25th Structural Engineering & Mechanics Symposium

Friday, February 26th, 2021
10am - 5pm

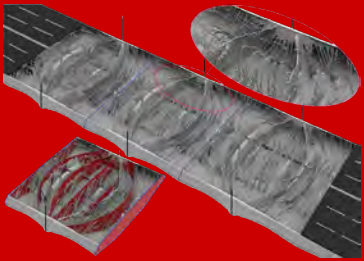
Department of Civil, Construction, & Environmental Engineering

NC STATE UNIVERSITY

STRUCTURAL ENGINEERING AND MECHANICS

Keynote Presentation

Multi-scale Topology Optimization



Ole Sigmund, Villum Investigator, Department of Mechanical Engineering, Technical University of Denmark

Seminar Abstract

Topology optimization was introduced as a multi-scale approach in the seminal paper by Bendsøe and Kikuchi in 1988. However, simpler isotropic density interpolation schemes soon substituted the original homogenization-based approach and have contributed to the breathtaking development of topology optimization methods – lately further spurred by the popularization and availability of advanced 3D printing techniques making it possible to realize complex, highly optimized topology optimized structures.

Multi-scale or homogenization-based topology optimization approaches have recently been revived, partly to save computational costs in giga-resolution studies and partly due to the possibility of building structures with architected infill through additive manufacturing techniques.

The seminar will give an overview of various techniques to perform multi-scale topology optimization and how to extract optimized designs through subsequent de-homogenization. This talk includes discussions of what microstructures are optimal for what loading conditions. For example, closed-walled microstructures are known to be stiffness optimal but may fail due to local buckling for low volume fractions.

Biography

Ole Sigmund is a world leading researcher within topology optimization. He is a Professor and Villum Investigator in the Department of Mechanical Engineering, Technical University of Denmark (DTU). He obtained his Ph.D. degree in 1994 and Habilitation in 2001 and has held research positions at University of Essen and Princeton University. He is a member of the Danish Academy of Technical Sciences and the Royal Academy of Science and Letters and is the former President (2011-15, now EC member) of ISSMO (International Society of Structural and Multidisciplinary Optimization) and former Chairman of DCAMM (Danish Center for Applied Mathematics and Mechanics, 2004-2010). Together with Noboru Kikuchi and Martin Bendsøe, Ole Sigmund is one of the founders and present main contributors to the development of topology optimization methods in academia and industry. His prolific publishing record including 200+ scientific papers and texbook on Topology Optimization have received numerous citations in the literature (see Google Scholar).

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Keynote Zoom Link: **https://ncsu.zoom.us/j/91506485933**
Sessions Zoom Link: **https://ncsu.zoom.us/j/94828670253**

Opening Remarks and Keynote Introduction	9:55am - 10:00am
Keynote Seminar	10:00am - 11:00am
Morning Break	11:00am - 11:30am
Session I - Modeling	11:30am - 12:30pm

- **Harleen Sandhu, PhD under Dr. Gupta**
  Digital Twin: Condition Monitoring of Nuclear Power Plant Pipes using Artificial Intelligence and Signal Processing
- **Guillermo Gonzalez, PhD under Dr. Pour-Ghaz**
  Estimation of Elastic Modulus of Finite Media through Vibrational Techniques
- **Lucas Lima, PhD under Dr. Hassan**
  Multiscale Experimentation and Modeling of Cladding Alloys towards Enhancing Resilience of Next Generation Nuclear Reactors
- **Abdelrahman Elmeliegy, PhD under Dr. Guddati**
  Full Waveform Inversion through a Double-Sweeping Inexact Newton Method
- **Gina Aliyeva, PhD under Dr. Kowalsky**
  Mechanical Model of Bar Buckling
- **Galib Muktadir, PhD under Drs. Ranjithan, Kowalsky & Proestos**
  Development of Optimized Prestressed Concrete Girders

Lunch	12:30pm - 1:30pm

Session II - Durability, Degradation, & Repair 1:30pm - 2:30pm

Taylor Brodbeck, PhD under Dr. Kowalsky
Rapid Repair of Reinforced Concrete Bridge Columns

Sheng-Hsuan Lin, PhD under Dr. Seracino
Retrofit of an In-service Deteriorated Prestressed Concrete Bridge using Mechanically Fastened Fiber Reinforced Polymer

Sherif Aboubakr, PhD under Dr. Patrick
Rapid Self-Healing of Structural Polymers via Integration of Microvasculature and Optical Fibers

Serena Sauers, BS under Dr. Gupta
Framework to detect degradation in Nuclear Power Plant

Francisco Jativa, PhD under Dr. Pour-Ghaz
CO2 Intermixing as a method to sequester carbon and increase durability of cement-based materials

Alexander Snyder, PhD under Dr. Patrick
Self-healing of Laminated Fiber-composites via In Situ Thermal Remending

Session III - Simulation & Analysis 2:30pm - 3:30pm

Tuhin Roy, PhD under Dr. Guddati
Full-wave Simulation for Arterial Shear Wave Elastography through Semi-Analytical Finite Element Method

Sangwoo Lee, PhD under Drs. Gupta & Proestos
Damping models for Nonlinear Time History Analysis of Reinforced Concrete Structures

Ashton Stuart, MS under Dr. Proestos
Predicting the Response of Shear Critical Reinforced Concrete Shell Elements Subjected to Combined In-Plane and Out-of-Plane Loading

Parth Patel, PhD under Dr. Gupta
Simulating Tornado Missile Impact on Reinforced Concrete Structures

Rajprabhu Thangappa, PhD under Drs. Seracino & Akhnoukh
Performance Evaluation of Integral Abutment Bridges

Pragya Vaishanav, PhD under Dr. Gupta
Computationally Efficient Approach for Risk-informed Decision Making

Afternoon Break 3:30pm - 4:00pm

Session IV - Experimental 4:00pm - 5:00pm

- **Urmi Devi, PhD under Dr. Patrick**
  Active-cooling in Bioinpsired Microvascular Composites

- **Atilla Kurt, MS under Dr. Lucier**
  Behavior of Ultra-High Performance Concrete Ledges Subject to Concentrated Loads

- **Dhanushka Palipana, PhD under Dr. Proestos**
  Quantification of Shear Transfer Mechanisms from Large-Scale Deep Beam Experiments

- **Zachary Phillips, PhD under Dr. Patrick**
  Investigation into the effects of Microvascular Topology on the Structural Integrity of Fiber Composites

- **Jessi Thangjithan, PhD under Dr. Kowalsky**
  The Seismic Performance of Grade 80 Rebar in RC Bridge Columns

- **Eric Throckmorton, MS under Dr. Proestos**
  Experimental Investigation of Long-Term Prestressing Losses in the Herbert C. Bonner Bridge

Award Ceremony and Closing Remarks 5:00pm - 5:15pm

CCEE

Special thanks is extended to our students, faculty, and staff who were involved in the preparation of this event

Designed by Sarah Mann, B.Arch, MS, and Dr. Jason Patrick

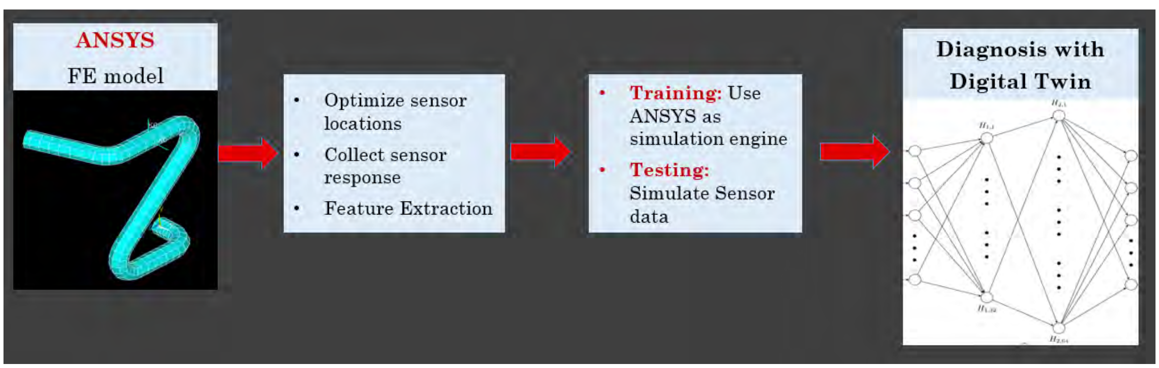
Digital Twin: Condition Monitoring of Nuclear Power Plant Pipes using Artificial Intelligence and Signal Processing

Harleen Kaur Sandhu[1*], Saran Bodda[1], Abhinav Gupta[1]

[1] *Department of Civil, Construction, and Environmental Engineering (CCEE)*
North Carolina State University (NCSU), Raleigh, NC, 27606, USA

Over the past decade, the use of AI techniques for degradation detection and health-monitoring has been explored. In this presentation, a Digital Twin framework is illustrated for data-driven condition monitoring of piping systems in Nuclear Power Plants. Over the course of time, degradation in the pipes can occur due to flow-accelerated erosion and corrosion. This degradation of aged nuclear pipes can often times go undetected by current inspection techniques. Thus, the immediate need to detect and reinforce such degraded locations in real time. In addition, continuous monitoring would enable safe operations and extend the operating lifetime for an NPP.

