Quarterly Progress Report:

Project Number and Title: 2.11 Culvert Rehabilitation using 3D Printed Diffusers
Research Area 2: New materials for longevity and constructability

PI: *Roberto Lopez-Anido, University of Maine*
Co-PI(s): *James Anderson and Douglas Gardner, University of Maine*

Reporting Period: *09/01/2020 to 12/31/2020*
Date: *12/31/20*

Overview:

A significant problem associated with repairing deteriorating highway culverts is the resultant lowered flow capacity. This can be mitigated by using culvert diffusers. This research project explores the use of large-scale 3D printing to manufacture thermoplastic composite culvert diffusers.

Work performed during the reporting period:

Phase 1

Task 1: Initial feasibility study: Design and manufacturing of a 3D printed diffuser prototype for demonstration at a site in Thorndike, Maine

The research work in this task showed that culvert diffusers can be manufactured using large-scale 3D printing technology at a lower price and a reduced manufacturing time. Large-scale 3D printing technology has proven to be well-suited for the manufacture of individualized culvert diffusers with unique geometrical design. The use of segmental manufacturing in conjunction with large-scale 3D printing was implemented for the manufacturing of a culvert diffuser prototype selected by MaineDOT for installation in Thorndike, Maine. Different post-processing techniques used for cutting, finishing, and joining the 3D printed segments were investigated. Figure 1 shows a 3D model of the culvert diffuser prototype with dimensions.

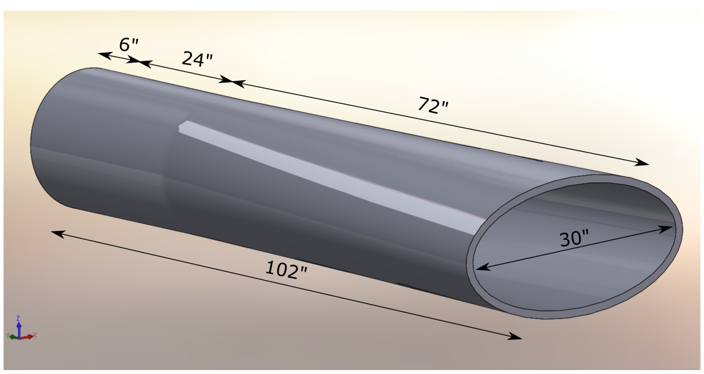

Figure 1: 3D model of the culvert diffuser prototype

A low-cost bio-based composite material, Polylactic acid (PLA) thermoplastic polymer with wood pellet filler, was selected for 3D printing the culvert diffuser segments. The culvert diffuser segments were successfully 3D printed using the large-scale 3D printer. The print was completed in 8 hours 41 minutes. The total cost 3D printed part was $2500 including the material costs, the equipment use cost, and the labor cost. Compared to the fiberglass diffuser, which cost $5110, the 3D printed culvert diffuser reduced the cost by a half. Similarly, the 3D printed part was manufactured in three 8-hour shifts, including the time for 3D printing, cutting and joining using adhesives. The Ph.D. candidate who worked on Task 1 of the project is shown in Figure 2 with the assembled 3D printed culvert diffuser.

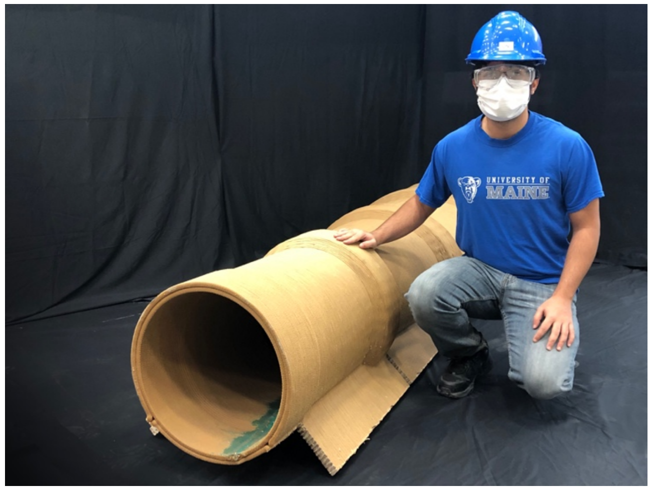

Figure 2: Ph.D. Candidate Sunil Bhandari with assembled 3D printed culvert diffuser

Figure 3 shows the final 3D printed culvert diffuser segments. The region at the start and end of the deposition path showed a rough surface finish. The roughness was more pronounced on the outer surface compared to the inner surface. The roughness of the inner surface is important as it affects the hydraulic efficiency of the diffuser. The surface was sanded down to an acceptable surface roughness.

