Quarterly Progress and Performance Indicators Report:
Project Number and Title: 2.11 Culvert Rehabilitation using 3D Printed Diffusers
Research Area: 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: *10/1/2021-12/31/2021*
Submission Date: *12/31/2021*

******IMPORTANT: Please fill out each section fully and reply with N/A for questions/sections with nothing to report. For ease of reporting to the USDOT, please do not remove, or change the order of, any sections/text. You may remove/add each rows in tables as needed. Thank you! ******
The report is due on the last day of the reporting period in .doc format to tidc@maine.edu.

Overview:

*Provide **BRIEF** highlights of activities performed during the reporting period. This summary should be written in lay terms for a general audience to understand. This should not be an extensive write up of findings (those are to be included in the final report), but a high-level overview of the activities conducted during the last three months **no more than 3 bullet points at no more than 1 sentence each** ….*

- Manufactured 3D printed plates for laboratory testing
- Evaluated the flexural strength and modulus of two 3D printed materials: bio-based filled-polymer, Wood Fiber/ Polylactic Acid, (WF/PLA), and synthetic filled-polymer Carbon Fiber/ Acrylonitrile Butadiene Styrene (CF/ABS).
- Assessed the durability of the additive manufacturing materials based on the change in flexural strength and modulus of specimens exposed to simulated environmental conditions.
- Produced preliminary design of culvert outlet diffuser to be installed in Exeter, NH

Meeting the Overarching Goals of the Project:
How did the previous items help you achieve the project goals and objects? Please give one bullet point for each bullet point listed above.

- Generate material properties for design
- Assess longevity of the material
- Implement the technology in a demonstration project

Accomplishments:
List any accomplishments achieved under the project goals in bullet point form…

- Deployed prototype of 3D printed diffuser system designed to increase hydraulic capacity by decreasing outlet losses.
- Developed rehabilitation technology for culverts with undersized pipes or deteriorated pipes.

Task Progress and Budget:

Complete the following tables to document the work toward each task and budget (add rows/remove rows as needed, make sure you complete the Overall Project progress row and include all tasks even if they have ended or have not been started)…

Table 1: Task Progress			
Task Number	**Start Date**	**End Date**	**% Complete**
Task 1.1: 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 1.2: Manufacturing of 3D printed diffuser parts for lab testing and material characterization	10/1/2021	8/31/2020	60%
Task 1.3: Material durability evaluation in the laboratory	1/1/2021	8/31/2021	35%
Task 2.1: Monitoring of the 3D printed diffuser at the site in Thorndike, Maine	10/1/2021	6/30/2022	10%
Task 2.2: Develop design concepts for 3D printed diffuser systems (Options 1, 2 & 3)	7/1/2021	8/31/2022	10%
Task 2.3: Commercialization and documentation of the rehabilitation technology	10/1/2021	8/31/2022	0%
Phase 1 Overall	9/1/2020	8/31/2021	Phase 1 % Complete
Phase 2 Overall	7/1/2021	8/31/2022	Phase 2 % Complete

Table 2: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date (include the date)**
Enter Phase 1 Full Budget $158,467	Enter Phase 1 Full Spend Amount (Federal + Cost Share)	Enter Phase 1 % Spent
Enter Phase 2 Full Budget	Enter Phase 2 Full Spend Amount (Federal + Cost Share)	Enter Phase 2 % Spent
Enter Phase 3 Full Budget	Enter Phase 3 Full Spend Amount (Federal + Cost Share)	Enter Phase 3 % Spent

Is your Research Project Applied or Advanced?

☒ **Applied** (*The systematic study to gain knowledge or understanding necessary for determining the means by which a recognized and specific need may be met.)*

☐ **Advanced** *(An intermediate research effort between basic research and applied research. This study bridges basic (study to understand fundamental aspects of phenomena without specific applications in mind) and applied research and includes transformative change rather than incremental advances. The investigation into the use of basic research results to an area of application without a specific problem to resolve.)*

Professional Development/Training Opportunities:

Describe any opportunities for training/professional development that have been provided. Did you provide a training to a State DOT/AOT or industry organization? What was the training? When was it offered? How many people attended? Did you meet with a State DOT/AOT or industry organization to inform them of your findings and how these findings could help their organization? When? How many attended the meeting?

