Department of

Civil, Construction and Environmental Engineering

Morton A. Barlaz, Ph.D., P.E.
Distinguished Professor and Head

Fall 2021
Established in 1895
10,700 B.S. degrees

Wallace C. Riddick
1895-1908

Carroll L. Mann
1916-48

Charles R. Bramer
1948-49; 1962-65

Ralph E. Fadum
1949-62

Donald L. Dean
1965-78

Paul Zia
1979-88

E. Downey Brill
1988-2005

George List
2005-10

Morton Barlaz
2010-22

Jackie MacDonald Gibson
2022-Present
AREAS OF EXPERTISE

- Computing and Systems
- Construction Engineering
- Environmental, Water Resources, and Coastal Engineering
- Geotechnical/Geo environmental Engineering
- Mechanics and Materials
- Structural Engineering and Mechanics
- Transportation Systems and Materials
WE ARE ONE OF THE LARGEST CIVIL/ENVIRONMENTAL ENGINEERING DEPARTMENTS IN THE NATION.

- 52 distinguished faculty, 17 winners of CAREER and other NSF young faculty awards
- Total research expenditures exceed $22.7 million
- 270 ongoing research projects
- Undergraduate enrollment of 739
- Graduate enrollment of 290
Who We Are?

- Structural Engineering and Mechanics (SEM)
- Environmental, Water Resources, and Coastal Engineering (EWC)
- Transportation Systems and Materials (TR)
- Geotechnical (GEO)
- Construction Engineering (CON)

Energy Cluster

WaSH Cluster

Mechanics and Materials (M&M)
Computing and Systems (CAS)
NC State University
Department of Civil, Construction, and Environmental Engineering

Strong Undergraduate and Graduate Program Rankings

20th
Undergraduate Civil Engineering

21st
Undergraduate Environmental Engineering

26th
Graduate Civil Engineering

21st
Graduate Environmental Engineering

21st
Graduate Environmental Engineering

1st
Civil Distance Education

2nd
Environmental Distance Education
<table>
<thead>
<tr>
<th>Rank</th>
<th>University</th>
<th>Degrees Awarded</th>
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<tr>
<td>1</td>
<td>Texas A&amp;M University</td>
<td>248</td>
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<tr>
<td>2</td>
<td>Iowa State University</td>
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<tr>
<td>3</td>
<td>Virginia Polytechnic and State University</td>
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<tr>
<td>4</td>
<td>Purdue University</td>
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<td>5</td>
<td>University of Illinois</td>
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<td>6</td>
<td>The Pennsylvania State University</td>
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<tr>
<td>7</td>
<td>California State University, Long Beach</td>
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<td>8</td>
<td>The University of Texas</td>
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<tr>
<td>9</td>
<td>The Ohio State University</td>
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<td>10</td>
<td>California Polytechnic State Univ. San Luis Obispo</td>
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<td>11</td>
<td>Louisiana State University</td>
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<td>12</td>
<td>University of Buffalo, SUNY</td>
<td>150</td>
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<tr>
<td>13</td>
<td>North Carolina State University</td>
<td>148</td>
</tr>
</tbody>
</table>

- NC State is 195 including Construction and Environmental
- NC State College of Engineering ranks 9th in degrees awarded – 1,801
Undergraduate Degrees

- Civil Engineering
- Construction Engineering
- Environmental Engineering
- 592 matriculated
- 810 with Engineering First Years, CE, CON, ENE

Intended Academic Programs: Undergraduate

Undergraduate Enrollment: Sophomore to Senior

<table>
<thead>
<tr>
<th>Year</th>
<th>CE</th>
<th>CON</th>
<th>ENE</th>
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<td>2021-22</td>
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</table>

2022-23
MEET THE
UNDERGRADUATE
CCEE STUDENT
AMBASSADORS

The select group of undergraduate students represents the department at a variety of academic, social and networking events throughout the academic year.
Undergraduate Research

- Undergraduates working with graduate students and faculty in a smaller setting
- Students involved in cutting edge work
- Undergraduate thesis option
Academic Programs: Site and Conference Visits

- ACI Convention, TRB Annual Meeting
- Design Competitions
Academic Programs: Site and Conference Visits

- American Concrete Institute
- Associated General Contractors
- American Society of Civil Engineers
- American Water Works Association
- Air and Waste Management Association
- Chi Epsilon
- Coasts, Oceans, Ports, and Rivers Institute
Academic Programs: Site and Conference Visits

- Construction Managers Association of America
- Earthquake Engineering Research Institute
- Engineers Without Borders
- Geotechnical graduate student association
- Institute of Transportation Engineers
- National Association of Home Builders
- Professional Engineers of North Carolina
Earthquake Engineering Research Institute

Seminars to Prepare

• Introduction
• Structural Dynamics
• Seismic Design
• Seismic Analysis of Frame Buildings
• Seismic Analysis of Dual Systems
• Materials — Balsa Wood
• SAP2000 — Time History Analysis
• SAP2000 Part II
• Master of:
  • Civil Engineering
  • Environmental Engineering
• Master of Science:
  • Civil Engineering
  • Environmental Engineering
• Distance Education
• Ph.D.

• Total of 301 graduate students
  • 150 students on assistantships
Academic programs: Graduate

- Dr. Meagan Kittle Autry, director of Graduate Professional Development
- Ph.D. Communication, Rhetoric and Digital Media with a focus on scientific and technical communication
  - Research Skills
  - Professional Skills
  - Career Support
- Summer Distance Education Course
- Extension to undergraduates

https://bit.ly/3zNEUKW
Graduate Programs

• Engineering Online Degree Programs
  • Master of Civil Engineering (MCE)
  • Master of Environmental Engineering (MENE)

• Average age of online student: 34 years

• EOL students in 45 states and 21 countries

• We offer about 15 courses a semester
<table>
<thead>
<tr>
<th>Category</th>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>Construction</td>
<td>CE 538</td>
<td>Information Technology and Modeling</td>
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<tr>
<td></td>
<td>CE 590</td>
<td>Facilities Engineering</td>
</tr>
<tr>
<td></td>
<td>CE 592</td>
<td>CII Best Practices</td>
</tr>
<tr>
<td>Environmental</td>
<td>CE 574</td>
<td>Chemical Principles of Environmental Engineering</td>
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<tr>
<td></td>
<td>CE 578</td>
<td>Energy and Climate</td>
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<tr>
<td></td>
<td>CE 586</td>
<td>Engineering Hydrology</td>
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<td>CE 588</td>
<td>Water Resources Engineering</td>
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<tr>
<td>Structural</td>
<td>CE 515</td>
<td>Advanced Strength of Materials</td>
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<tr>
<td></td>
<td>CE 522</td>
<td>Theory and Design of Prestressed Concrete</td>
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<td></td>
<td>CE 523</td>
<td>Theory and Behavior of Steel Structures</td>
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<tr>
<td></td>
<td>CE 525</td>
<td>Structural Analysis II</td>
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<td></td>
<td>CE 594</td>
<td>Nondestructive Evaluation of Concrete</td>
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<td>CE 723</td>
<td>Advanced Structural Dynamics</td>
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<tr>
<td></td>
<td>CE 724</td>
<td>Probabilistic Methods of Structural Engineering</td>
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<td></td>
<td>CE 725</td>
<td>Earthquake Structural Engineering</td>
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<tr>
<td></td>
<td>CE 726</td>
<td>Advanced Theory of Concrete Structures</td>
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<tr>
<td>Transportation</td>
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<td>Transportation Systems Engr</td>
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<td></td>
<td>CE 502</td>
<td>Traffic Operations</td>
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<td></td>
<td>CE 595</td>
<td>Asphalt and Bituminous Materials</td>
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<td></td>
<td>CE 707</td>
<td>Transportation of Policy and Funding</td>
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<td></td>
<td>CE 708</td>
<td>Transportation Logistics Planning</td>
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<tr>
<td></td>
<td>CE 755</td>
<td>Highway Pavement Design</td>
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<tr>
<td>Geotechnical</td>
<td>CE 548</td>
<td>Engineering Property of Soils</td>
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<tr>
<td></td>
<td>CE 584</td>
<td>Hydrology of Groundwater</td>
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<td></td>
<td>CE 741</td>
<td>Geomechanics of Stress Deformation</td>
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<td></td>
<td>CE 747</td>
<td>Geosynthetics in Geotechnical Engineering</td>
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<tr>
<td>Professional Development</td>
<td>CE 550</td>
<td>Professional Engineering Communication</td>
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</table>
CCEE-EOL Intro Videos

What's it take to earn a Masters Degree online?