The proposed DT utilizes sensor data to generate an AI database for predicting degraded locations and severity. The performance of a DT depends on the choice of key features used for its training. In this study, the Power Spectrum Density (PSD) is extracted as the representative training feature. Numerical simulations using FEM in ANSYS for EBRII Nuclear reactor Z-pipe system (degraded and non-degraded condition) are conducted to generate a training database and to verify the accuracy of the predictive framework. It is observed that the ANN can predict the degraded locations and severity within acceptable levels of confidence.



Graphical abstract title: Flowchart of the Digital Twin Framework

Keywords: Digital Twin, Condition Monitoring, Pipes, Signal Processing, Neural Network

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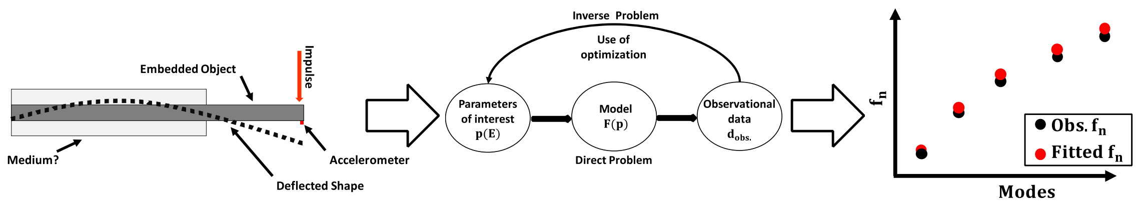
2021 Structural Engineering and Mechanics (SEM) Symposium

Estimation of Elastic Modulus of Finite Media through Vibrational Techniques

Guillermo C. Gonzalez-Berrios[1*], M. Pour-Ghaz[1]

[1] *Department of Civil, Construction, and Environmental Engineering (CCEE)*
North Carolina State University (NCSU), Raleigh, NC, 27606, USA

In this presentation we investigate whether the elastic modulus of a finite medium can be estimate by monitoring the vibration response of a rod embedded within it. The assumption is that the properties and geometry of the rod embedded in the medium are known. The problem then is an inverse problem of estimation of the elastic modulus of the medium or detection and quantification of liquid to solid transition of a medium. The problem has many application in Civil Engineering (e.g., soil nails) and Biomedical Engineering (e.g., osseointegrated implant). We have applied inverse problem schemes to obtain the parameters of the system.



(1) Natural frequencies of the system extracted from response

(2) Optimization is utilized to fit the elastic modulus of the media

(3) Elastic modulus is obtained and response of the model is plotted

Graphical abstract title: Procedure that is followed to obtain the elastic modulus of the media

Keywords: Non-Destructive Testing, Inverse Problems, Vibration

NC STATE UNIVERSITY

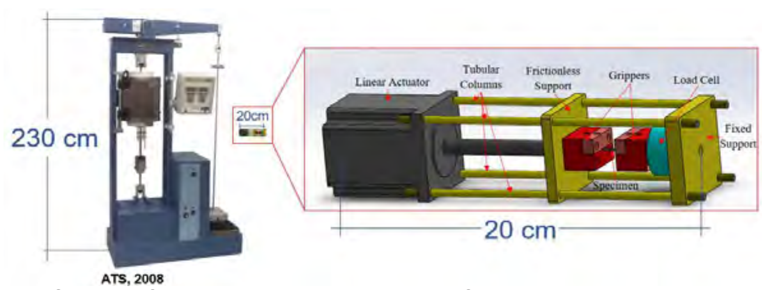
2021 Structural Engineering and Mechanics (SEM) Symposium

Multiscale Experimentation and Modeling of Cladding Alloys towards Enhancing Resilience of Next Generation Nuclear Reactors

Lucas M.A. Lima[1*], Tasnim Hassan[1]

[1] *Department of Civil, Construction, and Environmental Engineering (CCEE)*
North Carolina State University (NCSU), Raleigh, NC, 27606, USA

The Very High Temperature Reactor (VHTR) concepts have been developed under the DOE Generation IV programs for improving the thermal efficiency and thereby making nuclear energy more attractive economically. VHTRs will operate in the temperature range 700-1000ºC [1]. Hence, failures by corrosion, creep and creep-fatigue mechanisms are critical in the design of reactor components. To mitigate these failures, VHTRs uses cladding to create a multilayered wall for enhancing resilience of VHTR structural components. Material scientists are developing new cladding alloys with good corrosion resistance and mechanical properties at elevated temperatures. New alloys are usually developed in small batches and tested for performance evaluation. Due to the nonexistence of miniature specimen testing equipment for creep and creep-fatigue tests, currently only the tension tests are performed. This study is developing a miniature creep test system to perform both the ex-situ and in-situ tests within Scanning Electron Microscope (SEM) of irradiated and non-radiated specimens. The miniature creep tester development is about to be completed and challenges overcame will be presented. Upon completion of the creep tester development, high temperature creep tests on novel and neutron irradiated cladding alloys will be conducted and multiscale failure mechanisms will be investigated. We will also make effort to develop a multiscale simulation model.



Standard Creep Tester Miniature Creep Tester Load Frame

Keywords (Multiscale testing, Creep, Cladding alloys)

Reference

[1] Pioro, I.L. "Introduction: Generation IV International Forum." In Handbook of Generation IV Nuclear Reactors, 37–53. Woodhead Publishing, 2016. https://doi.org/10.1016/C2014-0-01699-1.

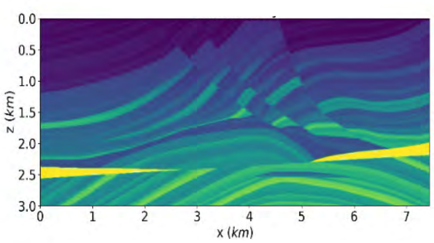
Full Waveform Inversion through a Double-Sweeping Inexact Newton Method

Abdelrahman M. Elmeliegy[1], Mehran Eslaminia[2], Murthy N. Guddati[1]

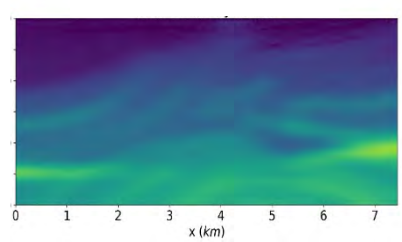
[1] *Department of Civil Engineering, North Carolina State University,* [2] Bentley Systems.

Full waveform inversion (FWI), which is widely used in geophysics, reconstructs the unknown material properties given the response at discrete locations at the surface by iteratively minimizing the misfit between observed and predicted data. FWI is computationally expensive, as it requires the solution of many large-scale forward Helmholtz solves. Past work on sweeping preconditioner [1] indicates that Helmholtz problems can be efficiently solved through preconditioner that capture the first arrival as well as the primary reflections.

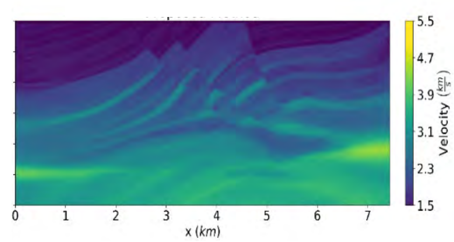
In this effort, we build on this success and adapt that technique in an inexact Newton setting, where the gradient and Hessian vector multiplication is made even more efficient thorough the (approximate) double-sweeping solver, leading to an efficient FWI methodology. In this talk, we present the new methodology supported by examples of varying complexities showing the effectiveness of the proposed methodology.



Sectional Elevation of the true velocity model of Marmousi.



Sectional Elevation of the initial velocity model.



Sectional Elevation of the reconstructed velocity model.

Marmousi velocity model: A complex 2D structural model which contains many reflectors, steep dips, and strong velocity variations in both the lateral and the vertical direction (with a minimum velocity of 1.5 km/s and a maximum of 5.5 km/s).

Keywords: Inverse Problems, Optimization, Helmholtz Equation, Wave propagation.

References

[1] Mehran Eslaminia, Murthy N. Guddati, A double-sweeping preconditioner for the Helmholtz equation, J. Comput. Phys., Vol. 314, 2016, 800-823.

