26th Structural Engineering & Mechanics Symposium

Friday, February 25th, 2022
10am - 6pm

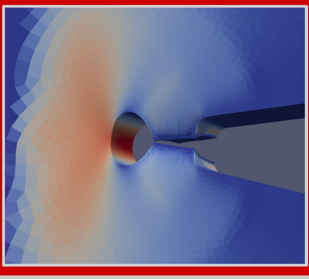
Department of Civil, Construction, & Environmental Engineering

NC STATE UNIVERSITY

STRUCTURAL ENGINEERING AND MECHANICS

Keynote Presentation

High-fidelity Simulation of Steel Components at Extreme Limit States - Challenges and Opportunities



Asst. Prof. Andy Ziccarelli, Department of Civil, Construction and Environmental Engineering, NCSU

Seminar Abstract

Over the past 30 years, significant advancements in analysis software and computational power have allowed engineers to develop methods to simulate structural response with greater accuracy than ever before. Nonlinear structural analyses are now routinely used to assess the performance and safety of structures due to earthquakes, strong winds, blasts, and other hazards. Within the domain of steel structures, detailed finite element models have been shown to accurately predict phenomenon such as yielding, global and local buckling, and strain localization.

While the capabilities described above represent a considerable step forward for the structural engineering community, validated tools to simulate several key limit states in steel structures are still lacking. In particular, models to predict the initiation of ductile fracture, stable crack propagation, and brittle cleavage fracture remain in development, despite being key limit states which often precipitate component failure and structural collapse.

This seminar will give an overview of research being performed in each of these key areas, along with a discussion of related topics, such as constitutive modeling and parameter optimization.

Biography

Andy Ziccarelli is an assistant professor in the Department of Civil, Construction and Environmental Engineering at North Carolina State University. His research focuses on nonlinear structural analysis, fracture simulation and earthquake engineering, with an emphasis on steel structures. His work includes both computational and experimental components. Andy earned his PhD at Stanford University in 2021, and joined the faculty at NC State in January 2022. Prior to his doctoral studies, Andy worked as a practicing structural engineer at TGRWA, LLC in Chicago from 2014-2017. He is a registered Professional Civil Engineer in California.

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Zoom Link:
https://ncsu.zoom.us/j/95438477737?pwd=aCtYSUpMd0xONjRZcGJibU9vVlpBQT09

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

Abdelrahman Elmeliegy, PhD with Dr. Guddati
Full-Waveform Shear Wave Elastography for Imaging Tumors

Gunay Gina Aliyeva, PhD with Dr. Gupta
Modeling Concrete Expansion due to Alkali-Silica Reaction

Guillermo Gonzales-Berrios, PhD with Dr. Pour-Ghaz
Monitoring Fluid-to-Solid Transition using Vibrational Techniques

Parth Patel, PhD with Dr. Gupta
Modeling Chloride Attack Degradation in Reinforced Concrete and Developing Artificial Neural Network Framework for Detection

Lunch	12:30pm - 1:30pm

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

Alexander Snyder, PhD with Dr. Patrick
Sustained Self-healing of Delamination Damage in Woven Fiber-Composites via *In situ* Thermal Remending

Dhanushka Palipana, PhD with Dr. Proestos
Crack Kinematic Behavior of Deep Beams throughout Loading using Full Field of View Digital Image Correlation

Zachary Phillips, PhD with Dr. Patrick
Rapid Self-Healing of a Structural Polymer via Integration of Microvasculature and Optical Fibers

Session III - Concrete Chemistry & Transport 2:30pm - 3:30pm

Hyunjun Choi, PhD with Dr. Pour-Ghaz
Can the Deposition of CaCO3 Increase the Mechanical Properties of Wood?