Listen to real stories from our online graduates about how they balanced work and family life, while watching the lectures and completing the coursework in way that worked for them.

Watch a 3 minute video featuring former graduates. »

https://go.ncsu.edu/ccee-eol_testimonial_vid

Are you ready to engineer your career?

You can earn a Masters of Civil Engineering (MCE) or a Masters of Environmental Engineering (MENE) online thru CCEE's highly ranked program. Think about how that could enhance your career. Hear from our professors, students, and administrators about how it works.

Find out how to earn a Masters degree in the place, and at the pace, that works for you. »

https://go.ncsu.edu/ccee-eol_overview_vid

Customize your online degree to support your interest.

We have one of the most comprehensive online programs in the nation. Choosing the right Degree, the right Concentration, and the right Coursework allow you to customize your plan of study to support your Career!

This very short animation clarifies how you can complete a degree that is just what you need. No more, no less. »

https://go.ncsu.edu/ccee-eol_custom_vid
Research: Diverse in Expertise and Strengths

- We model, we test, we analyze, and we solve
- We work at scales from nano to lab to pilot to full-scale field research
- We are helping to design sustainable infrastructure for society all over the world
- Our research capabilities and methodologies span from the fundamental to the applied
Research: In the News

Dr. Detlef Knappe’s PFAS research highlighted in New York Times article
Underwood’s asphalt research featured on CNN
July 26, 2021

With the world getting hotter, road crews should install pavement that is more heat-resistant. CCEE’s Dr. Shane Underwood leads research to understand and improve the behavior of asphalt concrete in changing climates. He was recently featured in a CNN story titled “Extreme weather events put spotlight on climate change’s toll on US infrastructure” that first appeared on July 23rd. The news story examines the effects of climate change on transportation systems including public transport, and highways. The feature was spurred in part by the incidents of pavement failure that occurred in Washington state during record-breaking temperatures in early July.
Dr. Katherine Anarde’s work on “Sunny Day Flooding” research featured on PBS
Trends in Funded Research

Research Expenditures

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
<th>Contracts &amp; Grants</th>
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<tr>
<td>13-14</td>
<td>18.5</td>
<td>14.2</td>
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<td>14-15</td>
<td>19.0</td>
<td>14.8</td>
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<tr>
<td>15-16</td>
<td>20.5</td>
<td>15.3</td>
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<tr>
<td>16-17</td>
<td>21.0</td>
<td>15.4</td>
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<tr>
<td>17-18</td>
<td>20.0</td>
<td>15.0</td>
</tr>
<tr>
<td>18-19</td>
<td>23.0</td>
<td>16.5</td>
</tr>
<tr>
<td>19-20</td>
<td>24.0</td>
<td>17.0</td>
</tr>
</tbody>
</table>
Illustrative Funding Sources

- Army Corps of Engineers
- Bill and Melinda Gates Foundation
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of Homeland Security (DHS)
- Environmental Research and Education Foundation
- Federal Highway Administration (FHWA)
- Health Effects Institute
- National Aeronautics and Space Administration (NASA)
- N.C. Renewable Ocean Energy Program
- N.C. Policy Collaboratory
- National Science Foundation (NSF)
- National Oceanic and Atmospheric Administration (NOAA)
- N.C., C.A., A.L. and U.S. Departments of Transportation
- Sloan Foundation
- U.S. Environmental Protection Agency (U.S. EPA)
- U.S. Geological Survey
Working Across Disciplines

Architecture
- Structural Engineering and Mechanics (SEM)
- Environmental, Water Resources, and Coastal Engineering (EWC)
- Transportation Systems and Materials (TR)
- Geotechnical (GEO)
- Construction Engineering (CON)
- Mechanics and Materials (M&M)
- Marine, Earth & Atmospheric Sciences
- Computer Science
- Operations Research
- Materials Science
- Industrial Systems Engineering

Microbiology
- Microbiology

Statistics
- Statistics

Mechanical & Aerospace Engineering
- Mechanical & Aerospace Engineering

Biological & Agricultural Engineering
- Biological & Agricultural Engineering

Computing and Systems (CAS)
“NC State University will emerge as a preeminent technological research university recognized around the globe for its innovative education and research addressing the grand challenges of society.”

We are home to two faculty excellence clusters:
- Global WaSH (Water, Sanitation, and Hygiene) (Dr. Francis De los Reyes)
- Sustainable Energy Systems and Policy (Dr. Joseph DeCarolis)
The pursuit of energy sustainability represents a multigenerational challenge to deliver clean, affordable, secure and reliable energy.

Our vision is to transform NC State into a preeminent and high visibility hub for transdisciplinary research that informs key energy decisions at the state, federal, and international levels.
Global Water, Sanitation and Hygiene

Mission

The NC State WaSH Cluster catalyzes and conducts transformational research and education to serve the water, sanitation and hygiene needs of marginalized people.

• Detection and transmission pathways of pathogens
• Creating effective indicators to track effectiveness of WaSH interventions
• Technology development for improving
  • Water quality
  • Sanitation services
Computing and Systems

• An interdisciplinary program in civil engineering
• Faculty expertise in core computing and systems areas and traditional areas such as structures, coastal engineering and environmental engineering
• Our graduates pursue careers at traditional firms, government agencies, national laboratories and universities and others such as SAS, Cisco, IBM, Microsoft, GE and Intel

• We are working to develop new computing and methodological tools to solve critical civil engineering problems
• Programming, algorithm design and analysis, and software development play major roles in our research
Computing and Systems

Developing innovative software and computer-based solutions

Tackling challenging problems with systems concepts

Domains
- Civil infrastructure
- Energy and the environment

Computing
- Software engineering
- Parallel processing

Systems
- Mathematical modeling
- Optimization and simulation
Four Core Areas of Strength

- **High-Performance Computing**
  Parallel and distributed computing, concurrent systems and performance analysis

- **Software Engineering**
  Programming methodology, formal approaches for reasoning about computer systems and verification and validation

- **Systems & Optimization**
  Mathematical modeling, search algorithms, decision support systems, stochastic modeling, inverse problems, forecasting and data assimilation, and uncertainty quantification

- **Numerical Methods**
  Algorithm development and analysis, finite element and other discretization methods, and particle methods
Better decision-making tools for network design and traffic management

**GOAL**

Design a software framework for the Highway Capacity Manual (HCM) that extends simulation with optimization and decision-support features

**APPROACH**

- Software design
- Mathematical optimization
- Integer programming
- Metaheuristics

**METHODS**

An intuitive component of a workflow that:
- Quantifies the effects of decisions
- Finds optimal management strategies
- Includes network design options

**IMPACT**

Optimization of Transportation Systems
GOAL
Increase energy efficiency of buildings

APPROACH
Coupling innovative optimization methods with building information models in architectural and engineering design

IMPACT
Green buildings and energy sustainability

METHODS
Optimization, simulation and modeling
GOAL

Prioritize infrastructure investments to improve lifeline service resilience

APPROACH

Storm hazard impact simulation, mathematical modeling and computational procedures

IMPACT

Civil infrastructure investment prioritization to improve lifeline service resilience to storm hazards

METHODS

Optimization, simulation and modeling
**GOAL**
Computational tools for leak detection, contaminant source characterization, and risk assessment in water networks.