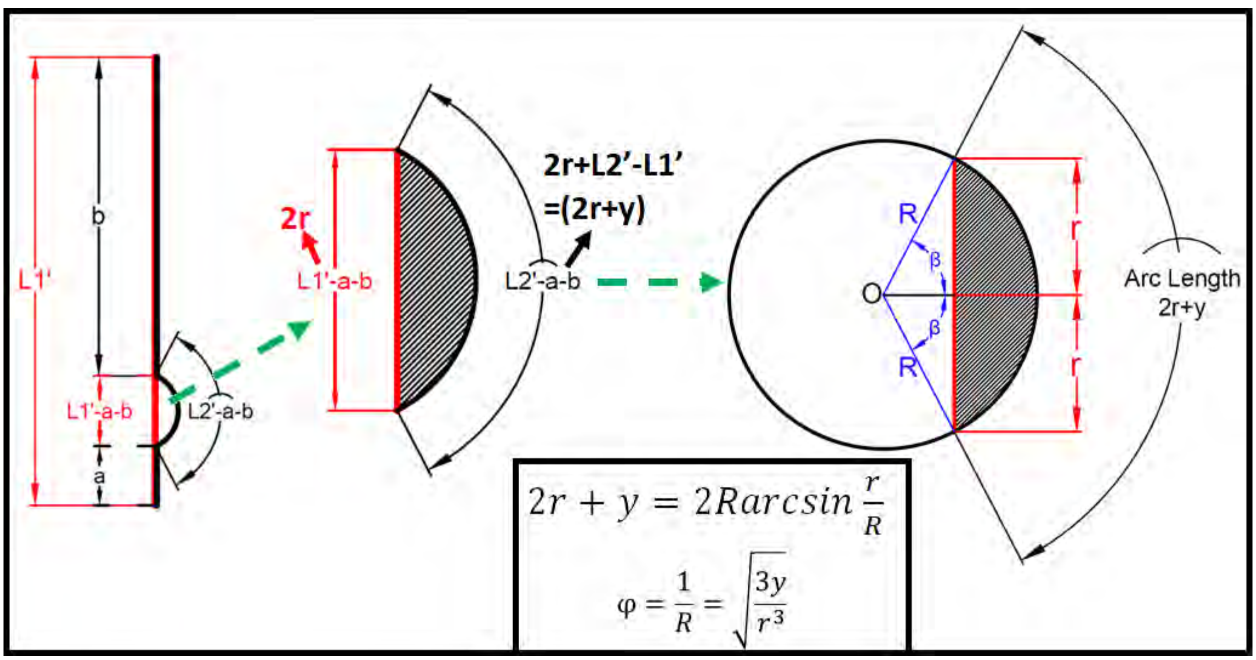
Mechanical Model of Bar Buckling

G.G. Aliyeva[1*], M.J. Kowalsky[2]

[1] *Constructed Facilities Lab, North Carolina State University (NCSU), Raleigh, NC, 27695, USA, Email: ggaliyev@ncsu.edu*

[2] *Department of Civil, Construction, and Environmental Engineering (CCEE) North Carolina State University (NCSU), Raleigh, NC, 27695, USA, Email: kowalsky@ncsu.edu*

The deformation capacity of well detailed modern reinforced concrete (RC) bridge columns can be defined by the fracture of previously buckled reinforcing bars. Previous research has shown that the level of buckling-induced bending strain that a reinforcing bar sustains is correlated to the tensile strain demand from the previous cycle, and that brittle fracture occurs when the critical bending strain is exceeded. With an accurate estimate of the bending strain in the buckled region, it is possible to develop a model for corresponding bar fracture. This study presents a mechanical model to calculate the bending strain. The model shows the change in the buckled region geometry in accordance with the elongation and shortening of the bar under cyclic loading to obtain the curvature of the buckled region and the corresponding bending strain. A bending strain equation is presented as a function of lateral column displacement, bar diameter, column diameter and transverse steel spacing. The equation developed from the mechanical model calculates accurate buckling-induced bending strains using minimum number of parameters.



Curvature of a buckled region

Keywords: reinforcing bar buckling, buckling-induced bending strain, RC bridge columns, mechanical model.

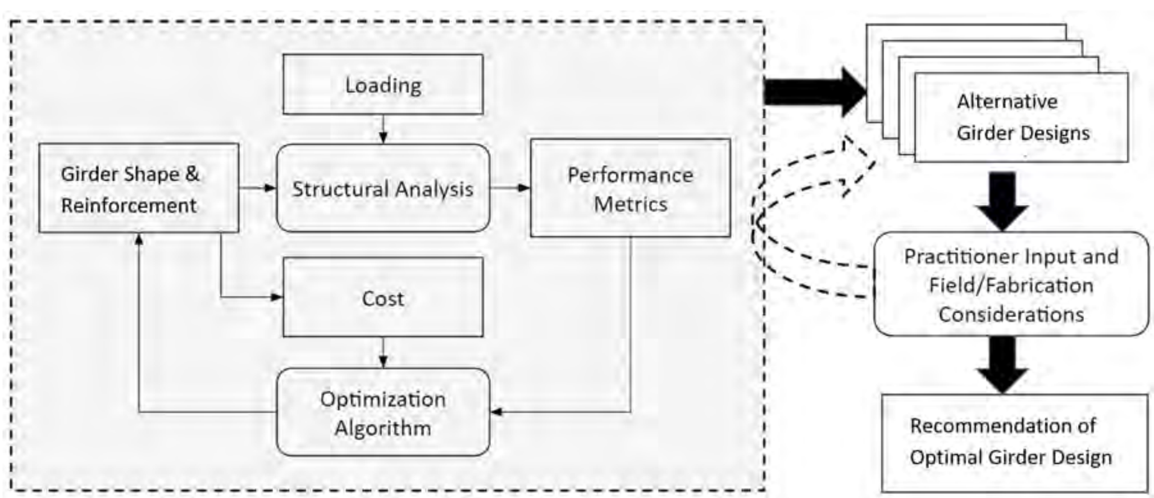
Development of Optimized Prestressed Concrete Girders

Muktadir, M.G.[1*], Kowalsky, M.J.[1], Proestos, G.T.[1], Ranjithan, R.S.[1]

[1] *Department of Civil, Construction, and Environmental Engineering (CCEE)*
North Carolina State University (NCSU), Raleigh, NC, 27606, USA

Traditional bridge design approaches typically use iterative trial-and-error methods to generate effective design alternatives based on the experience, intuition and ingenuity of the design engineers. The elegant bridges around the world demonstrate the merit of this approach. However, formal optimization approaches are scarcely used to identify alternative designs that simultaneously optimize cost, weight or volume of material, structural performance, and other considerations.

We aim to generate optimized prestressed concrete girder cross-section shapes and reinforcement details to increase the span length and to reduce the bridge life-cycle cost. We implement a metaheuristic search procedure that is coupled with structural analysis to navigate the multi-modal and highly nonlinear solution space by systematically and automatically changing the design variables to optimize cost and structural performance metrics while satisfying the design codes. The optimization algorithm is capable of identifying a small set of maximally different design alternatives that can potentially assist the practicing engineers during the design process as they consider a myriad of factors. We promote a practice of adopting a formal approach to find practically implementable improved designs of bridge structures both in terms of structural performance and overall cost and allocate limited resources more efficiently.



Highway Bridge Girder Optimization Procedure: Optimization algorithm exploring efficient girder designs by systematically and automatically changing the design variables based on cost and structural performance metrics

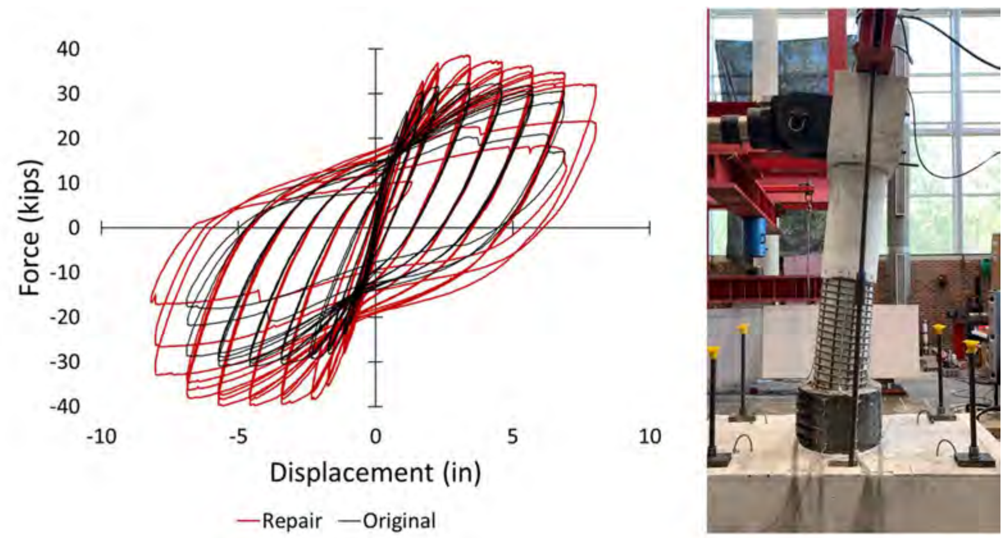
Keywords (design optimization, prestressed concrete, highway bridge girder, metaheuristic global search algorithm, cost efficient design)

Rapid Repair of Reinforced Concrete Bridge Columns

T.J. Brodbeck[1*], M.J. Kowalsky[1]

[1] *Department of Civil, Construction, and Environmental Engineering (CCEE)*
North Carolina State University (NCSU), Raleigh, NC, 27606, USA

Reinforced concrete columns subjected to earthquakes often experience severe levels of damage and require repairs to remain serviceable. However, for structures subjected to extensive aftershocks, it is often too late to design and implement a repair in a timely manner. In this presentation, a rapid repair technique will be introduced which relocates the plastic hinge to an undamaged section of the column using a steel jacket. A mechanically fastened connection and pre-embedded repair bars lead to timely implementation. Through this method, it is possible to restore the column to its original load carrying and deformation capacities before subsequent seismic events.