Laura Dalton, PhD with Dr. Pour-Ghaz
Supercritical, liquid, and gas CO2 reactive transport and carbonate formation in portland cement-based mortar

Josue Pazmino, PhD with Dr. Pour-Ghaz and Dr. Ducoste
Fat, Oil, and Grease (FOG) Formation and Adhesion to Concrete Treated with Soy Methyl Ester (SME)

Afternoon Break 3:30pm - 3:50pm

Session IV - Structural Analysis & Behavior 3:50pm - 5:10pm

Mohammad Qambar, PhD with Dr. Lucier and Dr. Proestos
Behavior of Dapped Ends in Thin-Stemmed Prestressed Concrete Beams

Mrinal Mahanta, PhD with Dr. Gupta
Experimental Validation of Performance-based Limit-state for the Seismic Fragility Assessment of T-joint in a Piping system

Jessi Thangjithan, PhD with Dr. Kowalsky
Bond-Slip Failure of Reinforced Concrete (RC) Bridge Columns under Seismic Loads

Nicholas Crowder, PhD with Dr. Gupta
BIM Interoperability Solutions for Model Data Exchange and Structural Analysis of Building-Piping Systems

Judging/Certificates Break 5:10pm - 5:30pm

Award Ceremony and Closing Remarks 5:30pm - 5:45pm

CCEE

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

Full-Waveform Shear Wave Elastography for Imaging Tumors

Abdelrahman M. Elmeliegy[1*], Murthy N. Guddati[1]

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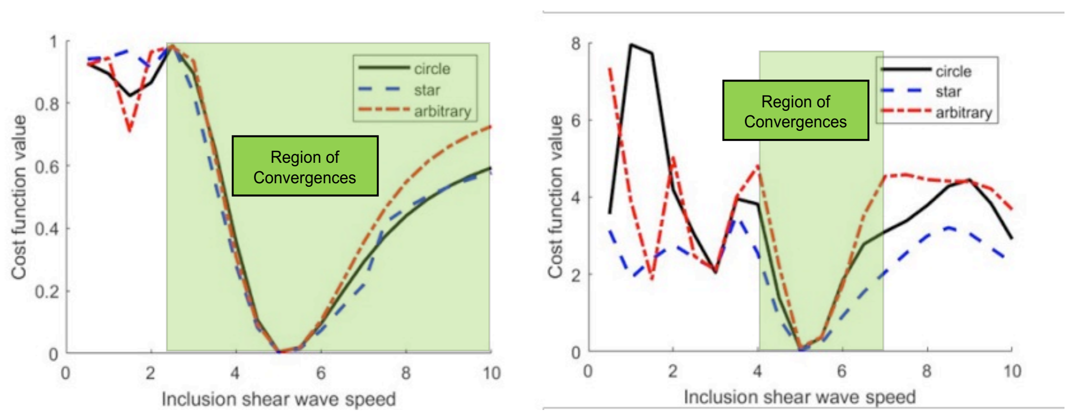
North Carolina State University (NCSU), Raleigh, NC, 27606, USA

Shear wave elastography (SWE) is a method of reconstructing the stiffness of soft biological tissues, by matching the observed and the simulated wavefields using an inverse optimization scheme. SWE reconstruction algorithms can be classified into two main categories, local and global methods. Global methods consider more complete physics of the waves, i.e. refraction and scattering, and thus have the potential to better characterize the heterogeneity of the domain. These approaches require full-waveform inversion (FWI), which is computationally expensive. More importantly, due to highly nonlinear nature, FWI has the limitation of converging to local minima, leading to erroneous reconstruction.

In this work, we address this issue and propose a cost functional that not only reduces the nonlinearity of the FWI but also results in a reconstruction algorithm that is independent of push amplitudes, less sensitive to the initial guess, and has a better convergence behavior compared to the classical least-squares cost functional. In this talk, we will present the details of the underlying formulation and examples showing the effectiveness of the proposed method.



The convergence region: (left) the cross-correlation-based cost functional and (right) the L2-norm-based cost functional.

Keywords (ultrasound imaging, biomedical imaging, shear wave inversion, inverse problem, nonlinear optimization)

Modeling Concrete Expansion due to Alkali-silica Reaction

G.G. Aliyeva[1*], A. Gupta[1]

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

Alkali-silica reaction (ASR) in concrete is a chemical reaction that produces a gel inside the concrete which swells and increases in volume in the presence of sufficient moisture. Swelling of the gel causes cracking and loss of strength of the concrete, and hence, it is important to investigate the mechanism of the ASR-affected concrete. Past research explores this complex mechanism with the assumption of a volumetric expansion of the gel and redistribution of the volumetric expansion depending on the state of stress in the concrete [1]. It's also shown that a chemo-damage model can be used to investigate the ASR-affected concrete [2].