**APPROACH**
Customized optimization and statistical techniques enabled by high-performance computing; testing and deployment with Town of Cary network.

**IMPACT**
Real-time water loss and contamination management as well as improved risk assessment.

**METHODS**
High-performance computing, optimization, software engineering and Bayesian inference.

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**Water Distribution System Management**

**Town of Cary**
Water Distribution
Western Pressure Zone
Sensors & Experiments

- Flushers
- Sensors
- PRV
- Tanks
- WPZ_Pipes
- > 100 GPM Experiment
- > 150 GPM Experiment
- > 200 GPM Experiment
- > 300 GPM Experiment
- > 400 GPM Experiment
- > 500 GPM Experiment

**Pressure Sensor Placement for Leak Detection**
Socio-Technical Systems Analysis for Adaptive Water Resources Sustainability

**GOAL**

An adaptive modeling method to integrate the dynamic interactions and feedbacks between the social system and water infrastructure design and management policies.

**APPROACH**

A novel adaptive simulation modeling procedure coupled with optimization techniques. Illustrative case applications for a large metropolitan area in Texas.

**IMPACT**

Adaptive water resources planning, design and operation considering social behavior.

**METHODS**

Complex adaptive systems modeling and optimization.
Energy Systems Modeling

**GOAL**
To perform system-level assessments of future technology deployment and public policy to inform decision-makers

**APPROACH**
Computational modeling of energy systems informed by technology explicit data

**IMPACT**
Insight relevant to U.S. energy and environmental policy

**METHODS**
Optimization, software engineering and high-performance computing
Integrated Solid Waste Management

**GOAL**
Evaluate solid waste system performance (i.e. economic, environmental) while accounting for changes to waste composition and generation, waste policy, the energy system, and potential future GHG mitigation policies

**APPROACH**
Innovative interfacing of data, measurements, analytical and decision models, and search algorithms for optimization

**IMPACT**
Enable integrated solid waste management by practitioners

**METHODS**
Process simulation modeling, optimization and software engineering

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GHC Policy

Energy System

SWM Process Models

LCA Model

- Impact Assessment Model (e.g., Global Warming, Smog Formation)
- Optimizable Integrated SWM System Model

Solid Waste Optimization Life-cycle Framework (SWOLF)

- Cost
- Emissions
- Energy Use
- Impacts

http://go.ncsu.edu/iswm
Hydroclimatology and Water Management

**GOAL**

Improve water-management practices by incorporating climate information

**APPROACH**

Innovative data fusion methods with statistical modeling and inference and optimization

**METHODS**

Stochastic modeling, simulation and optimization

**IMPACT**

Improved water sustainability, flood and drought management, reservoir operation, hydropower management, water quality and risk management

*Climate Informed Drought Management at Falls Lake*
Identify and evaluate strategies to mitigate air pollution and its impacts using computational models.

Multiscale modeling frameworks to simulate air quality and its interactions with other environmental and human systems.

Improve air quality and earth systems models, guide environmental regulatory decision-making and policy.

Numerical methods, uncertainty analysis, integrated assessment modeling and high-performance computing.
GOAL
To create modeling and problem-solving frameworks that enable users to make consistent and robust decisions when facing uncertainty.

APPROACH
Water-Energy Nexus, Electricity Power Systems and Systems Engineering.

IMPACT
Insight relevant to investors, system users and policymakers.

METHODS
Math programming, Stochastic optimization, decision analysis and high-performance computing.
Construction Engineering
Construction Engineering: Research Framework

Technology and Innovation

Sustainable Design and Construction “Green”

Lean Applications “Efficient”

Area of Sustainable Construction Innovation

SCI
Automate and Personalize Safety Training Interventions

**GOAL**
Replace one-size-fits all training approach with personalized need-based training solutions

**APPROACH**
Leverage capabilities of eye-tracking technology, virtual reality, computer vision and machine learning

**IMPACT**
Improve safety performance and reduce construction injury rates
Emerging Strategies for Construction Hazard Recognition

GOAL
Develop and test strategies to improve construction hazard recognition performance

APPROACH
Integrate Visual Cues

IMPACT
> 20% hazard recognition improvement after intervention

METHOD
Multiple baseline testing
Preventing falls among bridge workers

GOAL
Identify compatible fall protection solutions for bridge construction and maintenance workers

APPROACH
Leverage virtual prototyping to replace the manual trial-and-error based approach

IMPACT
Identify fall protection measures for more than 22,000 guardrails across North Carolina

Bridge Guardrail Prototype

Fall protection system prototype

Virtual compatibility testing
Visual Data Analytics and BIM in Construction

**GOAL**
Automate construction management practices

**APPROACH**
Visual data collection using unmanned aerial and ground vehicles; project controls using visual data — images, videos, and/or 3D point clouds — and BIM.

**METHOD**
Image processing/computer vision/machine-learning algorithm development

**IMPACT**
Improve project tracking and situation awareness; decentralized decision-making
Construction Automation and Robotics

**GOAL**
Automate construction management practices through advances in robotics

**APPROACH**
Autonomous navigation for construction performance monitoring; multiple robots interacting with humans; automated construction tasks using a robotic arm

**METHOD**
Custom-built unmanned aerial and ground vehicles for autonomous navigation on construction sites, both indoor and outdoor; robotic arm manipulation; image processing/computer vision/machine-learning algorithm development

**IMPACT**
Improve project tracking and situation awareness; decentralized decision-making; automated construction sites
Success on Complex Projects

**GOAL**

Improve cost and schedule performance on large, complex construction projects.

**APPROACH**

Understand critical success factors for improving project performance in project management, controls, technology readiness, and risk.

**IMPACT**

Enable owners and contractors to improve chances of meeting original cost, schedule, quality, and safety target values.
Risk Management at the Project Level

**GOAL**
Assess, mitigate, monitor and communicate projects risks to improve project performance

**APPROACH**
Understand successful risk-management procedures during all phases of a project and determine effective methods for implementation

**IMPACT**
Reduce negative effects of risk on projects and increase opportunities that lead to better project outcomes
Obstacles and Challenges of Collaborative Scheduling

**GOAL**
Maximize the benefit of Collaborative Scheduling with limited management time and efforts in construction projects

**APPROACH**
Use Information Theory analysis approach to identify the uncertainty and impact of various types of collaborative practices

**IMPACT**
Enable contractors to improve planning reliability given limited planning and management resources
Blockchain Technology for Trust Network in Construction

**GOAL**
Facilitate, verify, and enforce the negotiation and performance of Smart Contract

**APPROACH**
Use Shapley Value method to derive fair distribution of benefits and risk in collaboration; implement Blockchain technology to execute the Smart Contract

**IMPACT**
Enable fair, transparent, and instant Trust management in construction collaboration
Pollutant Emission Reduction

**GOAL**
Quantify CO2, NOx, PM emissions from construction equipment

**APPROACH**
Model emissions using data from measurements and published data; benchmark model forecasts against measurements

**IMPACT**
Enable planners to forecast construction equipment emissions for future projects
Advances in Construction of Nuclear Power Plants

**GOAL**
Improve cost and schedule performance of nuclear construction

**APPROACH**
Advances in modular construction, visual data analytics and BIM

**METHOD**
Automate and improve QA/QC process at off-site facilities; virtually connect performances at off-site facilities to the project site

**IMPACT**
Improved project tracking and situation awareness even at off-site facilities; connected sites for decentralized decision making; improved capital cost and return on investment.
Balancing Highway Asset Condition Improvement with Budget Allocation

**GOAL**
Understand how to determine how much to spend statewide to maximize an asset's condition level of service.

**APPROACH**
Determine a condition deterioration rate for each asset; model the relationship between deterioration and condition vs. budget allocation.