Repair of Previously Damaged Column

Keywords (repair, reinforced concrete, seismic design)

Retrofit of an In-service Deteriorated Prestressed Concrete Bridge using Mechanically Fastened Fiber Reinforced Polymer

Sheng-Hsuan. Lin[1*], Rudolf. Seracino[1]

[1] *Department of Civil, Construction, and Environmental Engineering (CCEE)*
North Carolina State University (NCSU), Raleigh, NC, 27606, USA

Many prestressed concrete (PC) bridges built prior to the 1970s have suffered deterioration due to steel corrosion, overload traffic, and natural aging, which has raised concerns for DOTs. The deteriorated bridges end up facing three situations: replacement, loading-post or closure, and cause inconvenience to the local communities. This research presents the first time NCDOT used the prestressed mechanically fastened fiber polymer (MF-FRP) as a retrofit method on the in-service deteriorated C-channel bridge, which can provide rapid repair and restore prestress losses. The retrofit was completed successfully, and additional instrumentations were installed on the system to provide long-term monitoring.

Figure: Deteriorated PC bridge retrofit using prestressed MF-FRP system.

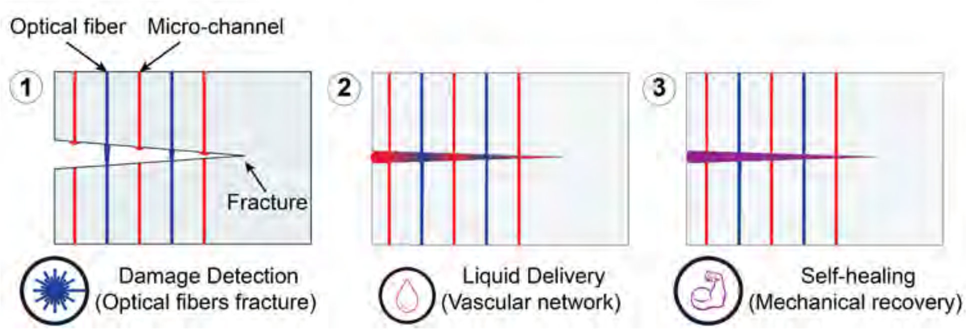
Keywords (Retrofit; Prestressed concrete; Mechanically fastened; Fiber-reinforced polymer (FRP); Restore prestress loss)

Rapid Self-Healing of Structural Polymers via Integration of Microvasculature and Optical Fibers

Sherif H. Aboubakr[1*], Jason F. Patrick[1]

[1] *Department of Civil, Construction, and Environmental Engineering (CCEE)
North Carolina State University (NCSU), Raleigh, NC, 27606, USA*

Interlaminar delamination in fiber-reinforced polymer composites is difficult to detect and nearly impossible to repair by conventional methods [1]. Bioinspired microvascular networks that rupture and release reactive liquid chemistries upon internal damage, offer the ability to self-heal modern structural composites. Two-part vascular healing systems have shown limited *in situ* mixing of viscous healing agents, resulting in slow polymerization kinetics (hours/days) and often blockages from cross-contamination [2,3]. Here we introduce a one-part, *in situ* self-healing system in a structural epoxy by combining vascular delivery of a photochemistry with light delivery via fractured optical fibers. This latest achievement recovers mode-I fracture toughness 100 times faster (minutes) than established two-part systems.



Self-healing structural polymer concept: (1) internal crack propagation and fracture of optical fibers (blue) releasing light; (2) simultaneous rupture of microvascular networks (red) for delivery of liquid photo-chemistry; (3) light-induced polymerization (violet) for *in situ* structural self-healing.

Keywords (self-healing, bioinspired, microvascular, fiber optics)

References

[1] Hart, K. R., Wetzel, E. D., Sottos, N. R., & White, S. R. Self-healing of impact damage in fiber-reinforced composites. *Composites Part B: Engineering* **173**, 106808 (2019).
[2] Patrick, J. F., Robb, M. J., Sottos, N. R., Moore, J. S., White, S. R. Polymers with autonomous life-cycle control. *Nature* **540**, 363-370 (2016).
[3] Qamar, I. P., Sottos, N. R., Trask, R. S. Grand challenges in the design and manufacture of vascular self-healing. *Multifunctional Materials* **3**, 013001 (2020).

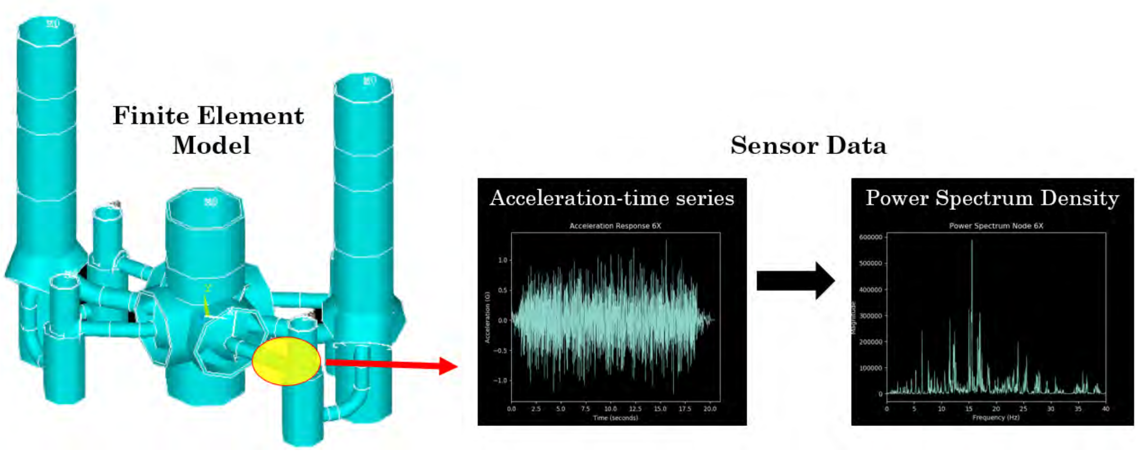
Framework to detect degradation in Nuclear Power Plant Pipes

Serena Sauers*, Harleen Kaur Sandhu, Abhinav Gupta[1]

[1] *Department of Civil, Construction, and Environmental Engineering (CCEE)*
North Carolina State University (NCSU), Raleigh, NC, 27606, USA

Critical facilities such as Nuclear Power Plants are immensely dependent on nonstructural components and systems, such as piping-equipment systems. In nuclear power plants, these are utilized to carry coolant fluids (such as water) to the reactor vessel, to maintain the fire sprinkler systems and to perform various other vital functions. Thus, the need to address the operational functionality of such piping-equipment systems in case of hazards such as earthquakes and during normal operations due to pump-vibrational loads is of utmost importance. Through this research, the behavior of such systems can be studied, such that it acts as an additional aid for prompt maintenance operations.

For the case study, a piping system is selected from the USNRC Piping Benchmark Problems. The Finite element model is created in ANSYS, to demonstrate degraded as well as non-degraded pipe conditions. A machine-learning algorithm is trained using the data collected from sensors. The time-domain sensor response is converted to frequency-domain Power Spectrum Density (PSD), and degradation sensitive features such as the maximum PSD, changes in PSD, and frequencies associated with PSD peaks are extracted from the sensor data. The performance of the machine-learning algorithm to predict degraded locations is also illustrated.