The aim of this study is to simulate the ASR-affected concrete expansion using a finite element analysis by coupling the chemical and physical mechanisms. ASR-affected concrete cylinder specimens with different states of stress are modeled using the concrete damaged plasticity (CDP) model and investigated considering the anisotropy of the swelling. Through this method, it is possible to determine the progression of strains in the ASR-affected concrete structures and determine their loss of strength over multiple decades.

Cracks in a median highway barrier affected by ASR [3]

Keywords (alkali-silica reaction (ASR), concrete degradation, anisotropic expansion, concrete damaged plasticity model)

References

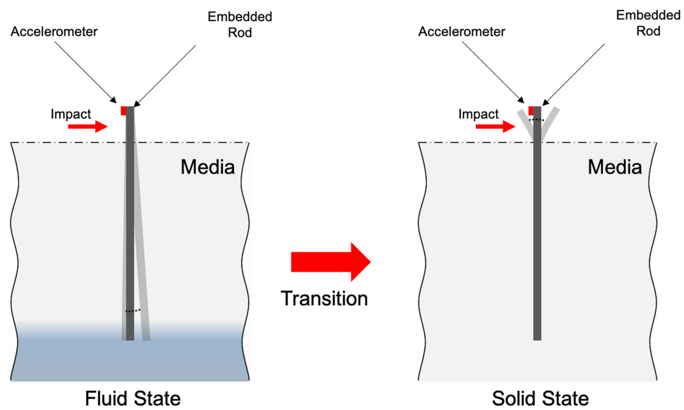
[1] Saouma, V. & Perotti, Luigi. Constitutive Model for Alkali-Aggregate Reactions. ACI Materials Journal. 103. 194-202 (2006).
[2] Jianwen Pan, Y.T. Feng, Feng Jin & Chuhan Zhang. Numerical prediction of swelling in concrete arch dams affected by alkali-aggregate reaction, European Journal of Environmental and Civil Engineering, 17:4, 231-247 (2013).
[3] Report on the Diagnosis, Prognosis, and Mitigation of Alkali-Silica Reaction (ASR) in Transportation Structures. Technical Report FHWA-HIF-09-004, Federal Highway Administration (2010).

Monitoring Fluid-to-Solid Transition using 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 study, we investigate whether the fluid-to-solid transition in cementitious materials can be quantified through monitoring the vibrational response of a rod embedded within it. The assumption is that the properties and geometry of the rod embedded in the cementitious medium are known. The problem then is an inverse problem of estimation of the properties of the medium or detection and quantification of liquid to solid transition of a medium. Before the transition, the viscous properties of the fluid significantly influence the vibration of the embedded rod; after the transition the elastic properties of the medium are the dominate parameters. The problem has many applications including assessment of anchoring elements including osseointegrated implants and soil nails.



Concept: Vibration response of the embedded rod in liquid (left) and solid (right) media.

Keywords: (non-destructive testing, inverse problems, vibration)

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Modeling Chloride Attack Degradation in Reinforced Concrete and Developing Artificial Neural Network Framework for Detection

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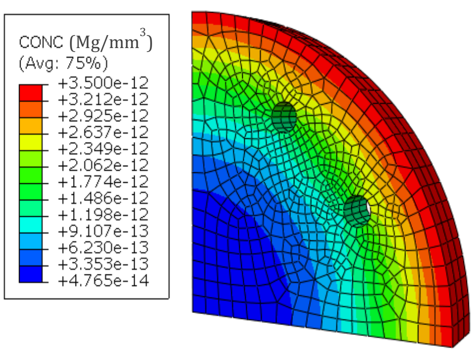
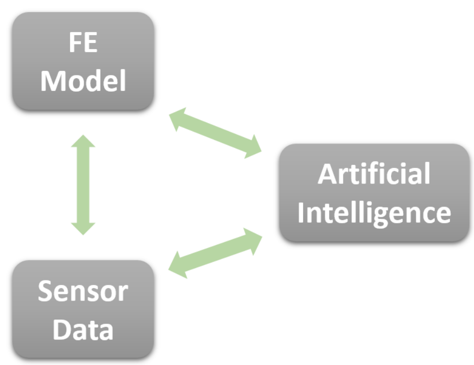
[1]*Department of Civil, Construction, and Environmental Engineering (CCEE)*
North Carolina State University (NCSU), Raleigh, NC, 27606, USA