**IMPACT**
Perform maintenance more efficiently, thereby improving condition and maximizing the impact of spending.
Coastal Engineering
Coastal Engineering

**Landform Change**
How do coastal landforms respond to natural (waves, sea level rise) and anthropogenic (beach nourishment) processes?

**Coastal Hazards**
What are combined effects of tidal and rip currents, waves, meteotsunami, storm surge and flooding?

**Inlet Formation & Evolution**

**Applied Remote Sensing and Geospatial Modeling**
How can we map and communicate impacts of coastal hazards on infrastructure?

**Habitat Mapping & Spatial Modeling**

**Flood Forecasting**

**Long-term Projections**
How can we connect climate variability to aid in decision-making?

**Hybrid Statistical-Dynamical Models**
How do natural processes and human decisions change our beaches, inlets and barrier islands?

**GOAL**
Generate knowledge on coastal processes to inform short-term (storm) and long-term (decadal) planning for vulnerable coastal regions (e.g. deltas, marshes, barrier islands) and their infrastructure.

**APPROACH**
Develop and use (1) numerical models to understand, visualize and develop solutions to coastal problems (2) geospatial techniques for multidimensional data.

**METHODS**
Analysis of field and remotely sensed data, model simulations of flow, sediment transport and morphology.

**IMPACT**
Engineering solutions to enhance resilience of coastal environments and communities.
How can we process and use observations of the coastal environment?

**GOAL**
Assess and communicate the short- and long-term coastal hazards on vulnerable highways, communities and ecosystems

**APPROACH**
Develop remote sensing algorithms and spatial modeling approaches for assessing and predicting changes in coastal ecosystems

**METHOD**
Software design, spatial algorithm development and machine learning

**IMPACT**
Improved understanding of physical processes to assess and predict:
- Beach, dune, and marsh response, recovery, and resilience
- Storm damage to infrastructure
- Potential adaptation pathways
Can we improve prediction of storm hazards by: 1) using flexible resolution along our coastline?

**GOAL**
An efficient computational approach for assessing storm surge and coastal flooding at many spatial scales:
- Ocean to shelf to floodplain to infrastructure
- Waves, circulation and coastal erosion

**APPROACH**
Develop models at high resolution and solve on supercomputers

**METHOD**
Seeking advances in:
1. Computational efficiency via adaptivity, submesh corrections and improved code
2. Additional physics via coupling to erosion and density-driven circulation

**IMPACT**
Connect waves and flooding to built infrastructure in real-time and long-term design

Sharing results with FEMA, the US Army Corps of Engineers, NC Emergency Management, and others
Can we improve prediction of storm hazards by:
2) capturing in situ observations of storm impact?

**GOAL**
- Obtain perishable observations of waves, overland flow, beach morphology and loading on infrastructure during storms

**IMPACT**
1. Identify feedbacks between infrastructure and physical processes during storms
2. Improve understanding of relevant processes needed for predictive modeling of morphological change

**METHOD**
1. Develop and deploy low-cost instrumentation that can transmit data in real time
2. Integrate field measurements with numerical modeling
Can we project coastal hazards to inform decisions by our coastal managers?

**GOAL**

Framework for climate variability in wave, surge, and erosion predictions
- Probabilistically account for randomness of storms and large-scale climate oscillations
- Make projections of beach nourishment volume loss, nuisance flooding and surges

**METHOD**

Hybrid statistical-dynamical models
- Create synthetic chronologies of coastal storms and hurricanes via weather regimes
- Surrogate emulators of flooding and erosion
- Validate with field observations of morphology change and storm impacts
- Inputs to decadal community decision models

**IMPACT**

Inform local management decisions for coastal defense policies

Field Work and Lab Facilities

**METHOD**

Utilize state-of-the-art technology to conduct experiments
- Real-Time Kinematic GPS
- UAV imaging and video
- LiDAR
- Current meters
- Pressure sensors
- Drifters
- Sediment grain sizer
- Sediment flume

**IMPACT**

Improved understanding of:
- Wave runup
- Marsh erosion
- Response of living shorelines
- Interactions between flow, vegetation and structures
Water Resources and Environmental Engineering
Engineering for Sustainable Civilization

• **Air**
  • On-road and nonroad vehicle emissions
  • Human exposure and risk management
  • Atmospheric aerosols
  • Energy and environmental health in developing countries

• **Water**
  • Watershed development and flow alteration
  • Water supply and quality
  • Contaminant removal
  • Groundwater remediation
  • Water and wastewater treatment
  • Water Sanitation and Hygiene (WaSH) in developing countries

• **Land/Solids**
  • Biological and chemical processes in landfills, energy recovery
  • Identification of waste management alternatives

• **Energy Systems**
  • Emissions
  • Transportation fuels and operations
  • Building energy efficiency
  • Regional energy systems optimization

• **Climate**
  • Greenhouse gas emissions
  • Climate change and watershed flow impacts
Implications and Impact

- Quantify contaminant releases and concentrations in the environment
- Process engineering for contaminant treatment and control
- Water, solid waste and air quality management
- Public and occupational health and safety
- Reduce exposure to toxic pollutants
- Emergency response (e.g., floods)
- Resource use and allocation
- Land use and environment
- Energy choices
- Water supply
Environmental Engineering and Science

• Physical Processes
  • Transport and fate of contaminants
  • Process technology mass balance
  • Adsorption processes for water treatment

• Chemical Processes
  • Oxidation processes for water treatment
  • Contaminant sequestration
  • Air pollutant formation and control

• Biological Processes
  • Mechanistic understanding of wastewater treatment and landfills
  • Groundwater remediation
  • Detection and quantification of microbes

• Decision Science
  • Risk Assessment
  • Support and Analysis
  • Data Assimilation, Algorithm Development
  • Optimization, operations research
  • Modeling and simulation
  • Integrated system assessment
GOAL
Optimize the efficiency of water and wastewater treatment processes

APPROACH
Use validated numerical transport models coupled with global search optimization algorithms

METHOD
CFD, Optimization and laboratory analytical measurements

IMPACT
Efficient treatment systems that enhance pollutant removal and uses less resources
Environmental Biotechnology

**GOAL**
Understand fundamental microbiological processes in waste treatment, develop waste-to-energy technologies, design appropriate sanitation for developing countries, quantify risk of water reuse

**APPROACH**
Analysis of microbial function in lab- and full-scale systems, application of ecological theory to bioreactors, detection and quantification of pathogens in water reuse systems, field testing of sanitation technologies

**METHOD**
Molecular (DNA/RNA) techniques, modeling, reactor studies and field testing

**IMPACT**
Improved bioreactor designs for nutrient removal, methane production, and low-cost systems; acceptable water reuse; solving the sanitation challenge for underserved areas