- *N/A*

Technology Transfer:

Complete all of the tables below and provide additional information where requested. Please provide ALL requested information as this is one of the most important sections for reporting to the USDOT. ***ONLY provide information relevant to this reporting period.***

Use the table below to complete information about conference sessions, workshops, webinars, seminars, or other events you led/attended where you shared findings as a result of the work you conducted on this project:

Table 3: Presentations at Conferences, Workshops, Seminars, and Other Events

Type	Title	Citation	Event	Location	Date(s)
i.e. Conference, Symposium, DOT/AOT presentation, Seminar, etc.	Presentation Title	Full Citation	Name of event (i.e. TIDC 1st Annual Conference) or who was the presentation given to?		
Graduate Student Poster	Evaluation of large-scale extrusion-based 3D printed WF/PLA, CF/ABSS and WF/aPLA composites	Saavedra, F. "Evaluation of large-scale extrusion-based 3D printed WF/PLA, CF/ABSS and WF/aPLA composites," 2021 TIDC Student Posters and Presentations, Dec. 1, 2021.	2021 TIDC Student Posters and Presentations https://www.tidc-utc.org/2021-student-posters-and-presentations	Virtual	Dec. 1, 2021
Symposium	Culvert Rehabilitation using 3D Printed Outlet Diffusers	2021 Symposium on New England Railroad Infrastructure: Challenges, Solutions, and Opportunities, University of Maine, https://www.tidc-utc.org/events/2021-new-england-rr-symposium/	New England Railroad Symposium	Virtual	Nov. 10, 2021
Conference	Large Scale 3D Printing for Construction: Formwork for Precast Concrete Production and Culvert Outlet Diffusers	Lopez-Anido, R. "Large Scale 3D Printing for Construction: Formwork for Precast Concrete Production and Culvert Outlet Diffusers," Changing Course – A Virtual Gathering, Maine Transportation Conference, Dec. 2, 2021.	Maine Transportation Conference	Virtual	Dec. 2, 2021

Use the table below to report any publications, technical reports, peer-reviewed articles, newspaper articles referencing your work, graduate papers, dissertations, etc. written as a result of the work you conducted on this project. Please list only completed items and exclude work in progress.

Table 4: Publications and Submitted Papers and Reports

Type	Title	Citation	Date	Status
i.e. Peer-reviewed journal, conference paper, book, policy paper, magazine/newspaper article	Publication title	Full citation		i.e. Submitted, accepted, under review
Best Paper Award of the Additive Manufacturing sessions at ANTEC 2021 from The Society of Plastics Engineers (SPE)	Large-scale extrusion-based 3D printing for highway culvert rehabilitation	Bhandari, S., Lopez-Anido, R.A., Anderson, J. and Mann, A. "Large-scale extrusion-based 3D printing for highway culvert rehabilitation," ANTEC 2021, Classic, SPE Inspiring Plastics Professionals, Hybrid Edition.	Award received on Dec. 13, 2021	Accepted

Answer the following questions (N/A if there is nothing to report):

1. Did you deploy any technology during the reporting period through pilot or demonstration studies as a result of this work? If so, what was the technology? When was it deployed?
   Yes. The technology was deployed in Thorndike, ME, 2021-08-22.
2. Was any technology adopted by industry or transportation agencies as a result of this work? If so, what was the technology? When was is adopted? Who adopted the technology?
   Yes. MaineDOT and NH DOT adopted the 3D printed culvert outlet diffuser technology.
3. Did findings from this research project result in changing industry or transportation agency practices, decision making, or policies? If so, what was the change? When was the change implemented? Who adopted the change? N/A
4. Were any licenses granted to industry as a result of findings from this work? If so, when? To whom was the license granted?
   N/A
5. Were any patent applications submitted as a result of findings from this research? If so, please provide a copy of the patent application with your report.
   N/A
6. Were any industrial contracts awarded base on furthering planned research and development activities as a result of findings from this work? If so, when? How much was awarded? Who awarded the contract?
   N/A

