



ARKANSAS
TRANSPORTATION SUMMIT

USE OF INDIGENOUS SOILS IN 3D PRINTED CONCRETE FOR HORIZONTAL CONSTRUCTION

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**IOWA STATE
UNIVERSITY**



ROBOTIC CONSTRUCTION PBBJ
FDM CONCRETE 3D PRINTING
RAPID PROTOTYPING 3D PRINTING **ADDITIVE CONSTRUCTION** DED
LARGE-SCALE ADDITIVE MANUFACTURING LAYERED MANUFACTURING
DLP **ADDITIVE MANUFACTURING** SLA
SLS **3D CONCRETE PRINTING (3DCP)** SLM
CONTOUR CRAFTING DMLS
MATERIAL JETTING

Benefits of Additive Construction (AC)

- **Increased flexibility through on-demand construction closer to the point of need. No longer a need to stockpile items.**
- **Increased flexibility with unique geometries that are nearly impossible with prior construction methods.**
- **Decreased material usage through optimized shape geometries**
- **Decreased construction crew sizes through use of robotics in the additive construction process.**
- **Decreased logistical burden (and cost) through use of local materials in the additive construction process.**





ADDITIVE CONSTRUCTION MANEUVER ENHANCING TECHNOLOGY



Research Challenges

Item Design

- What items are needed? What are the use case requirements that make sense?
- How do we create a printable geometry using a continuous print path?
- What is the appropriate bead height and width?
- Is rebar needed and where and how should it be placed?
- What is the appropriate design protocol and procedure?

Material Design

- How do we characterize indigenous materials? What properties are important?
- How do we process indigenous materials into printable media?
- What mix design will create a printable mix (flowability and buildability)?
- What tests can be used to determine whether a mix is printable?
- What influences the hardened properties of the mix and what tests are needed?
- How do we do QA/QC in the field?

Software & Equipment

- How do we “slice” the object and create the G-code for the printer?
- What equipment is needed to mix, pump, and print the material?
- How do we regulate the speed of the printer and pump?
- How do we reduce the “hard labor” load and the required crew size?

ACME Tech - Program Overview

Task 2: Development of Indigenous Materials as Additive Construction Media Mixtures



Task 4: Development of Mobile Additive Construction Equipment



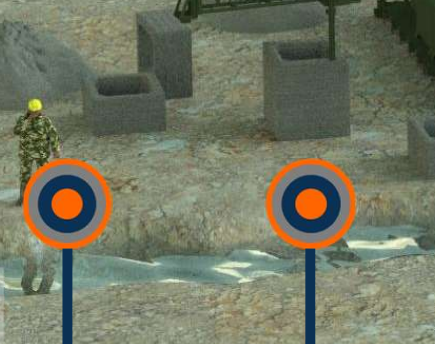
Task 5: Development of Autonomous and Teleoperated Systems



Task 3: Development of Software Controls for Design Items to Additive Construction



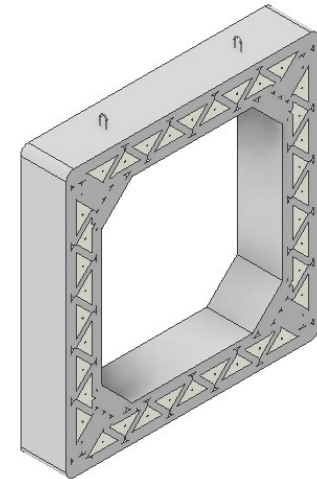
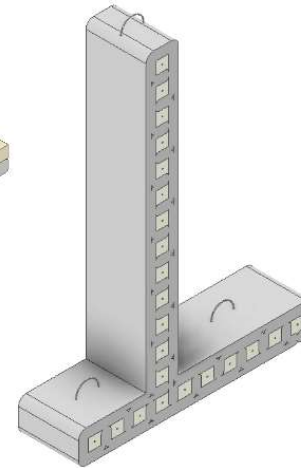
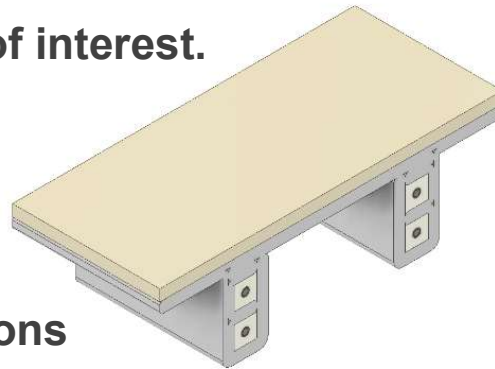
Task 1: Development of Catalog of Additive Construction Printable Items