Graphical abstract title: FEM of the nuclear piping-equipment system and sensor data visualization

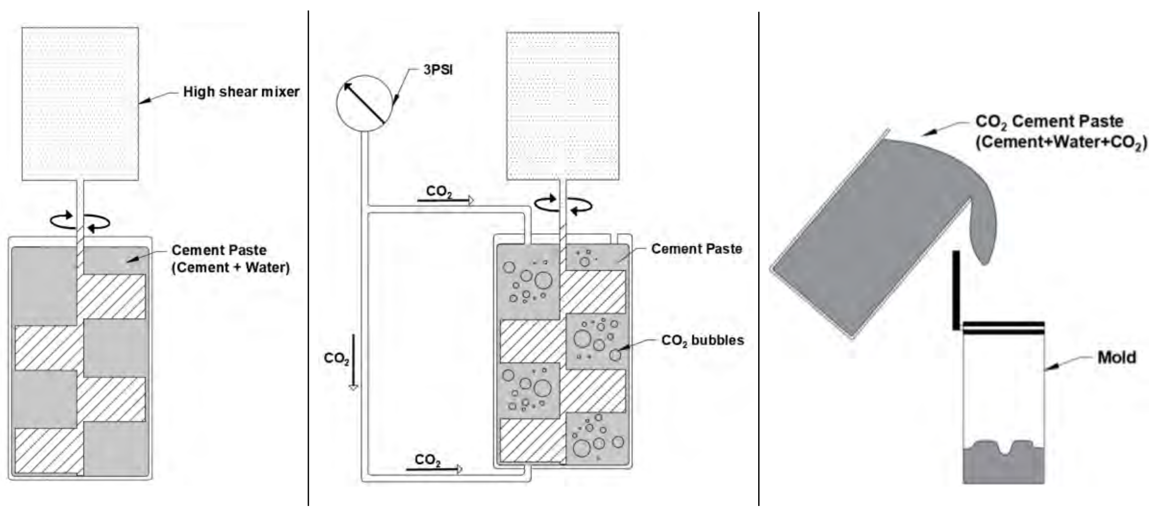
Keywords: Degradation, Finite Element Modelling, ANSYS, Pipes, Machine Learning

CO_2 Intermixing as a method to sequester carbon and increase durability of cement-based materials

Francisco W. Jativa[1*], Laura E. Dalton[2], M. Pour-Ghaz[1]

[1*] *Department of Civil, Construction, and Environmental Engineering (CCEE)*
North Carolina State University (NCSU), Raleigh, NC, 27606, USA

CO_2 intermixing with cement paste is proposed as a method to sequester carbon and reduce the $Ca(OH)_2$ content in cement-based materials. The $Ca(OH)_2$ and $CaCO_3$ content was measured using thermal gravimetric analysis; the dynamic modulus , compressive strength, and saturated hydraulic conductivity were tested in control (without gas intermixing), CO_2 and N_2 intermixed specimens made with three different w/c ratios. It was found that a 4.5% CO_2 emission offset from cement manufacturing is possible using this method. After 120 days seal curing, the dynamic modulus results of CO_2 intermixed specimens were 8-12% higher when compared to N_2 intermixed specimens and show no difference when compared to specimens without gas intermixing; the saturated hydraulic conductivity of CO_2 intermixed specimens was 12-18% lower than N_2 intermixed specimens, and similar to specimens without gas intermixing; the compressive strength results for CO_2 intermixed specimens was 9% higher than N_2 intermixed specimens and similar to specimens made without gas intermixing.



1) Cement and water are mixed for 3 minutes

2) CO_2 is injected to the cement paste for a period of 25 minutes

3) CO_2 intermixed cement paste is poured in different molds.

CO_2 Intermixing with cement paste: CO_2 intermixing process to sequester CO_2 as $CaCO_3$ in cement paste.

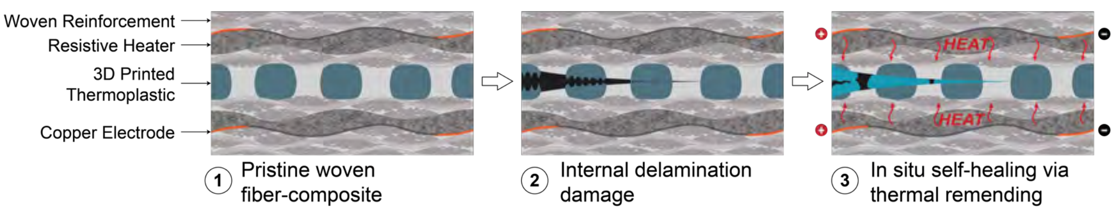
***Keywords*:** CO_2 Intermixing, CO_2 sequestration, compressive strength, dynamic modulus, saturated hydraulic conductivity.

Self-healing of Laminated Fiber-composites via In Situ Thermal Remending

Alexander D. Snyder[1*], Jason F. Patrick[1,2]

[1] *Department of Mechanical and Aerospace Engineering (MAE)*
[2] *Department of Civil, Construction, and Environmental Engineering (CCEE)*
North Carolina State University (NCSU), Raleigh, NC, 27606, USA

Interlaminar delamination remains one of the most critical damage modes limiting the reliability of fiber-reinforced composites in structural applications [1]. Here we achieve rapid (minute-scale) self-healing of delamination in fiber-composites by incorporating low-power, resistive heaters as textile reinforcement to enable dynamic bond reassociation of 3D-printed thermoplastic domains. In contrast to prior work, our thermal remending occurs *in situ* and below the glass-transition temperature of the host epoxy matrix, maintaining elastic properties during healing [2,3]. This multifunctional architecture has minimal effects on laminate structural integrity. Unprecedented heal cycle repeatability (100+) is achieved in a mode-I fracture specimen for both glass and carbon-fiber composites.



***In Situ* Thermal Remending:** (1) Pristine composite laminate with resistive heater interlayers and 3D printed thermoplastic on woven fiber reinforcement; (2) Delamination cohesively fractures thermoplastic domains; (3) Electrical power is supplied to embedded resistive heaters where thermally-driven dynamic bond reassociation repeatedly restores mechanical integrity over many *in situ* self-healing cycles.

Keywords: (fiber-reinforced composites, self-healing, 3D printing, thermal remending)

References

[1] Patrick, J.F., Hart, K.R., Krull, B.P., Diesendruck, C.E., Moore, J.S., White, S.R. & Sottos, N.R. Continuous self-healing life cycle in vascularized structural composites. *Advanced Materials* **26**, 4302–4308 (2014).
[2] Pingkarawat, K., Wang, C.H., Varley, R.J., & Mouritz, A.P. Self-healing of delamination cracks in mendable epoxy matrix laminates using poly[ethylene-co-(methacrylic acid)] thermoplastic. *Composites Part A* **43**, 1301-1307 (2012).
[3] Hostettler, N., Cohades, A., & Michaud, V. Statistical fatigue investigation and failure prediction of a healable composite system. *Frontiers in Materials* **7**, 317-325 (2020).

Full-wave Simulation for Arterial Shear Wave Elastography through Semi-Analytical Finite Element Method

Tuhin Roy[1], **Murthy Guddati**[1]

[1]Department of Civil, Construction, and Environmental Engineering,
North Carolina State University, Raleigh, NC, USA

Abstract

Arterial stiffness is one of the important biomarkers for many cardiovascular diseases. In Shear Wave Elastography (SWE) the wave-propagation after exciting the arterial wall is measured, and then the data is employed to estimate arterial-wall elastic modulus by matching phase-velocity dispersion curves. Although this approach can estimate the elastic modulus, it does not yield the required accuracy for the attenuation estimation. This problem can be addressed through simulating full-wave data where we include both propagating and evanescent waves with the appropriate mode participation. Our model can consider any material model (from viscous damping to generic model such as Fractional models). In this talk, we will present a novel computational approach that is highly efficient (takes less than one-quarter minute for viscous damping and 3 minutes for spring-pot model) to simulate full-wave response.

Keywords: Artery stiffness; Shear Wave Elastography; Acoustic Radiation Force; Viscoelasticity; Modal analysis