Opening the bioreactor “black box”
Drinking Water Treatment

**GOAL**

Improve drinking water safety

**APPROACH**

- Develop analytical methods for unregulated organic contaminants
- Characterize the effects of wastewater contaminants on the quality of drinking water sources (e.g. Cape Fear River)
- Identify effective management and treatment approaches for controlling organic contaminant levels in drinking water

**IMPACT**

Inform policy decisions and treatment process selection, reduce human exposure
Renewable Electricity Generation

GOAL
Recover energy from wastewater and salinity gradients

APPROACH
Develop effective (bio)electrochemical technologies to:
• Simultaneously recover energy and treat wastewater, and
• Generate electricity from the controlled mixing of low- and high-salt waters

METHOD
Electrochemical techniques, micro/molecular biology and reactor studies

IMPACT
Transform wastewater utilities into net-positive energy facilities and generate grid-scale electricity from coastal and inland salinity gradients
Pathogen Detection and Transmission Pathways & Creating Effective WaSH Indicators

**GOAL**

Identifying fecal contamination transmission pathways

**APPROACH**

- Interviews and observations on local behaviors
- Field and laboratory water quality sampling

**METHODS**

Structured surveys, randomized controlled trials, molecular and microbiology detection and enumeration techniques

**IMPACT**

Domestic animals are often an overlooked source of fecal contamination in household settings

Recommendations for water-quality sampling and reductions to human exposure to fecal pathogens
Understand biological and chemical processes in landfills as they affect energy potential, waste decomposition and heat accumulation.

Laboratory simulations integrated with field observation and mathematical modeling.

Improved predictive models for methane generation, use in national emissions inventories, development of landfill waste acceptance strategies and manage elevated temperature landfills.
**GOAL**
Create water treatment technologies for resource constrained settings

**APPROACH**
- Laboratory and field methods for detecting chemical contaminants from pesticides, industrial effluents and pharmaceutical residues
- Establish effective methods for creating and using biochar adsorbents for chemical toxin removal

**METHODS**
- Mass spectrometry and pyrolysis

**IMPACT**
Increased access to safe and healthy drinking water
Improving Sanitation Services

**GOAL**
Develop cost-effective technologies along the sanitation chain (user interface, collection, treatment, and reuse of fecal sludge)

**APPROACH**
Experimental and modeling studies, field testing in Asia and Africa

**METHOD**
CAD, CFD Modeling, rapid prototyping, time-motion studies and field testing

**IMPACT**
Reductions in fecal contamination; providing dignity to sanitation workers; scaling up solutions

https://bit.ly/3tna0qf
Understanding Atmospheric Aerosols

**GOAL**
Reduce air emissions' health and climate impacts at home and abroad, including from indoor solid fuel use in developing countries

**APPROACH**
Develop data, tools and insights to improve our understanding of sources and atmospheric transformations of emissions

**IMPACT**
Aid in optimal selection of technologies and policies to protect health and address climate change
Identify effective ways to reduce real-world energy use and emissions of on-road and nonroad vehicles

Measure vehicle activity, energy use, and emissions with portable emission measurement systems (PEMS); develop high-resolution vehicle energy use and emission models

Improve vehicle operations, traffic management, traffic control and infrastructure design; evaluate fuels and technologies
Measurement and Modeling of Human Exposure

**GOAL**
Quantify human exposure to air pollution and identify ways to reduce exposures

**APPROACH**
Measure air pollution exposure concentrations using portable instruments; model individual and population exposures

**IMPACT**
Prevent high exposures by modifying human activity, emission sources or enclosed environments (e.g., home, car)

Exposure Hotspots On Hillsborough St.
Exposure Measurement
Modeling Air Quality Under Global Change

**GOAL**
Identify and evaluate strategies to reduce air pollution and its impacts through computational modeling.

**APPROACH**
Develop multiscale frameworks to simulate air quality and its interactions with climate, health, energy resources and other environmental systems.

**IMPACT**
Improve air quality and earth systems models, guide environmental regulatory decision-making and policy.
Geotechnical / Geoenvironmental Engineering
Offshore Renewable Ocean Energy

**GOAL**
Develop innovative systems for anchoring and mooring of offshore marine hydrokinetic devices in waves, tidal and ocean currents.

**APPROACH**
Develop the use of Plate Anchors and Micropiles in marine environment and investigate construction approaches for deploying formed Micropiles and Plate Anchors.

**IMPACT**
Specification guidelines and “road map” for deploying cost effective anchoring systems in offshore environments in support of an emerging renewables energy market.
**GOAL**

Improve the strength and stiffness of energy byproduct materials, like coal ash ponds, while also immobilizing heavy metals within the material.

**APPROACH**

Utilize bio-cementation within the energy byproduct material to improve the mechanical properties and immobilize heavy metals.

**IMPACT**

Leachability, compressibility and geophysical tests are conducted on treated and untreated coal ash material to assess suitability of bio-cementation.

**METHOD**

Provide a natural, innocuous method to improve the long-term performance of coal ash impoundments and other energy byproduct materials.
Scour Assessment & Mitigation

**GOAL**

Understand soil susceptibility to scour within onshore and offshore environments and reduce the susceptibility to scour using natural methods.

**APPROACH**

Assess soil susceptibility to scour using In Situ Erosion Evaluation Probe (IEESP) and predictive modeling and prevent scour using bio-cementation.

**IMPACT**

- ISEEP is the first tool developed to assess soil erosion parameters with depth.
- Deployed to study breaching during NC hurricanes.
- Bio-cementation can be used to reduce erosion from wave action and reduce scour adjacent to offshore foundations without harmful ecological consequences.
Flood Defense Structures

GOAL

Develop a framework to assess the stability of flood defense earth structures and integrate a comprehensive multiscale levee monitoring program to assess the probability of exceeding predefined performance limit states.

APPROACH

The concept of deformation-based limit states is introduced, using coupled deformation-seepage analyses and including various scenarios for rehabilitation measures; monitoring is achieved through coupled satellite-based JSInSAR and in-ground monitoring at high-risk sections.

IMPACT

Method to diagnose current levee conditions, prognosis under varying future conditions, and assess potential property damage and loss of life, as well as impact of repair and rehabilitation of damaged levee.

LIMIT STATE I: No visible signs of flooding, landside boils, through or under seepage, or significant deformation.

LIMIT STATE III: Levee is breached with major flooding of the protected property. Rebuild is needed.

DInSAR interferometric phase change along the levee toe.
**Geotechnical Earthquake Engineering**

**GOAL**
Improve the characterization of site-specific effects on ground motions and characterize spatial variability of hazard- and performance-relevant ground motion intensity measures.

**APPROACH**
Numerical analysis of the propagation of seismic waves through porous media, uncertainty analyses and dynamic soil testing.

**IMPACT**
To improve our understanding of the impact that local soil conditions have on ground shaking intensity and distribution, while elucidating correlations with the response of critical infrastructure (e.g., lifelines, nuclear power plants).
Seismic Hazard Assessment

**GOAL**
Investigate the characteristics and variability of strong ground motions, near-surface wave propagation effects, and the correlation between ground motion parameters and structural response.

**APPROACH**
Numerical and statistical analyses of global ground motion databases, development of analytical and physics-based models of the near-surface propagation of seismic waves.

**IMPACT**
Advance the assessment of multihazard resilient soil-foundation-structural systems.
Seismic Hazard Mitigation

GOAL
Improve soil behavior subjected to dynamic loading conditions through the introduction of natural microbial processes in the form of bio-cementation.

APPROACH
Soil bacteria can be harnessed to create cementation within the soil, reducing the susceptibility of both sandy and silty soil to liquefaction.