Throughout the service life, concrete structures often interact with various chemical and physical degradation agents. One of the primary degradation type is chloride attack. It causes severe alterations in the structural properties, such as corrosion in reinforcement bars, loss of concrete-rebar bond, and cracks in concrete that leads to reduction in durability and load-carrying capacity. These degraded structures have the potential of harming human lives in the event of a collapse. Along with that, it leads to substantial financial losses in order to restore or renew the complete structure. Therefore, detection of concrete degradations at early stages becomes very important. The early detected degradations can be easily repaired, and it can save lives as well as enormous economic losses.

Hence, the objective of this research is to first model the chloride attack and degradation of concrete structure using Finite Element analysis to understand behavior of degradation. Subsequently, use the validated degradation model to perform nondestructive testing. Lastly, use measured data to develop and train an artificial neural network (ANN) architecture for detecting the location and severity of concrete degradation.



Chloride diffusion in concrete



Framework

Graphical Abstract Title: Chloride diffusion model and framework for our proposed methodology

Keywords (Concrete degradation, Finite element modeling, Artificial Intelligence)

References

[1] Chen, D., & Mahadevan, S. (2008). Chloride-induced reinforcement corrosion and concrete cracking simulation. Cement and Concrete Composites, 30(3), 227-238.

Self-Healing of Woven Composite Laminates via *In Situ* Thermal Remending

A.D. Snyder[1*], J.F. Patrick[1,2]

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

Fiber-reinforced polymer-matrix composites are attractive structural materials due to their corrosion resistance and high specific strength/stiffness. Despite these advantages, lack of through-thickness reinforcement in laminated composites renders susceptibility to fiber-matrix debonding, i.e., interlaminar delamination. Such subsurface damage is difficult to detect and repair using conventional methods and consequently remains a significant factor limiting the reliability of composites in lightweight structures. Thus, novel approaches for mitigation of this incessant damage mode (e.g., self-healing) are of tremendous interest [1].

Here we detail the development of an intrinsic self-healing woven composite laminate based on thermally-induced dynamic re-bonding of a 3D-printed polymer interlayer (**Fig. 1**). In contrast to prior work [2], self-repair occurs *in situ* and below the glass-transition temperature of the epoxy matrix, while maintaining 90% of the elastic modulus during healing. This new platform has been deployed in both glass- and carbon-fiber composites demonstrating application versatility. Remarkably, up to 100 rapid (minute-scale) self-healing cycles have been achieved with healing efficiencies exceeding 100% of the interlayer toughened (4-5x) composite laminate. This latest self-healing advancement exhibits unprecedented potential for perpetual in-service repair coupled with material multi-functionality (e.g., deicing ability) to meet modern application demands.

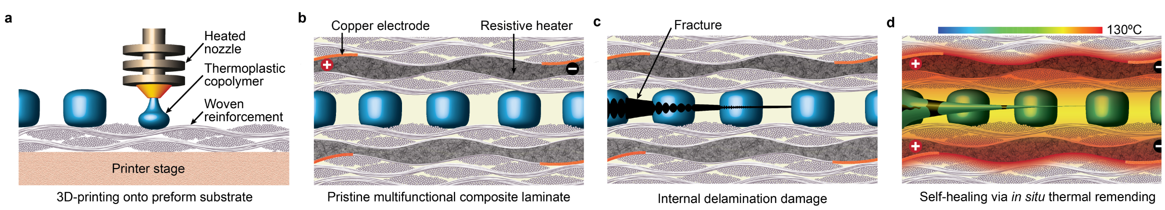


***Figure 1 - In situ* thermal remending strategy: (a)** Micro-domains of polyethylene-co-methacrylic acid (EMAA) are 3D printed directly onto woven fiber-reinforcement. **(b)** Composite laminate constructed via infusion of epoxy matrix into textile preform containing EMAA-modified reinforcement and symmetrically placed resistive heater interlayers. **(c)** Interlaminar delamination cohesively fractures EMAA and separates composite laminae. **(d)** Electrical power input to the resistive heaters increases temperature causing EMAA to melt and flow into the crack for self-healing via thermal remending.