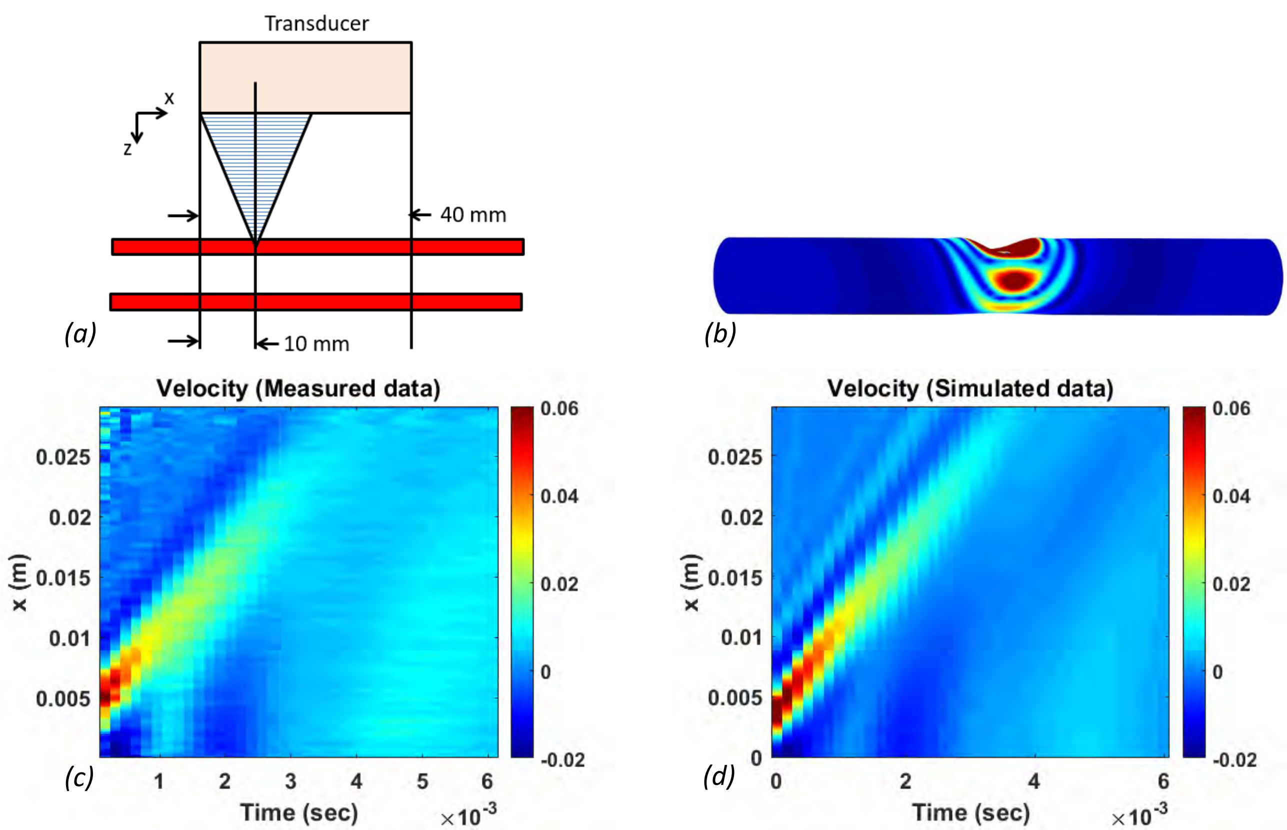


Figure 1 SWE Experimental setup (a), and the Full-wave results at an intermediate time point (b) are shown here. The full animation will be presented during the talk. A preliminary validation is performed with a phantom experiment (by Mayo Clinic) in which rubber tube is employed to mimic the healthy human carotid artery. The measured and simulated data are shown in (c) and (d) respectively.

Damping models for Nonlinear Time History Analysis of Reinforced Concrete Structures

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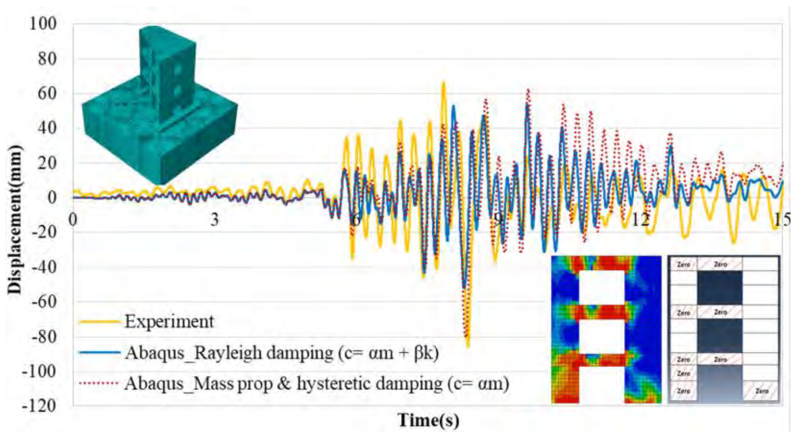
Rayleigh damping is widely used to model the damping matrix in both linear and nonlinear analysis of structures. However, many studies have shown that consideration of Rayleigh damping in Nonlinear Time History Analysis (NTHA) leads to unintended excessively high damping force resulting in under prediction of responses. The main objectives of this study is to show how the responses of Reinforced Concrete (RC) structure vary depending on the selection of damping models through the comparison of the experimental results and to provide a holistic approach for NTHA of RC shear wall using ABAQUS.



Graphical abstract title: Comparison of experimental and numerical response depending on the

Keywords (Rayleigh damping, Nonlinear Time History Analysis, Reinforced concrete, Experimental validation)

Predicting the Response of Shear Critical Reinforced Concrete Shell Elements Subjected to Combined In-Plane and Out-of-Plane Loading

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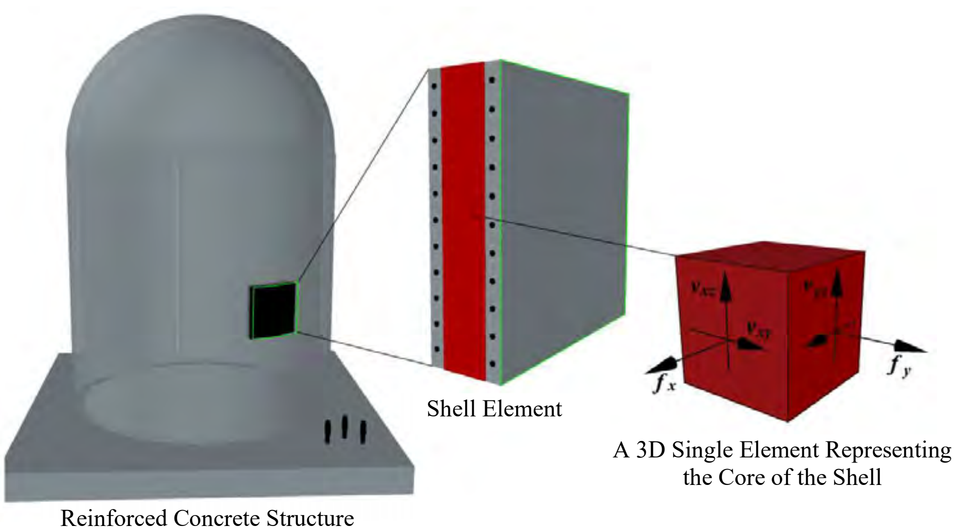
Reinforced concrete shell structures can be simultaneously subjected to combinations of in-plane and out-of-plane actions. The interaction of combined loading effects is complex and greatly influences the member response [1-3]. This presentation summarizes a new, simplified approach that can be used to predict the response of shear critical shell elements subjected to combined in-plane and out-of-plane loading at a section. The new approach, called the 3D Single Element Method, applies the Modified Compression Field Theory (MCFT) in three-dimensions to predict the full stress-strain response of shells subjected to all eight stress resultants using a single element capable of transmitting three shear stresses, v_{xy}, v_{xz}, v_{yz}, and three axial stresses f_x, f_y, f_z.



Three-dimensional Single Element Method: Representation of a single element used to predict shear response for concrete shells subjected to combined loading.

Keywords reinforced concrete, combined loading, shear response, shells, assessment

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Simulating Tornado Missile Impact on Reinforced Concrete Structures

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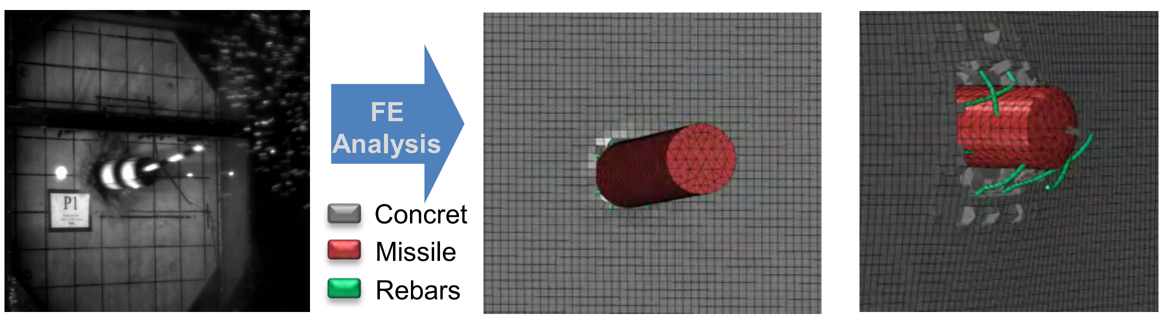
In recent years, many experiments have been conducted to study the missile impact on RC structures. Even with the most advanced analysis and modeling tools, the problem of evaluating the behavior of impact in RC structures is highly sensitive and unstable. We propose a novel approach for modeling the behavior of RC structures subjected to missile impact. First, we use one experimental study to develop and calibrate various models for finite element analysis. Then, the calibrated models are used to conduct a blind predictive analysis for a different experiment to provide confidence in the predictive capability of our developed approach.



Missile impacting RC Slab [1] | Front face of Impact | Back face of Impact

Simulation of Missile Impact Experiment using Finite Element Analysis: Figure shows damage in concrete and reinforcement during the Impact.