METHOD
Liquefaction susceptibility is assessed through cyclic shear strength tests; study changes in flow properties of the soil to assess potential in situ implementation.

IMPACT
Provide a natural ground improvement alternative to improve the performance of infrastructure during earthquakes.

SEM of bio-cemented sand  
CSR curve for treated sand  
Cyclic simple shear testing
Temporary Slopes and Retaining Systems

**GOAL**
Design approach for temporary slopes and retaining structures in North Carolina residual soils, taking into account the unsaturated properties of the soil

**APPROACH**
Field testing on sheet pile wall and three steep slopes, coupled with numerical analyses incorporating suction effects

**METHOD**
Full-scale testing of field structures with supplemental laboratory testing and extensive numerical modeling

**IMPACT**
Reduced construction costs, as steeper slopes and lighter wall sections might be possible during temporary construction with the incorporation of soil suction
Structural Engineering

- Advanced/innovative infrastructure systems
- Development of fundamental models for performance of concrete and steel structures
- Development of novel assessment techniques
- Probabilistic analysis and design
- Repair of concrete, masonry and steel structures with advanced fiber-composites
- Earthquake engineering
- Nuclear power plant structures and components
- Structural health monitoring and prognostics
Assess performance of shear critical reinforced concrete infrastructure and use crack information to directly quantify level of safety

GOAL

Conduct heavily instrumented, large-scale experiments to assist in the development of fundamental mechanical models

APPROACH

Improve understanding of how structures carry load and modernize safety assessments of critical infrastructure

IMPACT
Rapid Repair of Damaged Columns by Plastic Hinge Relocation

GOAL

Repair rather than replace columns heavily damaged in an earthquake

APPROACH

New repair techniques using portions of the column previously undamaged; verify with full-scale seismic testing and analysis

IMPACT

Suite of rapid repair techniques for bridge engineers
Brittle behavior of unreinforced masonry walls in out-of-plane bending subject to wind, earthquake or blast loading

**GOAL**

**APPROACH**

Develop advanced fiber composite strengthening alternatives to enhance the deformation capacity of existing walls

**IMPACT**

Enhanced resilience and public safety from premature failure, and extended service life of existing infrastructure
GOAL
Develop innovative seismic performance enhancement techniques for welded steel building connections

APPROACH
Heat treatment of beam to induce seismic damage at desired beam location and thereby reduce stress or strain concentrations at weld; develop robust numerical models to simulate failure mechanisms

IMPACT
Enhanced seismic performance of steel building
Monitoring critical infrastructure for damage and corrosion requires advanced sensing technologies.

**GOAL**

We have developed a large-area sensing skin that enables detection of cracks and aggressive elements such as chlorides.

**APPROACH**

Rapid and reliable monitoring solution for critical infrastructure that can be combined with prognostic methods to get more out of our new and aging infrastructure.

**IMPACT**

NCSU team has developed full-scale sensing skin.

NCSU’s team has developed technology to print the sensing skin to be installed like wallpaper.
**GOAL**
Determine the effect of residual stresses on local fatigue crack initiation

**APPROACH**
Develop an experimentally validated thermo-mechanical simulation model to estimate residual stresses and their effect on crack initiation life

**IMPACT**
Improved estimation of structures and component lives and thereby improve design methodologies

Residual stress measurement at Oak Ridge National Lab

Simulation of residual stresses at welded joints
Currently there is no method to determine structural performance of fire-damaged steel structures.

**ISSUE**

**APPROACH**

Develop a simulation model to determine fire damage in steel structures and its influence on structural performance under seismic loading.

**IMPACT**

Structural rehabilitation to extend life of fire-damaged structures.

Simulation of fire damage in steel frame.
Bridge performance is related to material strains, which can be affected by earthquake characteristics.

Full-scale seismic testing of columns; fiber and finite element analysis for parameter studies.

New bridge performance measures and design methods.
**ISSUE**
Limited ductility capacity due to connection geometry, weld size and weld quality

**APPROACH**
Full-scale seismic testing of existing design; finite element modeling of existing and new designs to develop alternatives; dynamic shake table testing for proof-of-concept; full-scale seismic testing of new designs to resist high seismic demands

**IMPACT**
New bridge performance measures and design methods

**Imagery**
- Full-scale lab test
- Bird Creek Pedestrian Bridge (Compliments of AKDOT)
- Improvement in Performance graph
GOAL

Improve the resiliency of nuclear power plant structures, systems, and components during normal operations as well as extreme external hazards.

APPROACH

Create “Digital Twin” of systems and components using high fidelity simulations and plant sensor data; use Digital Twin for Diagnosis and Prognosis to optimize plant maintenance; support operators during accident condition by providing ranked list of actions.

IMPACT

Reduction in uncertainty, enhanced safety, reduction in cost of operating existing plants and building new ones.

Digital Twin for Nuclear Structures

Nuclear Steam Supply System (NSSS)

RCP: Reactor Coolant Pump
SG: Steam Generator
RPV: Reactor Pressure Vessel
GOAL
Evaluate interdependencies among different external hazards and determine potential vulnerabilities of nuclear power plants due to such correlations.

APPROACH
Mapping of Logic Tree models into Bayesian networks; account for potential correlations between failure modes and events; use Bayesian Inference to determine vulnerabilities.

IMPACT
Significant advancement in risk-assessment for beyond design basis events.
GOAL
Simulating the seismic behavior of electrical substations and switchgears for robust design

APPROACH
Use of advanced simulations; reconciliation of simulation models with experimental data; account for interactions between multiple units and supporting structures

IMPACT
San Francisco International Airport; Disneyland in Anaheim, C.A.
Simulating the behavior of reinforced concrete slabs subjected to impact with a tornado missile

**GOAL**
Use of advanced simulations; reconciliation of concrete material models with experimental data; blind prediction analysis

**APPROACH**

**IMPACT**
Accurate prediction of missile residual velocity and penetration depth
Nondestructive Testing of Pile Foundations

**GOAL**

Estimate unknown depth of pile foundations

**APPROACH**

Novel physics-based data processing of dispersive wave propagation — effective dispersion analysis of reflections (EDAR)

**IMPACT**

Reliable estimates of strength for continued use for old bridges and reuse of foundations for new bridges

EDAR Plot used for estimating embedded depth

In laboratory settings, EDAR resulted in <5% error compared to as much as 45% from the current state-of-the-art
Surface Wave Testing of Soils and Pavements

GOAL
Estimate layered properties of soil and pavements

APPROACH
Invert for material properties from observed dispersion of waves propagating along the surface

IMPACT
(a) Site characterization for geotechnical earthquake engineering; (b) Nondestructive testing for damage, delamination and oxidation of pavements

Geotechnical site characterization: comparison with borehole data
Our method (left) results in more accurate results in less than 1/300th time compared to the state-of-the-art (right)
Interdisciplinary group working towards the common goal of:
Understanding, modeling and improving a wide spectrum of traditional and emerging materials — using theoretical, experimental and computational mechanics that span the nano- to macro-scale
Develop structural fiber-reinforced composites (FRC) with capabilities for in-situ self-repair and real-time health monitoring.

