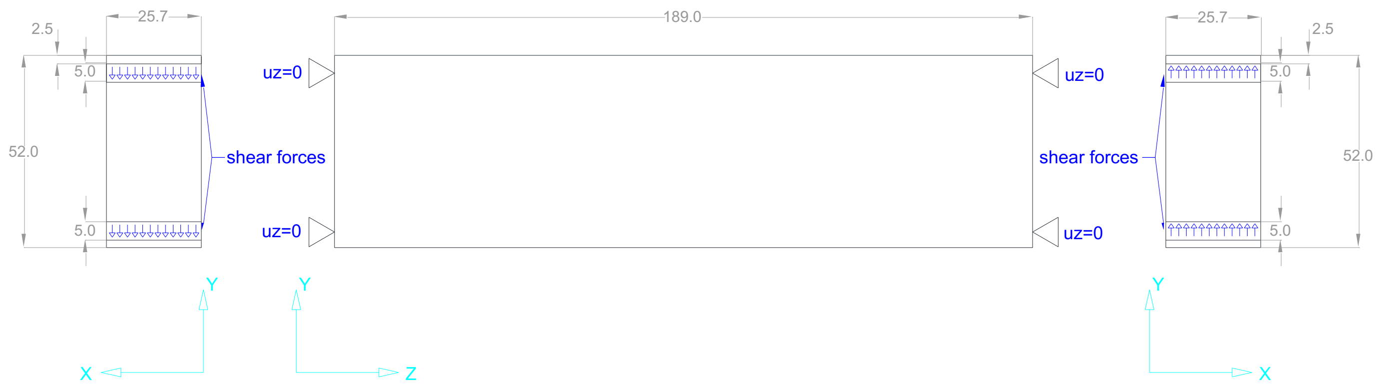

Figure 4: Dimensions, loading (for load case I) and boundary conditions for a prismatic diaphragm used for topology optimization.

The 3D printed forms for the topology optimized precast concrete diaphragm are shown in **Error! Reference source not found.**

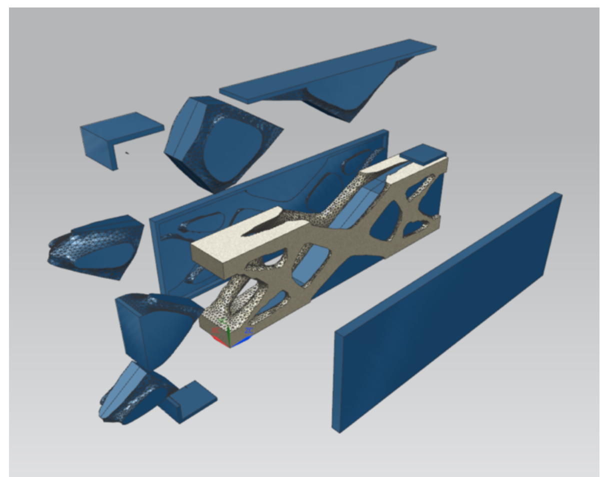

Figure 5: 3D printed forms (in blue) for topology optimized precast concrete diaphragm

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, conducted research
- Organizations that have been involved as partners on this project: PCI – New England
- Other collaborators or contacts been involved: Oak Ridge National Lab

Changes:

The fabrication of the formwork will start when UMaine new large-scale 3D printing is commissioned.

Planned Activities:

We will identify in collaboration with PCI-New England and the New England DOTs applications for optimized bridge diaphragms using the 3D printed formwork.

References:

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2. Jipa, A., et al. 3D-printed stay-in-place formwork for topologically optimized concrete slabs. in 2016 TxA Emerging Design+ Technology conference. 2016. Texas Society of Architects.
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