Task 1 – AC Item Catalog & Object Design

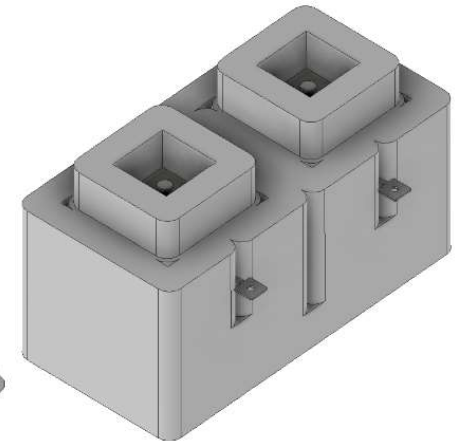
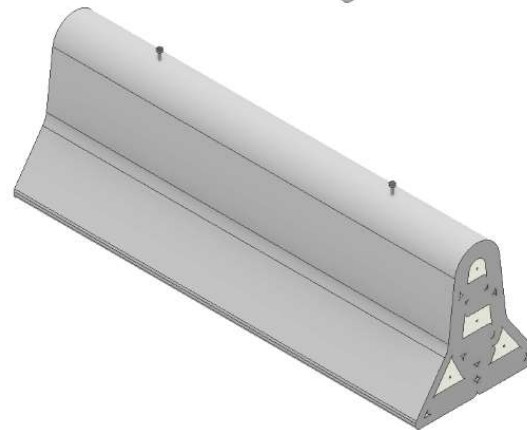
- Stakeholder input on items of interest.

- Mobility
- Counter-mobility
- Other Items of Interest



- Evaluate geometric adaptations needed to make possible item candidates feasible for additive construction.

- Develop engineered design catalog of items that can be constructed using additive construction methods.



AC Catalog – Printed Items



Large-Scale Testing



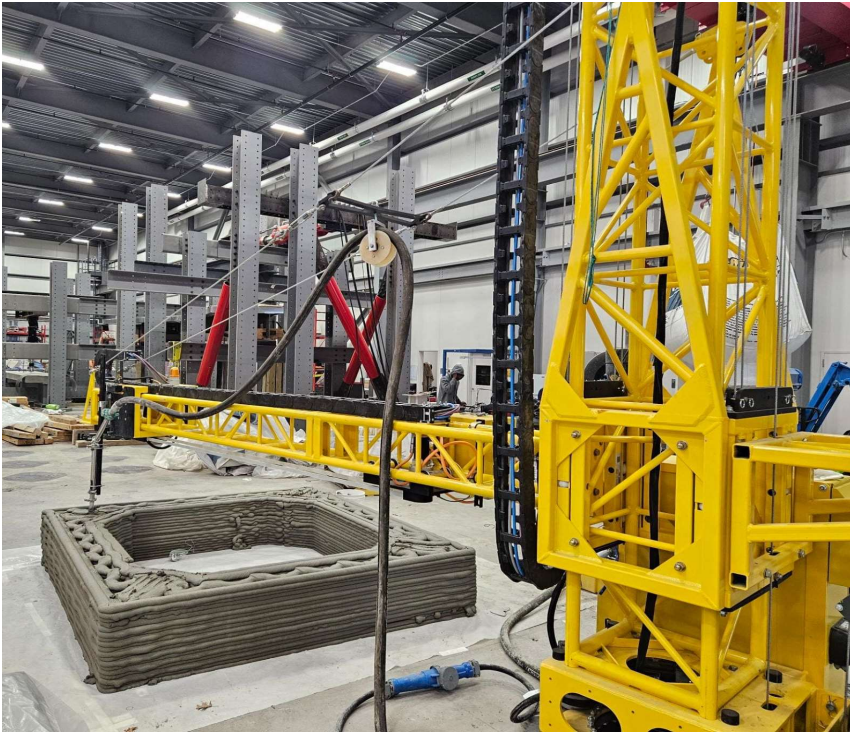
Specimen Printing and Preparation

- 6 ft culverts with 13" (MLC 8) and 15" wall thicknesses (MLC 150)
 - Tested to date: 10 total

- 6 AC culverts
 - Printed and plastic cured
 - ASTM cast cylinders (4"x8", 1.5"x3"), plastic cured with culvert and some moisture room cured
 - Printed zig-zag, plastic cured, cored for triaxial and unconfined compression testing on the days the culverts were tested (4"x8" and 2"x4" cored specimens)
 - Cast sample block, plastic cured, and then cored and tested