**GOAL**

**APPROACH**

Integration of bioinspired microvascular networks with embedded optical fibers

**IMPACT**

Enhanced safety, resilience, and reliability of FRC for aerospace, automotive, naval, civil, and energy sectors.
Multifunctional Microvascular Metamaterials

**GOAL**
Develop structural composites with *multifunctional* capabilities including active cooling & electrical modulation

**APPROACH**
Fluid circulation within internal microvascular networks created from 3D printing of sacrificial polymer

**IMPACT**
Enhanced versatility, operating conditions, and new applications for polymer matrix fiber-composites
Reduction of spurious reflections through
new absorbing boundary conditions

Predicted substructure of a valley
using the new imaging algorithm

GOAL

Model large-scale structures under
earthquakes

Detecting hidden objects by exciting the
surface using high-frequency waves

APPROACH

Efficient methods to capture dynamic
interaction between soil and structure; use
elastic wave equation, finite element
methods, computational science

Special imaging algorithms; newly
developed equations (one-way wave
equations)

IMPACT

Better design of earthquake-resistant
structures

Crack detection, mapping oil reservoirs,
medical imaging

GOAL

Efficient methods to capture dynamic
interaction between soil and structure; use
elastic wave equation, finite element
methods, computational science

Special imaging algorithms; newly
developed equations (one-way wave
equations)

IMPACT

Better design of earthquake-resistant
structures

Crack detection, mapping oil reservoirs,
medical imaging
Ca(OH)$_2$ is a secondary hydration product of cement that is unstable and is contributor to many durability problems.

**GOAL**

Ca(OH)$_2$ reacts with CO$_2$ forming CaCO$_3$ which is stable, sequestering carbon and improving concrete performance.

**APPROACH**

The production of Portland cement is energy intensive and results in CO$_2$ liberation; we put some of the CO$_2$ back in concrete and make it more durable.

**IMPACT**

Sequestering Carbon in Concrete

Reduction in Ca(OH)$_2$ and increase of CaCO$_3$ in CO$_2$ intermixing concrete.

X-ray CT showing distribution of CaCO$_3$ (bright particles).
Quantifying the Rate of Transport of Volatile Organic Compounds (VOCs) through Concrete

**ISSUE**
At times, subsurface utilities including water and/or drainage pipes need to be installed, in soil and groundwater that are contaminated with VOCs.

**APPROACH**
Quantifying the rate of transport of benzene and PCE through concrete and modeling transport; developing novel measurement techniques.

**IMPACT**
Understand (1) how fast VOCs transport through concrete (2) whether their concentration poses any...
Non-Nuclear Imaging of Concrete

ISSUE
The resistance of concrete structures to the ingress of moisture and aggressive ions is considered a measure of their durability; methods for monitoring moisture ingress in concrete materials are needed.

APPROACH
We use electrical conductivity imaging of concrete to quantitatively monitor moisture ingress in concrete materials with and without cracks.

IMPACT
This method enables imaging concrete materials and potentially other porous media without the use of nuclear methods such as neutron tomography.

Electrical conductivity image of cracked concrete showing preferential flow of water in the crack; also shown is the actual specimen tested.
Organic Acid Attack on Concrete

**ISSUE**
Premature deterioration of concrete overlays in waste transfer stations as a result of simultaneous exposure to leachate and mechanical abrasion

**APPROACH**
Understand factors contributing to the deterioration and resistance of concrete against organic acids and mechanical abrasion; develop design-for-durability specification

**IMPACT**
Provide owners and operators with data and tools that can be used to develop specifications and performance requirements to reduce the premature deterioration of concrete overlays

Porosity of the matrix and harness of aggregates are important in resisting acid and abrasion
In below-ground structures (e.g., carbon sequestration wells), cement-based materials have the potential to be exposed to gas, liquid and supercritical CO2. How does this affect their microstructure and therefore their mechanical and durability performance?

Measure the effect of gas, liquid and supercritical CO₂ transport on cement-based materials by quantifying carbonate formation and phase dissolution.

Provide an understanding of the rate of degradation of below-ground structures and the rate of release of sequestered carbon back into the atmosphere.

X-ray CT shows carbonates form in concrete when exposed to gas, liquid and supercritical CO2.
At times, subsurface utilities including water and/or drainage pipes need to be installed in soil and groundwater that are contaminated with volatile organic compounds (VOCs). How do VOCs degrade polymeric utilities?

Quantify the rate of transport and degradation of PVC and gaskets exposed to benzene and PCE; develop service life model

Understand how fast polymeric utilities (PVC and gasketed pipelines) are expected to deteriorate in contaminated zones

\[
T_{N,m} = Ae^{-B\beta t}
\]

\[
\beta = \ln \left( \frac{S}{100} \right) \cdot \frac{100}{S} (1 - \frac{S}{100})
\]

Service life models have been developed that allows owners and operators to make informed decisions.
Reappraisal of the Specification of Aggregate Base Course

**GOAL**
Link mechanical performance to the aggregate base course (ABC) material specification (e.g., gradation, geometric properties and mineralogy)

**APPROACH**
Use material testing, mechanical performance and numerical techniques to enhance ABC specification

**IMPACT**
Improve ABC performance and directly relate to ABC design
Carbonate Formation in Concrete during CO$_2$ Ingress

**ISSUE**
Carbonate formation in cement-based materials during CO$_2$ transport results in the formation of CaCO$_3$, altering transport properties of cement-based materials. Advanced characterization methods are needed to understand the kinetics of reaction.

**APPROACH**
Quantitative X-ray tomography methods are developed to monitor the formation of a carbonate shell and its impact on multiphase flow.

**IMPACT**
Understand the conditions that promote formation of carbonates and how carbonates alter the rate of ingress of fluids in concrete; this has implications on design of underground carbon sequestration technologies.

Formation of carbonate shell in cement-based materials during transport of CO$_2$
Asphalt Material and Pavement Modeling

**GOAL**
Develop material and structure level models to predict long-term performance of asphalt pavement under realistic loading and environmental conditions

**APPROACH**
Apply mechanistic and computational principles

**IMPACT**
Accurate prediction of long-term pavement performance; provide a foundation to mechanistic pavement design and performance-related specifications
**GOAL**

Increased operating temperature increases energy efficiency of machines and plants

**APPROACH**

Develop advanced material model for simulation based structural design and analysis

**IMPACT**

Economy and sustainability of high-temperature industries and systems

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Next generation nuclear power reactor

Gas turbine jet engine

Superheater boiler header
Multiaxial Miniature Testing System for Advanced Material and Engineering Research

**GOAL**
Develop a testing system capable of performing elevated temperature multiaxial tests inside a scanning electron microscope

**APPROACH**
A team of investigators from various disciplines and industry experts designed and developed the system

**IMPACT**
Efficient and economic design of new materials and high-performance components
Asphalt Binder and Mixture Testing

**GOAL**
Develop efficient test methods to characterize the behavior of asphalt binder and mixture

**APPROACH**
Apply mechanistic principles and advanced techniques

**IMPACT**
Improved efficiency and accuracy of test methods in predicting material behavior under various conditions; allow the seamless integration into pavement structure models

**Asphalt Mixture Performance Tester**

**Bitumen Bond Test**

**Direct tension fatigue test**
Asphalt Mixture Performance-Related Specification (AM-PRS)

**GOAL**
Develop PRS for asphalt mixtures for design-build projects, warranty projects, and estimating penalty-bonus factors

**APPROACH**
Integrate asphalt mixture performance test results into pavement structural model to assess how deviations in materials and construction properties affect pavement performance

**IMPACT**
Improved condition of the largest investment in civil infrastructures in the U.S.; asphalt pavements
Specifications for Asphalt Emulsions Used in Preservation Surface Treatments (PSTs)

**GOAL**
Develop PRS for asphalt emulsions used in preservation surface treatments

**APPROACH**
Identify binder properties that correlate to critical preservation surface treatments performance thresholds

**IMPACT**
Improved selection of asphalt emulsions in preservation surface treatments, preventing premature failure
Biorenewable Alternative to Asphalt

**GOAL**
Produce sustainable alternative to petroleum-based asphalt binder

**APPROACH**
Produce biorenewable bio-binders through Top-Lit Updraft Kilning (TLUK) of biomass

**IMPACT**
Biorenewable alternative to asphalt; 30 millions tons of asphalt consumed annually in the U.S. to support transportation infrastructure
Asphalt Mixture Performance-Related Specification (AM-PRS)

GOAL
Develop high reclaimed asphalt pavement (RAP) mixture designs based on better understanding of RAP binder blending

APPROACH
Carbon and Titanium Energy Dispersive Spectroscopy (EDS) map of RAP mixtures using Scanning Electron Microscopy (SEM)

IMPACT
Improved understanding of RAP binder blending and high RAP mixture design
Safety of Earthen Storm Water Infiltration Best Management Practices (BMP)

**GOAL**
Develop design guidelines for soil amendments that increase stormwater infiltration without negatively affecting roadside safety.