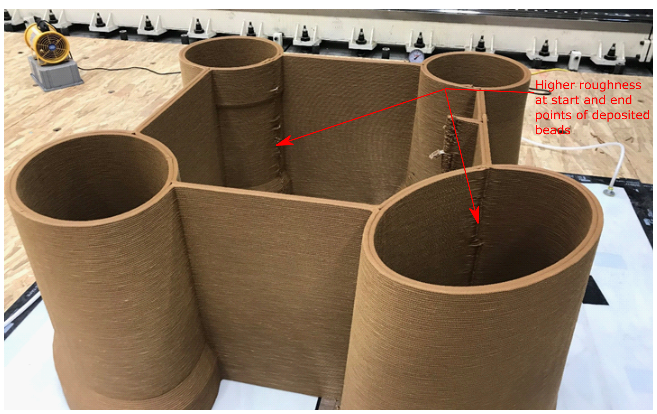

Figure 3: 3D printed culvert segment.

The PLA/wood thermoplastic composite material has a relatively low glass transition temperature of 131°F (55°C) and a melting temperature of 302°F (150°C). The material started softening due to heat generated during the cutting process. Small holes were drilled at 0.4-inch distance along the length of the web and a handheld saw was used to cut the part. Although the method was successful in cutting the part, it was very slow and labor intensive.

Pliogrip 7770, a urethane adhesive produced by Ashland, was used to fill in voids and to join the different culvert segments. The assembled 3D printed culvert diffuser is shown in Figure 4. The bonding surface was lightly sanded to remove loose particles. The surface was cleaned with denatured alcohol and the surface was allowed to dry. The adhesive application was carried out under a fume hood for adequate ventilation. The adhesive application and the assembly process were completed in 1 hour. The alignment of the parts was aided by the webs that acted as legs for the assembly. A visual check was performed to verify the alignment.

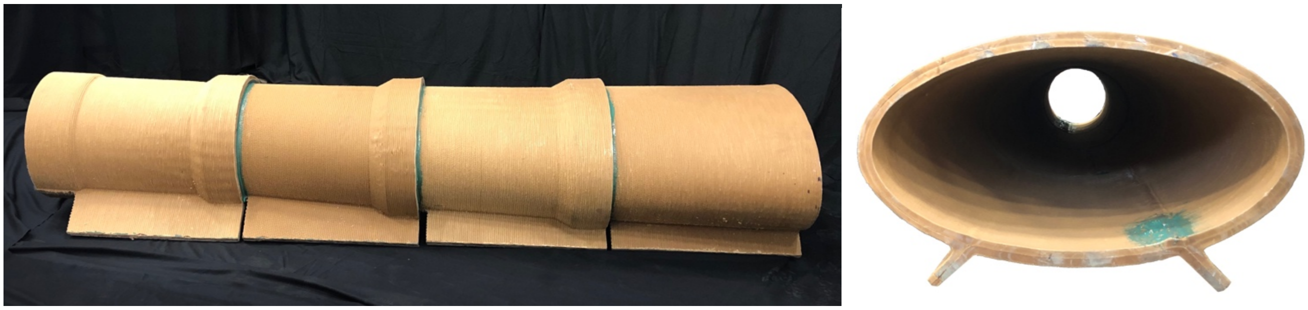

Figure 4: Side view and end view of assembled 3D printed culvert diffuser

The 3D printed culvert diffuser was picked up from the ASCC at UMaine by MaineDOT personnel and transported to the site in a pickup track on 12-11-2020. The 3D printed culvert diffuser prototype is scheduled to be installed by MaineDOT at a demonstration site in Thorndike, Maine during the Summer of 2012 to assess the hydraulic performance. In addition, the durability of the bio-based 3D printed composite material and the urethane adhesive under service conditions of the culvert diffuser will be monitored at the site.

One finding from this task is that further research is needed into cutting and joining methods for large-scale 3D printed parts for segmental manufacturing of culvert diffusers that are larger than the build envelope of the large-scale 3D printer. We plan to address this issue in Task 5.

Task 2: Manufacturing of 3D printed diffuser parts for lab testing and material characterization

PLA/wood composite plates were extracted from the webs of the 3D printed segments of the culvert diffuser manufactured in Task 1. Specimens will be cut from the plates for material characterization and durability evaluation.

Task 3: Material durability evaluation in the laboratory

The AASHTO Guide Specifications for Design of Bonded FRP systems for Repair and Strengthening of Concrete Bridge Elements (2012) specifies: "Water-Samples shall be immersed in distilled water having a temperature of 100 ± 3°F (38 ± 2°C) and tested after 1,000, 3,000, and 10,000 hours of exposure." The only resin material mentioned in the guide is epoxy, however the provisions of the guide are applicable to other thermoset polymers (for example, vinyl ester). This guideline does not address the unique durability characteristics of thermoplastic polymers (for example, PETG, PEI, ABS, PC, PLA) used for large-scale 3D printing.