- 4 Cast culverts
 - Cast and plastic cured
 - ASTM Cast 4"x8" cylinders, 1.5"x3" cylinders, and some mortar cubes were cast and plastic cured with the culverts and in the moisture room
 - Cast sample blocks, plastic cured, and then cored for triaxial and unconfined compression testing on the days the culverts were tested (4"x8" and 2"x4" cored specimens)

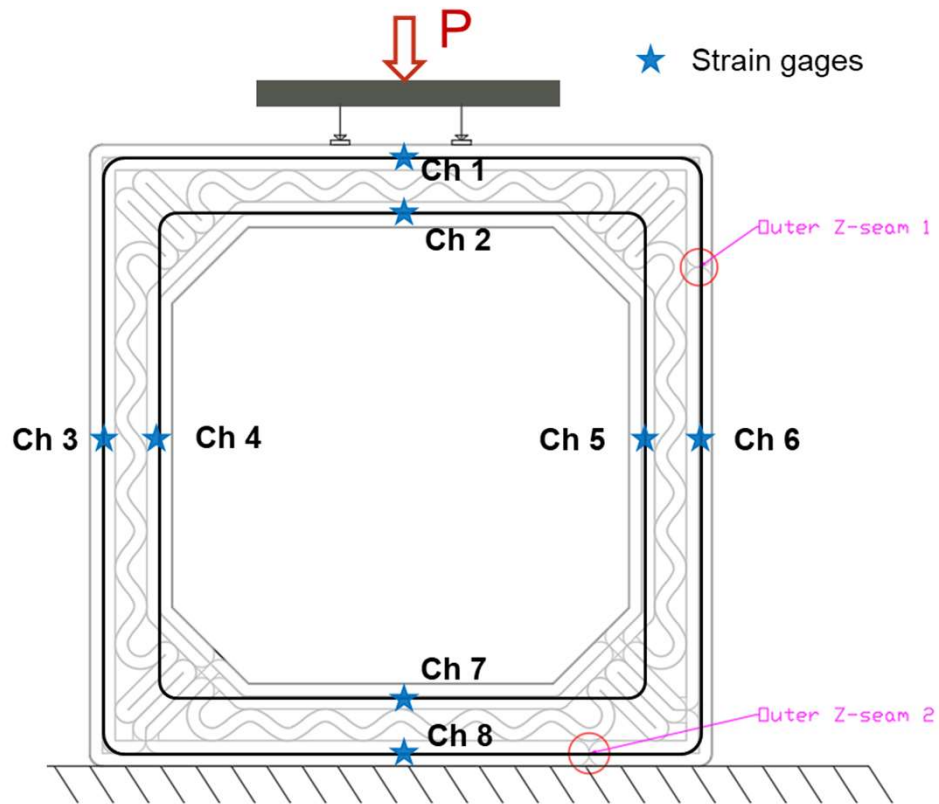
Large-Scale Testing



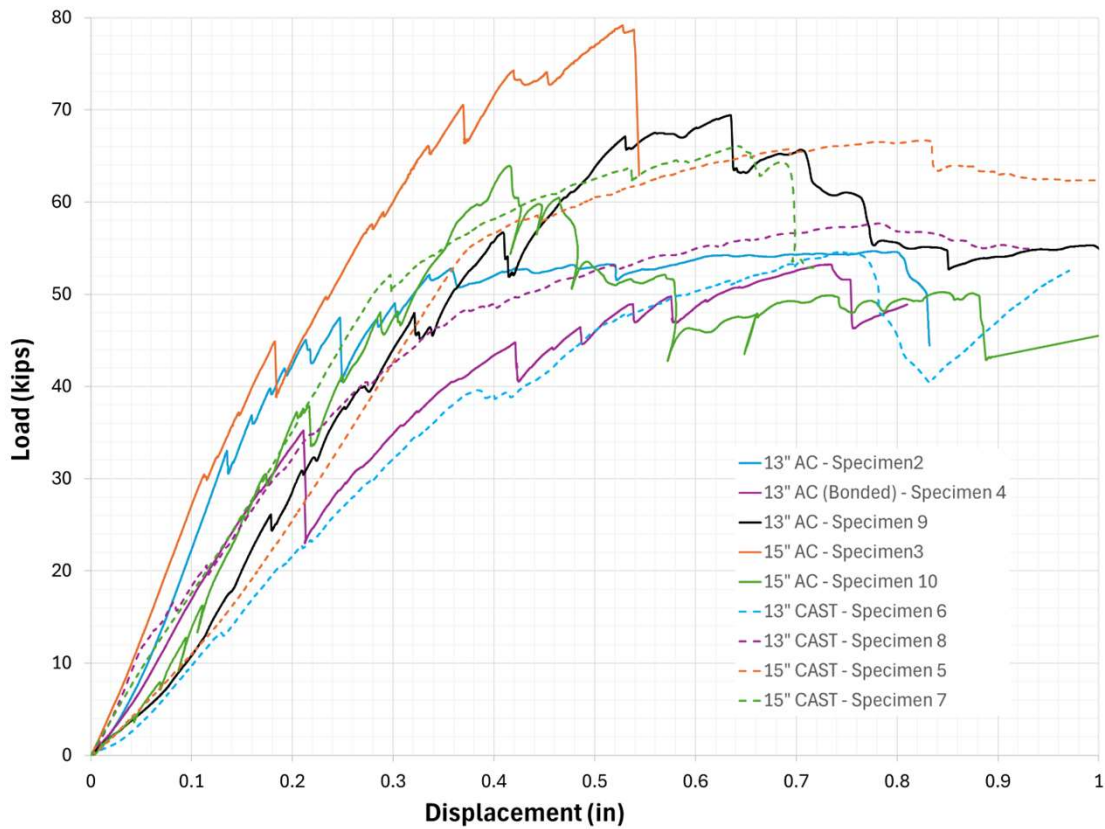