Keywords (Missile impact, Concrete damage, Reinforced concrete, Experimental validation)

References

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Performance Evaluation of Integral Abutment Bridges

Rajprabhu Thangappa[1*], Rudolf Seracino[1], Amin K Akhnoukh[2]

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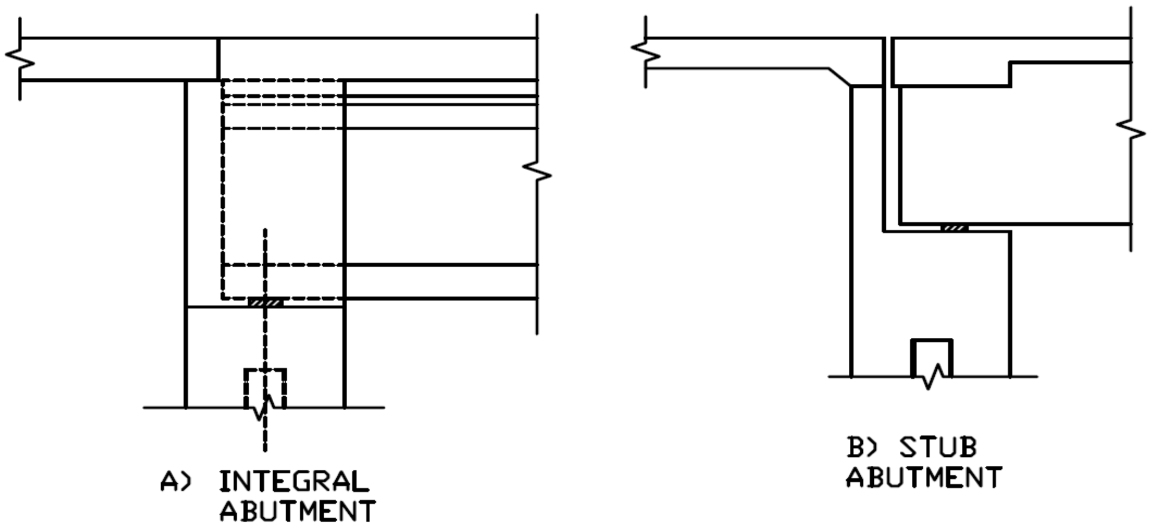
Integral abutment bridges(IAB) are preferred over conventional bridges for its accelerated construction and cost savings in maintenance across several states in the US. However, the IABs have other issues related to complex behavior and soil-structure interaction effects resulting in cracks in the bridge decks, approach slabs and the abutment. This project aims at addressing the maintenance issues of IABs in North Carolina through visual inspection and field monitoring. The end goal is to revise the existing geometric criteria limitations and construction practices of IABs by parametric investigations through calibrated analytical models from field monitoring.



Schematic representation of Integral vs Stub Abutment

Keywords: Integral abutments, cost savings, soil-structure interaction, field monitoring, parametric investigations

References

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Computationally Efficient Approach for Risk-informed Decision Making

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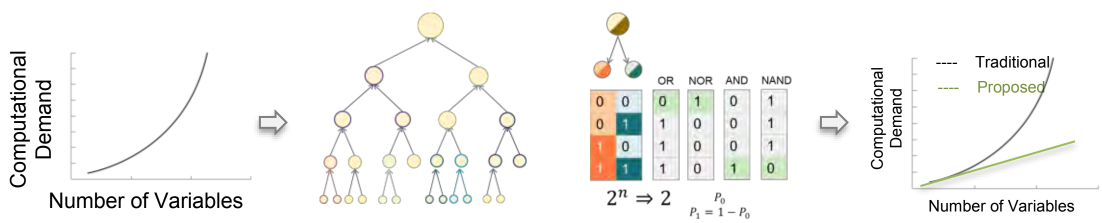
Probabilistic risk assessment (PRA) is an illustrious tool to ensure safety during normal operations as well as safeguard against external hazards in nuclear power plants. The currently available PRA framework renders computationally satisfactory results for a small number of failure scenarios. However, as the number of the failure scenario increases and thousands of events are analyzed simultaneously, it slows the decision making in PRA due to an exponential computational complexity imposed by traditional PRA approaches.

Contemplating the issues involved with traditional PRA approaches, we have developed an efficient algorithm that the takes advantage of the binary logic of failure scenarios and divides the network in several simplified parts to reduce the overall computational demand. It replaces the exponential complexity of traditional approaches to a linear complexity for many of the failure scenarios. The computationally efficient approach shows a great potential to allow a real-time decision-making for probabilistic risk assessment.



Computational demand by traditional methods

Segregation of the network

Leveraging the properties of binary network

Computational efficiency of the proposed

Graphical abstract title: Computational efficiency of the proposed approach compared to traditional methods

Keywords: Risk assessment, Binary network, Nuclear power plant, Decision-making, Fault tree

Active-cooling in Bioinspired Microvascular Composites

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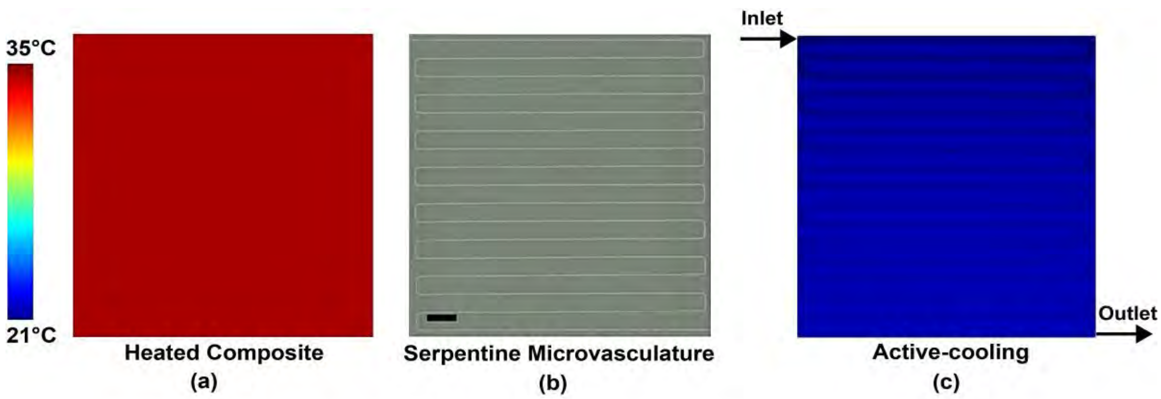
Bioinspired vascularization of fiber-reinforced polymer (FRP) composites can augment existing lightweight structural performance with dynamic functionalities via liquid circulation through an internal micro-fluidic network [1,2]. Specifically, active-cooling in vascular composites can achieve rapid removal of heat in thermally demanding applications, particularly where FRP materials have been traditionally excluded due to low thermal stability (~150°C) of the polymer matrix [3,4]. Here we detail a comprehensive experimental and computational investigation into the heat transfer efficiency of variable spaced serpentine micro-channels in a glass-fiber composite. Our findings show that channel topology and liquid coolant properties play a more critical role than host material thermal conductivity on the steady-state active-cooling performance.



Actively-cooled Fiber-composite. **(a)** Infrared image of a laminated glass-fiber epoxy-matrix composite heated from below; **(b)** Midlayer serpentine microvasculature created by vaporization of 3D printed sacrificial polymer (scale bar = 10 mm); **(c)** Infrared image showing an actively-cooled composite at steady-state via circulation of distilled water.

Keywords (fiber-composites, bioinspired, microvascular, active-cooling)

References

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Behavior of Ultra-High Performance Concrete Ledges Subject to Concentrated Loads

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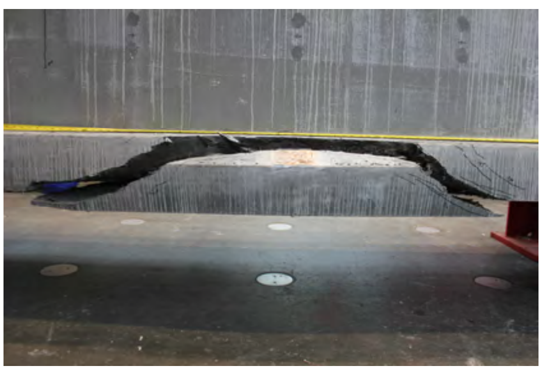
Ledges, such as those found in inverted-tee (IT) beams, are typically subject to eccentric concentrated loads applied at the member's tension chord. This unique loading scenario introduces a multitude of potential failure modes (including punching shear, hanger failure, and cantilever bending) [1], prompting designers to heavily reinforce these sections. This tedious method of reinforcing increases both cost and construction time. This presentation will discuss the results of ledge tests performed on optimized IT beams constructed using ultra-high performance concrete (UHPC; a steel-fiber reinforced concrete with superior mechanical and durability properties [2]), with little to no discrete ledge reinforcement.



UHPC Ledge Punching Shear Failure: Left, overall view; right, close-up showing fibers

Keywords (Ledges, punching shear, UHPC)

References

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Quantification of Shear Transfer Mechanisms from Large-Scale Deep Beam Experiments

Dhanushka K. Paliapana[1*], Giorgio T. Proestos[1]

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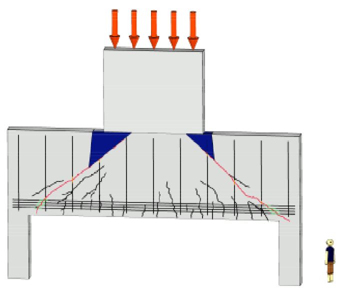
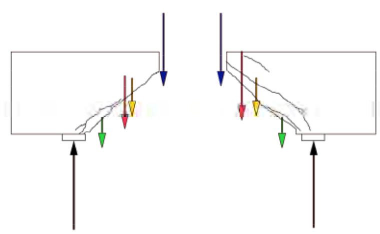
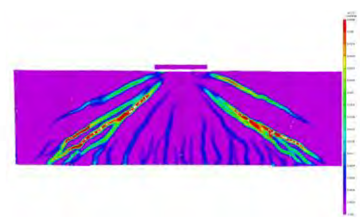
Reinforced concrete deep beams, which have shear-span-to-depth ratios typically less than 2.5, transfer shear through four mechanisms: in the critical loading zone, aggregate interlock, transverse reinforcement, and dowel action [1]. Developing a better understanding of these mechanisms is important in being able to design and assess such structures. This presentation outlines the quantification of these shear transfer mechanisms for five previously tested deep beam tests by directly calculating each mechanism using experimental data and constitutive laws. Full field of view 3D Digital Image Correlation (DIC) data for an additional series of deep beam experiments is then discussed.