The main difference between the two types of polymers is that thermosets require a curing process, which is a chemical reaction, and cannot be remolded after the initial forming, while thermoplastics can be reheated and remolded without causing any chemical changes.

The large-scale 3D printing technology is capable of using different thermoplastic composite materials according to structural and environmental requirements.

We propose to assess the durability of thermoplastic materials that are used for large-scale 3D printing through accelerated laboratory testing. The durability conditions for thermoplastic composites that we are considering for laboratory testing are:

1) Weathering: UV exposure and water spraying up to 2000 hours;
2) Moisture: water immersion at 60°C (140°F) until saturation is achieved based on weight measurements;
3) Thermal cycling cold/dry: 300 cycles of -40˚C (-40°F) to 4.5°C (40°F), at near dry condition (approximate 1800 hs); and
4) Thermal cycling hot/wet: 300 cycles of 15.6°C (60°F) to 93°C (200°F) at 90% relative humidity (approximate 1800 hs).

Table 1.1: Phase 1 - Task Progress			
Task Number	**Start Date**	**End Date**	**Percent Complete**
Task 1: Initial feasibility study: Design and manufacturing of a 3D printed diffuser prototype for demonstration at a site in Thorndike, Maine	9/1/2020	12/31/2020	100%
Task 2: Manufacturing of 3D printed diffuser parts for lab testing and material characterization	10/1/2021	8/31/2020	5%
Task 3: Material durability evaluation in the laboratory	1/1/2021	8/31/2021	0%

Table 1.2: Phase 2 - Task Progress			
Task Number	**Start Date**	**End Date**	**Percent Complete**
Task 4: Monitoring of the 3D printed diffuser at the site in Thorndike, Maine	10/1/2021	6/30/2022	0%
Task 5: Develop design concepts for 3D printed diffuser systems (Options 1, 2 & 3)	7/1/2021	8/31/2022	0%
Task 6: Commercialization and documentation of the rehabilitation technology	10/1/2021	8/31/2022	0%

Table 2: Budget Progress		
Entire Project Budget	**Spend Amount**	**Spend Percentage to Date**
To be completed by Grant/Fiscal Manager, Advanced Structures and Composites Center, UMaine		

Table 3: Presentations at Conferences, Workshops, Seminars, and Other Events				
Title	**Event**	**Type**	**Location**	**Date(s)**
Large-scale extrusion-based 3D printing for highway culvert rehabilitation	ANTEC 2021, Society of Plastic Engineers	International	Hybrid Edition	March 22-23, 2021

Table 4: Publications and Submitted Papers and Reports				
Type	**Title**	**Citation**	**Date**	**Status**
N/A				

Participants and Collaborators:

Table 5: Active Principal Investigators, faculty, administrators, and Management Team Members			
Individual Name	**Email Address**	**Department**	**Role in Research**
Roberto Lopez-Anido	RLA@maine.edu	UMaine Civil and Environmental Engineering	Project PI, Graduate student supervisor, and Structural design and material durability lead.
James Anderson	James.m.anderson@maine.edu	UMaine Advanced Structures and Composites Center	Co PI, Large-scale 3D printing lead
Douglas Gardner	douglasg@maine.edu	UMaine School of Forest Resources	Co PI, Extruded material formulation lead.

Table 6: Student Participants during the reporting period				
Student Name	**Email Address**	**Class**	**Major**	**Role in research**
Sunil Bhandari		Ph.D. Candidate	Civil Engineering	Task 1: Structural design and modeling, 3D printing process design and implementation

Table 7: Student Graduates			
Student Name	**Role in Research**	**Degree**	**Graduation Date**
N/A			

Table 8: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**
Maine DOT	Augusta, ME	x	x		x	

Technical Champion:
Name: Alexander Mann
Title: Hydrologist
Organization: MaineDOT
Location (City & State): Augusta, ME
Email: Alexander.Mann@maine.gov

Changes:

The schedule has been affected by disruptions of day-to-day campus and field work due to the University restrictions imposed in response to COVID-19 health safety precautions.

Planned Activities:

The following activities are planned for the next three month period:

- Train and supervise a new graduate student (MS in Civil Engineering) who will start working on the project on 1/01/2021
- Manufacture 3D printed diffuser parts/plates for laboratory testing and material characterization (Task 2)
- Review the literature and guidelines on environmental durability evaluation of thermoplastic composite materials for large-scale 3D printing (Task 3)
- Select accelerated durability testing protocols in the laboratory (Task 3)
- Identify potential demonstration projects for culvert diffusers in collaboration with MaineDOT (Task 5)