Large-Scale Testing



Large-Scale Testing

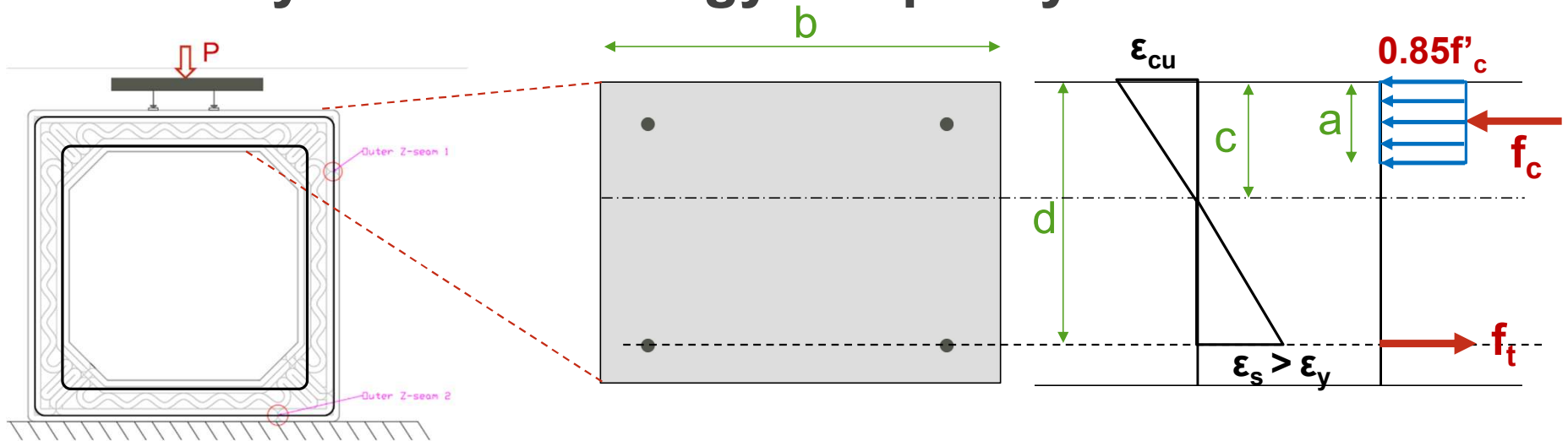


Results – Culverts



Specimen No.	Size & Preparation Method	Curing Method	Curing Duration (days)
1	15" – AC (PF@1/2)	Ambient	30
2	13" – AC	Plastic	40
3	15" – AC	Plastic	48
4	13" – AC (bonded)	Plastic	49
5	15" – CAST	Plastic	52
6	13" – CAST	Plastic	45
7	15" – CAST	Plastic	28
8	13" – CAST	Plastic	28
9	13" – AC	Plastic	52
10	15" - AC	Plastic	29