Please add figures/images that can be included on the website and/or in marketing/social media materials to further clarify your research to the general public.

spe INSPIRING PLASTICS PROFESSIONALS

The Society of Plastics Engineers (SPE) Additive Manufacturing & 3D Printing Technical Interest Group (TIG) is pleased to present the

Best Paper Award

of the Additive Manufacturing sessions at SPE's Annual Technical Conference ANTEC® 2021 to

Sunil Bhandari[1,2], Roberto A. Lopez-Anido[1,2], James Anderson[1], and Alexander Mann[3]
of [1]Advanced Structures and Composites Center, University of Maine; [2]Department of Civil and Environmental Engineering, University of Maine; and [3]Maine Department of Transportation

for the paper entitled

Large-Scale Extrusion-Based 3D Printing for Highway Culvert Rehabilitation

on this date

July 22, 2021

Patrick Farrey
CEO, SPE

Matthew Thompson
Board Past Chair, SPE AM TIG

Figure 1. Best Paper Award Certificate

Describe any additional activities involving the dissemination of research results not listed above under the following headings:

Outputs:

Definition: Any new or improved process, practice, technology, software, training aid, or other tangible product resulting from research and development activities. They are used to improve the efficiency, effectiveness, and safety of transportation systems. List any outputs accomplished during this reporting period:

- Example: New sensing technology was developed. This technology will…

- A 3D printed diffuser prototype was deployed in an operational environment in Thorndike, ME.
- A second 3D printed outlet diffuser was designed for a 42-in CMP liner and inlet upgrade project, Rocky Hill Brook at NH 85/Newfields Rd, in Exeter, NH. Manufacturing of the 3D printed diffuser and installation is planned in 2022.

Outcomes:

Definition: The application of outputs; any changes made to the transportation system, or its regulatory, legislative, or policy framework resulting from research and development activities. List any outcomes accomplished during this reporting period:

- Example: The developed sensing technology was installed in Bridge A in town, state on 1/1/2021. This installation will…

- A memorandum of agreement with New Hampshire DOT was signed f or the purpose of manufacturing a culvert outlet diffuser for use in Exeter, state project #43254, at a proposed rehabilitation of a culvert carrying Rocky Hill Brook under NH Route 85.

Impacts:

Definition: The effects of the outcomes on the transportation system such as reduced fatalities, decreased capital or operating costs, community impacts, or environmental benefits. The reported impacts from UTCs are used for the assessment of each UTC and to make a case for Federal funding of research and education by demonstrating the impacts that UTC funding has had on technology and education. NOTE: The U.S. DOT uses this information to assess how the research and education programs (a) improve the operation and safety of the transportation system; (b) increase the body of knowledge and technologies; (c) enlarge the pool of people trained to develop knowledge and utilize technologies; and (d) improves the physical, institutional, and information resources that enable people to have access to training and new technologies. List any outcomes accomplished during this reporting period:

- Example: The developed sensing technology's successful deployment resulted in the adoption of the technology by the StateDOT. The technology will be installed in all new bridge installments of this type. This adoption will…

- Improved asset performance: The 3D printed diffuser system can increase the capacity of the culvert by about 40%, eliminating the need for replacement of the existing pipe.
- Environmental benefit: The diffuser and outlet weir serve as an effective energy dissipator, addressing environmental concerns related to outlet scour and downstream sedimentation.
- Ease of installation: The 3D printed diffuser system can be installed by a maintenance staff without creating traffic disruption.