1 Shear transfer mechanisms in deep beams: Critical loading zone, aggregate interlock, transverse reinforcement, and dowel action



2 Quantification of four shear transfer mechanisms using crack kinematics and constitutive relationships



3 Full field of view DIC data of large-scale deep beam experiment

Quantification of shear transfer mechanisms in deep beams: Four shear transfer mechanisms quantified using measured deformations from large-scale deep beam experiments

Keywords shear, deep beams, reinforced concrete, cracks, assessment

References

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Investigation into the Effects of Microvascular Topology on the Structural Integrity of Fiber Composites

Z.J. Phillips[1*], J.F. Patrick[1]

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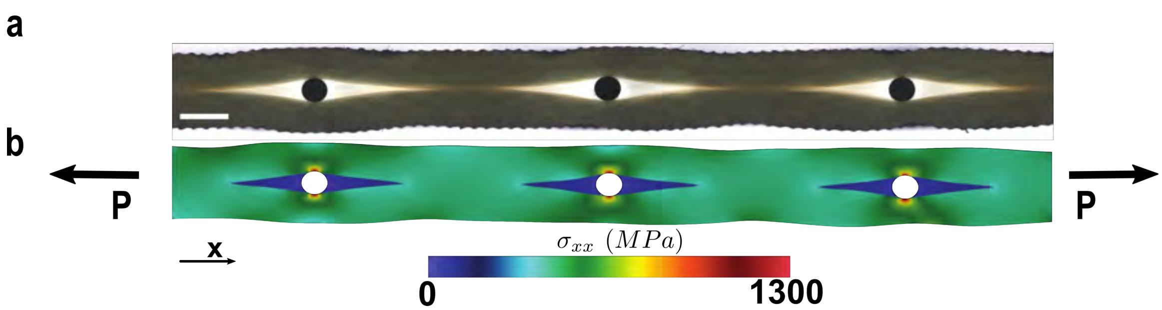
Incorporating microvascular networks within fiber-reinforced polymer (FRP) composites can augment their exceptional structural capabilities through infiltration of functional fluids (e.g., liquid-metal for electromagnetic reconfiguration) [1]. However, sacrificial templates used for vascular fabrication introduce waviness in the surrounding reinforcement and promote matrix-rich domain formation. A current lack of understanding regarding the structural impact of microvasculature on laminated woven composites limits widespread adoption of these multifunctional materials [2][3][4]. Here we reveal the in-plane tensile response of glass-fiber composites with embedded micro-channels at various spacings in parallel/orthogonal orientations to the loading direction. A detailed experimental investigation is supplemented with numerical simulations to provide guidelines for structural deployment.



Microstructural effects on axial stress distribution: (top) Optical microscopy of a glass-fiber composite revealing localized epoxy domains around micro-channels (scale bar = 1mm); (bottom) Normal stress contours from finite element analysis revealing stress concentrations under tensile loading.

Keywords (fiber-reinforced composites, microvasculature, finite element analysis)

References

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The Seismic Performance of Grade 80 Rebar in RC Bridge Columns

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The advantages of high-strength steel reinforcement are self-evident as it reduces congestion and cost. Despite this, there are restrictions in bridge design codes that prohibit the use of Grade 80 steel in RC columns forming plastic hinges due to lack of sufficient research to quantify its behavior under cyclic loading. This study explores whether Grade 80 steel can replace the standard Grade 60 steel. Large-scale reverse cyclic tests have been conducted on columns reinforced with both steels to compare performance. Results show that Grade 80 rebar can match and, in some cases, exceed the displacement capacity of Grade 60 rebar.

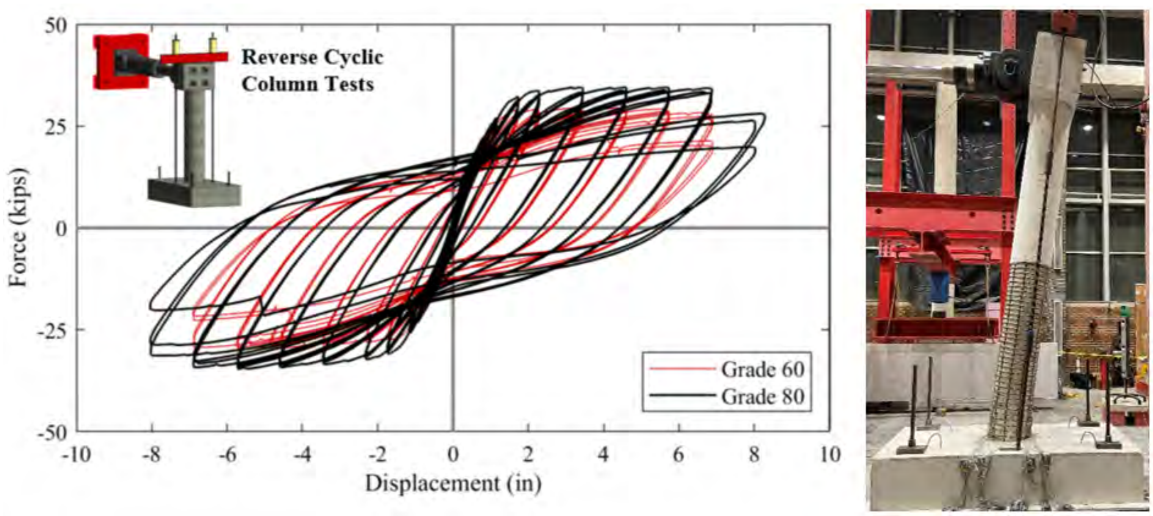

Figure: Comparison of Hysteretic Response of Grade 60 and Grade 80 Columns with Matched Detailing, Test Setup, and Deformed Column

Keywords (grade 80 steel; seismic; column; concrete; large-scale)

Experimental Investigation of Long-Term Prestressing Losses in the Herbert C. Bonner Bridge

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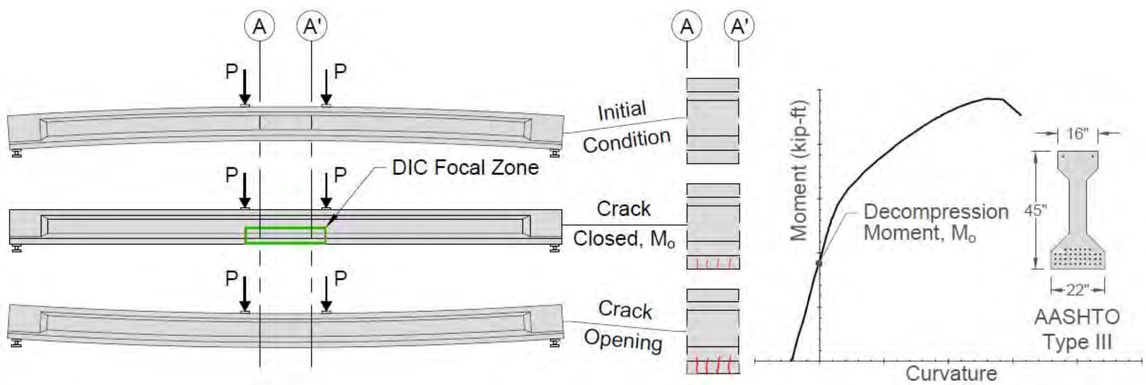
Prestressed concrete structures experience time dependent effects such as creep, shrinkage, and relaxation that cause the quantity of prestressing to decrease over time [1]. Prestressing loss is a critical factor in determining the lifespan of prestressed concrete bridges because, as the quantity of prestressing reduces, tensile stresses can develop at service loads. As a result, some transportation authorities may load post, or limit the load allowed on the bridge, causing traffic disruptions. This presentation describes analyses of field data collected from the nearly 60-year-old bridge girders and compares predicted prestressing losses of the AASHTO Type III Girders with results from the field data [2]. The presentation also discusses testing procedures and predictions for the response of full-scale girders recovered from the Bonner Bridge that will be tested in the Constructed Facilities Lab to better determine the long-term losses and performance under severe loading conditions [3].



Strand Stress Estimation by Decompression Moment: Flexural testing to determine decompression moment at the midspan section of the girders.

Keywords prestressed concrete, long-term losses, creep, shrinkage, relaxation

References

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