Culvert Analysis Methodology - Capacity

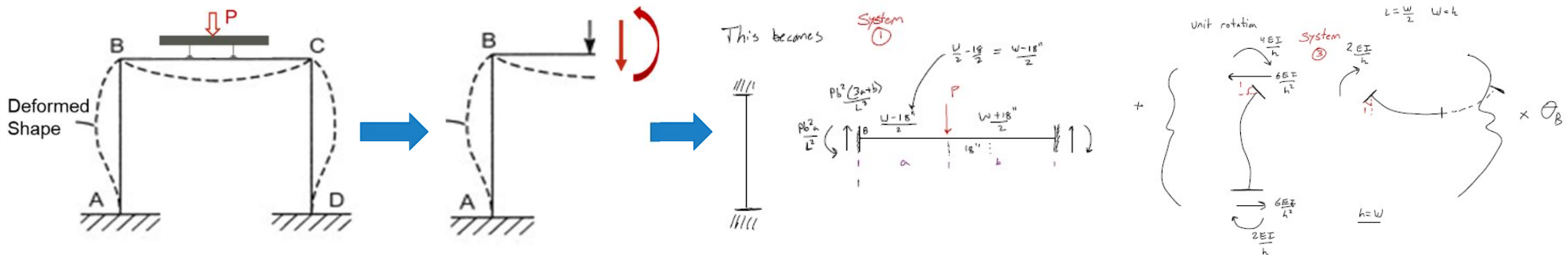


ACI 318

- Calculates the nominal moment capacity, M_n , of the concrete section (max moment it can develop before failing)
- Prior to any factoring
- Uses the material properties from experiments as well as as-built dimensions

Culvert Specimen No.	d	b	f'_c	M_n	M_u
1					
2					
...

Culvert Analysis Methodology - Demand

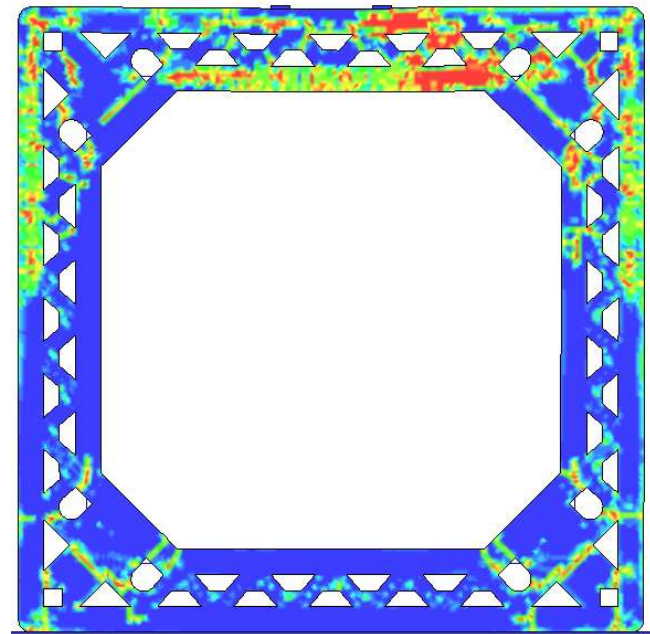


Frame with fixed supports

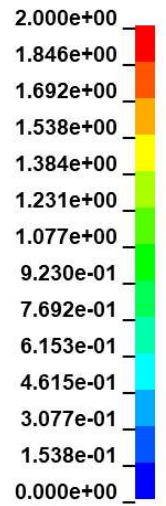
- Assuming no rotation at the support and at points B and C
- P comes from the experiment
- As-built dimensions are used
- Calculates the ultimate moment, M_u , based on the loading scenario
- Prior to any factoring

Culvert Specimen No.	d	b	f'c	Mn	Mu
1					
2					
...