Participants and Collaborators:

*Use the table below to list **all** individuals (compensated or not) who have worked on the project.*

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

*Use the table below to list **all** students who have participated in the project during the reporting period. (This includes all paid, unpaid, intern, independent study, or any other student that participated in this project.) **ALL FIELDS ARE REQUIRED.***

Table 6: Student Participants during the reporting period								
Student Name	**Start Date**	**End Date**	**Advisor**	**Email Address**	**Level**	**Major**	**Funding Source**	**Role in research**
				Email is not included in the external report and is only used for internal purposes.	(i.e. Junior, Master's Ph.D)		(i.e. TIDC, University (non TIDC match i.e. study abroad program), unpaid intern, independent study student, etc.	What work are they conducting? Please be descriptive. Student research assistant is not enough info.
Sunil Bhandari	2020-09-01	present	R. Lopez-Anido and D. Gardner		Ph.D. Candidate	Civil Engineering	TIDC	Structural design and modeling, 3D printing process design and
Felipe Saavedra	2021-01-01	present	R. Lopez-Anido		M.S. student	Civil Engineering	TIDC	implementation Material durability evaluation in the laboratory

Use the table below to list any students who worked on this project and graduated or received a certificate during this reporting period. Include information about the student's accepted employment (i.e. the student is now working at MaineDOT) or if they are continuing their students through an advanced degree (list the degree and where they are attending).

Student Name	**Degree/Certificate Earned**	**Graduation/Certification Date**	**Did the student enter the transportation field or continue another degree at your university?**
Sunil Bhandari	Ph.D. in Civil Engineering	Dec. 15, 2021	Please list the organization or degree Postdoctoral Research Associate, TIDC-ASCC, University of Maine

Use the table below to list any students that participated in Industrial Internships:

Table 8: Industrial Internships			
Student Name	**Degree/Certificate Earned**	**Graduation/Certification Date**	**Did the student enter the transportation field or continue another degree at your university?**
			Please list the organization or degree

*Use the table below to list **organizations** that have been involved as partners on this project and their contribution to the project.*

Table 9: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**
		List the amount	List the amount	Mark with an "x" where appropriate		

*Use the table below to list **individuals** that have been involved as partners on this project and their contribution to the project.*
*(**List your technical champion(s) in this table.** This also includes collaborations within the lead or partner universities who are not already listed as PIs; especially interdepartmental or interdisciplinary collaborations.)*

Table 10: Other Collaborators				
Collaborator Name and Title	**Contact Information**	**Organization and Department**	**Date(s) Involved**	**Contribution to Research**
	For internal use only			(i.e. technical champion, technical advisory board, test samples, on-site equipment, data, etc.)
Alexander Mann, Hydrologist	Alexander.Mann@maine.gov	MaineDOT	2021-10-01 to 2021-12-31	Technical champion
Timothy S. Mallette, P.E.	Timothy.Mallette@dot.nh.us	NHDOT Specialty Section, Hydraulics	2021-10-01 to 2021-12-31	Lead for demonstration project in Exeter, NH
Don LeBlanc, P.E., President	don@dlvews.com	DLVEWS, Inc.	2021-10-01 to 2021-12-31	Culvert design consultant

Use the following table to list any transportation related course that were taught or led by researchers associated with this research project:

Table 11: Course List						
Course Code	**Course Title**	**Level**	**University**	**Professor**	**Semester**	**# of Students**
i.e. CE 123		Grad or undergrad?	Where was the course taught?	Who taught the course?	Enter Spring, Fall, Summer, Winter and the year	How many students were enrolled in the class?

Changes:

List any actual or anticipated problems or delays and actions or plans to resolve them (list no-cost extension requests here)…
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.

List any changes in approach and the reasons for the change…

Planned Activities:

List the activities planned during the next quarter.

- Investigate the durability and dimensional stability of thermoplastic composite material systems under different exposure conditions of moisture and freeze-thaw.
- Design and manufacture a large-size 3D printed culvert outlet diffuser that will be installed at a highway in Exeter, NH.
- Investigate segmental manufacturing techniques for the diffusers to enable easy assembly at the site.