**APPROACH**
Identify the effect of soil amendments on soil strength and use these findings to simulate rollover potential with computer simulation.

**IMPACT**
Improved stormwater management without negatively affecting traveler safety.
Calibration of Structural Layer Coefficients for North Carolina Pavements

**GOAL**
Develop updated design standards for NCDOT pavement design that more accurately reflect modern materials

**APPROACH**
Identify performance of existing asphalt pavements; characterize current NCDOT materials; conduct advanced pavement performance simulations to update standards

**IMPACT**
Improved material consideration will reduce costs and increase longevity of pavements in the state

- Collect asphalt pavement performance data from NCDOT PMS
- Aggregate Base
- Full Depth
- Process Database
- Calibrate Layer Coefficients (asphalt concrete by layer type, aggregate base course, treated subgrade)
- Link asphalt mixture properties to layer calibrated coefficients
- Develop Layer Coefficients Tables for NCDOT Materials
**GOAL**
Develop improved field-testing framework for quality control of asphalt emulsion placement in tack coats and chip seals

**APPROACH**
Evaluate construction variability in emulsion application and quantify pavement emulsion absorption rates in field projects throughout North Carolina using the Tack Lifter

**IMPACT**
Improved quality control of emulsion application will extend pavement life and decrease life-cycle costs
Performance Evaluation of Geosynthetic Paving Interlayers

**GOAL**
Develop performance testing methodologies and performance criteria for geosynthetic interlayers

**APPROACH**
Evaluate reflective cracking and delamination potentials of AC specimens reinforced by geosynthetic interlayers using four-point bending notched beam fatigue test with DIC and MAST

**IMPACT**
Geosynthetic interlayer specifications and product selection guidelines for NCDOT based on performance tests
Transportation Systems: Sustainability

**GOAL**
Achieve sustainable operation and funding and minimize the negative environmental impacts of transportation activities

**APPROACH**
Improvements in transportation technology, policy, and operational control in tandem with capacity investments to improve productivity, efficiency and sustainability

**IMPACT**
Industry practice, economic development, land use planning, environmental quality, travel time reliability, safety, and fiscal viability

**METHODS**
- System Operations
- Environmental Impacts
- Design Innovations
- Impact Assessments: Economic and Socioeconomic
- Large-scale System Optimization

Close relationship with the Institute for Transportation Research and Education
itre.ncsu.edu/
Maximize system productivity and efficiency

GOAL

Improvements for system monitoring, management and planning

APPROACH

IMPACT

- Connected vehicle research
- Highway Capacity Manual procedures
- National guidebook for transportation system simulation
- National guidebook for travel time reliability monitoring
- Operational efficiency and pedestrian safety for roundabouts
- Work zone practice

METHODS

- Data from connected, autonomous and other probe vehicles
- Simulation and optimization
- Model and tool building
- Guidebook development
Traffic Control with Automated Vehicles

**GOAL**
Advance real-time traffic control in large-scale transportation networks with enhanced system information connectivity and automated vehicles

**APPROACH**
Develop distributed techniques for traffic system monitoring, management and planning

**IMPACT**
Improvement in:
- Traffic operations
  - Safety
  - Environment

**METHODS**
- Modeling
- Optimization
- Data analysis
- Simulation
Environmental Quality

**GOAL**
Maximize the energy efficiency of transportation activities, minimize the negative impacts (e.g. fuel consumption, emissions of greenhouse gases and other pollutants), both passenger and freight

**APPROACH**
Monitor and model transportation networks to identify hotspots in both temporal and spatial dimensions

**IMPACT**
- Regional emissions modeling (EPA)
- Environmental impacts of intelligent transport systems
- Environmental-focused model calibration
- Trade-offs of safety and environmental objectives

**IMPACT**
- Multiscale simulation modeling
- Empirical data collection
- High resolution in-vehicle sensing
Coordination with Economic Growth

GOAL
Foster economic prosperity through coordinated transportation investments (MAP-21)

APPROACH
Focus on freight productivity and efficiency as well as personal mobility

IMPACT
Recommended investment actions and policies that foster economic growth

IMPACT
- Economic impact analysis
- Input-output models
- Benefit-cost analysis
- Land use and transportation planning
- Modal and intermodal innovation
Design Innovation

**GOAL**
Consume less space per unit of capacity, provide better operational performance, reduce delays, enhance safety

**APPROACH**
Innovative design ideas

**IMPACT**
Documentation of facility performance, experimentation with innovative designs

**METHODS**
- Performance assessment tools and techniques
- Design concepts
- Analysis tools
Social Prosperity

GOAL
Enhance prosperity via policies and actions that provide mobility for all socioeconomic groups and foster efficiency and equity in transportation systems and land use

APPROACH
Study interdependencies between patterns of urban development and transportation systems and policies

OUR CONTRIBUTIONS
Policies and operational strategies that ensure equitable access to public transportation, social inclusion, improved quality of life, urban sustainability

METHODS
• Equitable transit-oriented development
• Quasi-experimental studies
• Spatial analysis and econometrics; policy analysis
• Sustainable water resources development
• Urban water system planning and optimization
• Hydroclimatology, drought and flood management
• Water-quality modeling and forecasting
• Uncertainty quantification and reduction
• Integrated system analysis and risk assessment
Hydroclimatology and Water Management

GOAL
Improve water management practices by incorporating climate information

APPROACH
Innovative data fusion methods with statistical modeling and inference, and optimization

METHOD
Stochastic modeling, simulation, optimization

IMPACT
Improved water sustainability, flood and drought management, reservoir operation, hydropower management, water quality, and risk management

Climate Informed Drought Management at Falls Lake
Socio-Technical Systems Analysis for Planning Water Reuse Programs

**GOAL**
Novel modeling approach for how humans interact with infrastructure to improve engineering design and management policies.

**APPROACH**
An adaptive model of diffusion of innovation coupled with infrastructure expansion plans; illustrative case application for Cary, N.C.

**METHOD**
Agent-based modeling, optimization.

**IMPACT**
Evaluate plans for new infrastructure based on simulation of willingness of consumers to adopt water reuse technologies.
GOAL
Predict how human actions impact water quality

APPROACH
• Assess water quality impairments, such as hypoxia and harmful algal blooms, through geospatial modeling and data fusion
• Develop biophysical models to forecast impairments based on pollutant loading, weather and climate

IMPACT
Inform watershed, fisheries, and water supply management; raise public awareness through timely water quality forecasts
Protection of Freshwater Resources

GOAL
Develop strategies to protect and restore water quality

APPROACH
• Field and experimental studies to measure water quality, algae proliferation, and controlling factors
• Develop numerical models that generalize field and experimental results

IMPACT
Improve water quality in lakes and reservoirs through science-based engineering and management solutions
Thank you for your interest

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