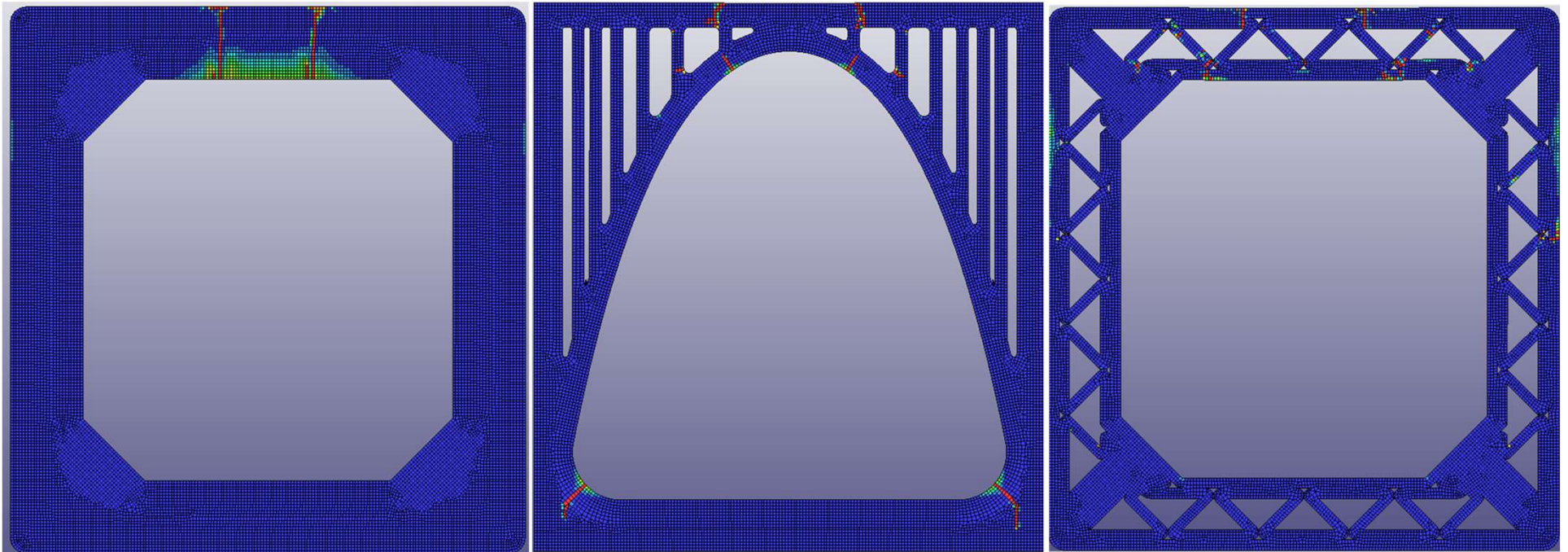
Large-Scale Culvert Testing



Effective Plastic Strain



Large-Scale Culvert Testing



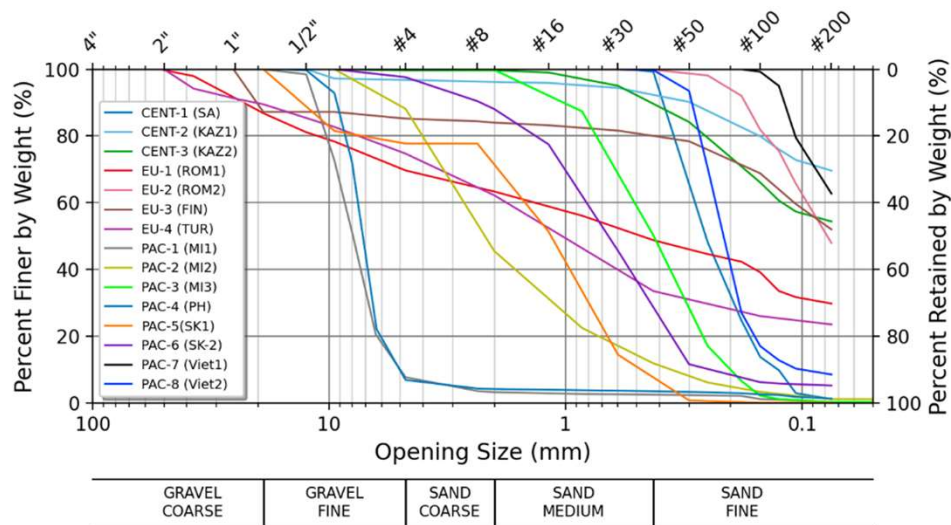
Task 2 – Development of Indigenous Material Mixtures

- Collected and analyzed material from across the world
 - 16 OCONUS Soils
 - 23 CONUS Soils
- Captured every category in the USCS classification system
- Conducted soil and aggregate characterization tests on each material following ASTM and AASHTO procedures
- Created an indigenous materials database

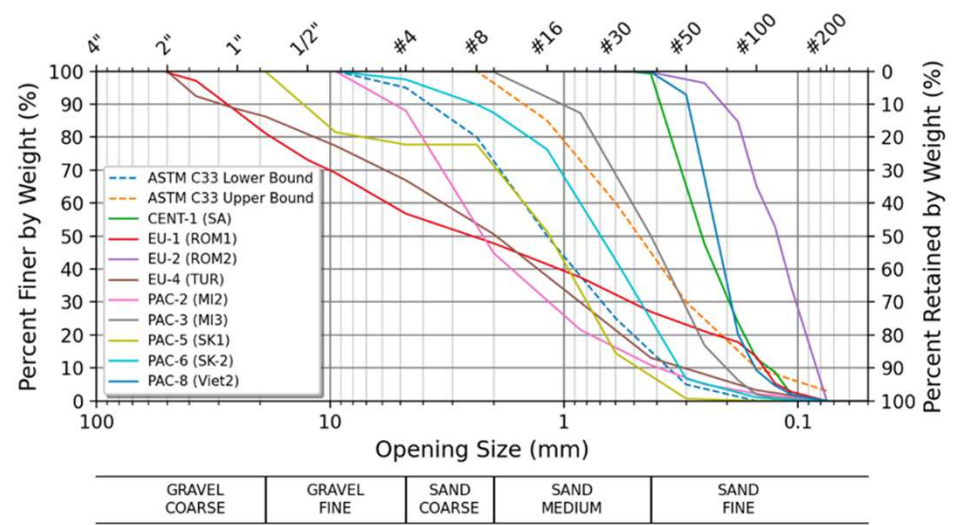


Task 2 – Development of Indigenous Material Mixtures

OCONUS



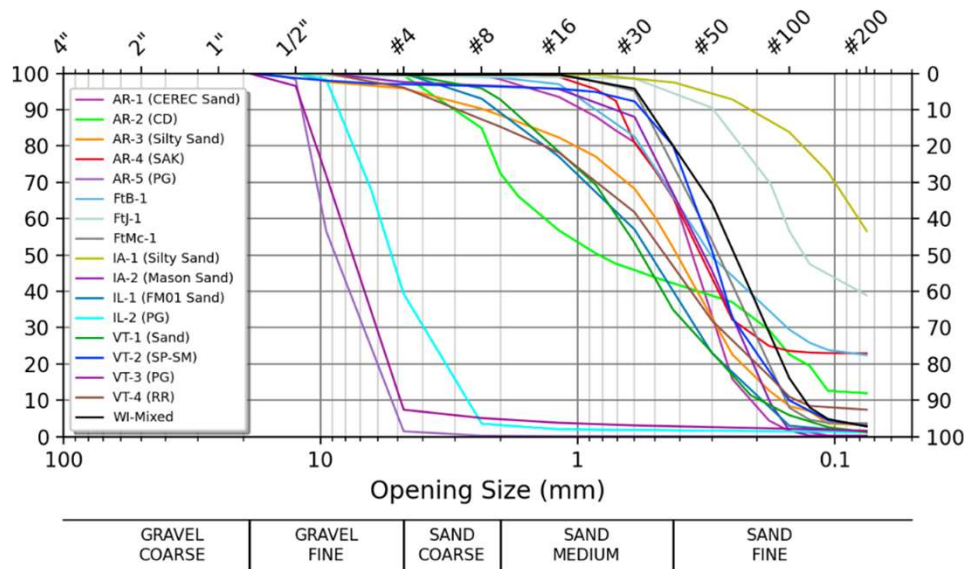
As Received



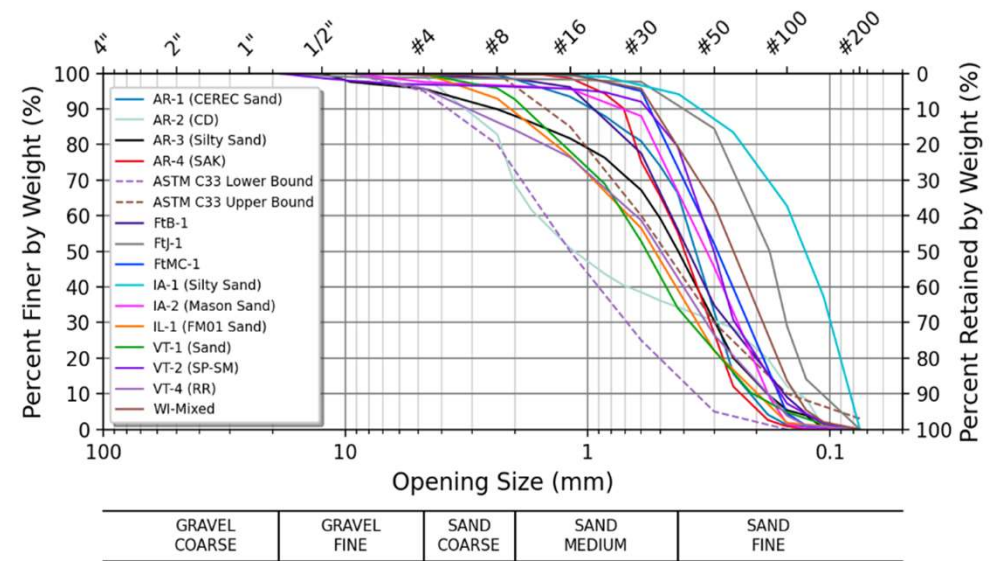
Coarse Only

Task 2 – Development of Indigenous Material Mixtures

CONUS



As Received



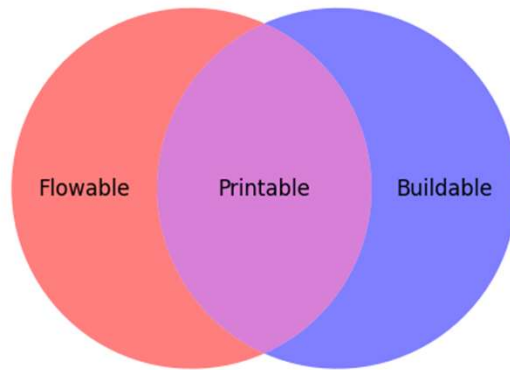
Coarse Only

Task 2 - Material Processing

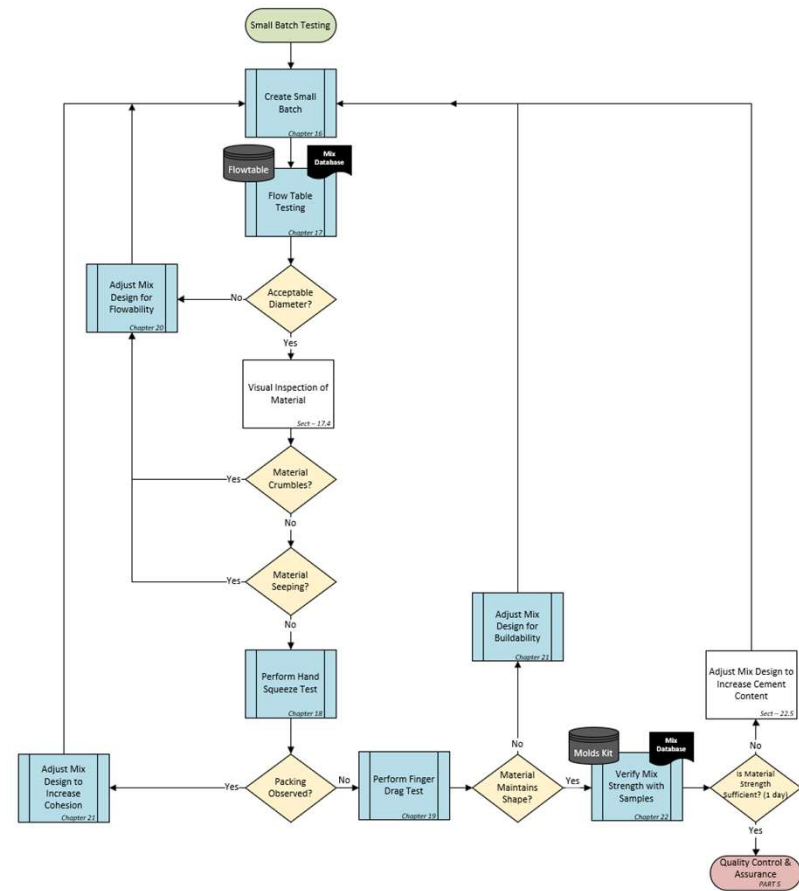


- Developed equipment package and procedures to process raw materials onsite to make them usable for additive construction
- Performed testing on materials with a variety of hardnesses and gradations
- Analyzed gradations achieved from material processing
- Developed sequence or scheme to be used to process geomaterials for use in AC
 - Crushing, screening, washing, other processing?

Task 3 – Mix Design and Printability



- Developed mix design procedure to guide creation of printable AC mixes
- Selected appropriate testing to qualify a mix
- Created an AC mix design database



Task 3 – Mix Design and Printability

Flowability



Buildability



Task 3 – Mix Design and Printability



Task 4 – Prototype AC System Major Equipment



ACME

Prototype Printer Photos



Prototype Printer Photos



ACME Tech – NOV25 Experiment Culvert Scenario



ACME Tech – JUN25 Experiment Bridge Scenario



ACME Tech – 15SEP2025 Experiment Concept



How Does this Translate to Civilian Infrastructure?

Key Considerations

- How can we best leverage the AC technology?
 - Unique optimized geometries
 - Novel repairs
 - Human safety and/or “hard labor”
- Where can we use indigenous materials to reduce cost and logistical burden?
- What other materials could be used to reduce the cement content?
- What types of applications could benefit from the flexibility and mobility of the equipment?
- We must develop solid design procedures and QA/QC field methods to effectively implement AC in practice.

Potential Applications of AC (with soils)

- Optimized designs using less material to carry the same loads effectively (arch culvert, honeycomb infill, etc.)
- Ground improvement (pavements, foundations, etc.)
- MSE and other earth retaining walls
- Lightweight backfills with reduced lateral pressure (i.e. geocells and soil “fabrics” resulting in a negative Poisson’s ratio)
- Replace micropiles, aggregate piers, and even pile foundations with printed geometrical columns
- Shallow foundations mimicking tree roots
- Construction in underdeveloped or disaster areas
- Foundations on the moon and mars
- Others?

ACKNOWLEDGEMENTS