Keywords (fiber-composites, delamination, self-healing, multi-functional)

References

[1] Patrick, J.F., M.J. Robb, N.R. Sottos, J.S. Moore, and White, S.R. “Polymers with autonomous life-cycle control,” *Nature*, **540**, 63-370 (2016).
[2] Cohades, A., Branfoot, C. Rae, S., Bond, I., & Michaud, V. Progress in self-healing fiber-reinforced polymer composites. *Advanced Materials Interfaces* **5**, 1800177 (2018).

Crack Kinematic Behavior of Deep Beams Throughout Loading using Full Field of View Digital Image Correlation

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

[1] *Department of Civil, Construction, and Environmental Engineering (CCEE)*
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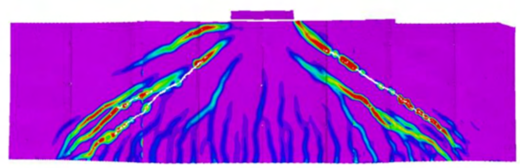
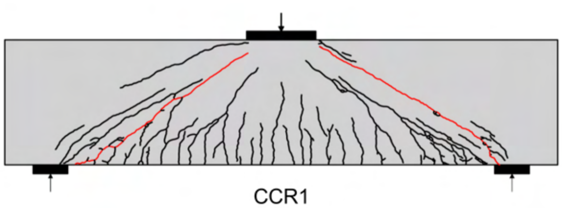
Reinforced concrete deep beams are common structural elements in buildings and bridges that are used to transfer large loads. Throughout the life of such structures, these members undergo regular inspection and monitoring to ensure their safety. As vision and field data collection techniques improve, including drones and other unmanned vehicle technology, methods need to be developed to interpret full field of view displacement field data.
This presentation outlines the results from an experimental series, the CCR series, of six shear critical reinforced concrete deep beam experiments monitored with full field of view, three-dimensional Digital Image Correlation (DIC) equipment. The presentation discusses the critical crack information obtained using the open-source Automated Crack Detection and Measurement (ACDM) tool [1], variation of crack widths with crack slips throughout loading and the trends observed in the crack dilatancy at multiple locations. The results are important in assessing the quality of existing aggregate interlock models and informing new aggregate interlock models specific to deep beams.

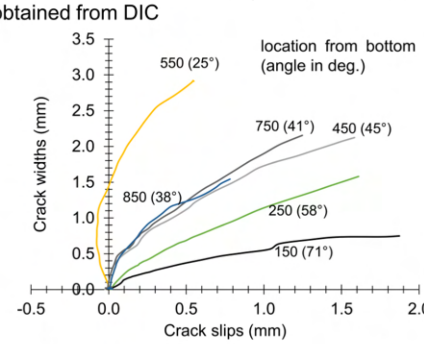
1) Large-scale deep beam experiments conducted using DIC



2) Principal tensile strains (ε_1) at peak load for CCR1 obtained from DIC



3) Crack information obtained using the ACDM tool



4) Observed Crack dilatancy for CCR1

Crack kinematic behavior of large-scale deep beams: The crack kinematics are obtained by inputting DIC data to the ACDM tool.

Keywords reinforced concrete, crack dilatancy, deep beams, digital image correlation

References

[1] Gheri, N., Mata-Falcón, J., Kaufmann, W. Automated crack detection and measurement based on digital image correlation. Construction and Building Materials **256**. 1-14. 10.1016/j.conbuildmat.2020.119383. (2020).

Rapid Self-healing of a Structural Polymer via Integration of Microvasculature and Optical Fibers

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

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

Susceptibility to internal brittle fracture offsets the inherent advantages of corrosion resistant and high strength fiber-reinforced polymer (FRP) composites [1]. Bioinspired vascular self-healing strategies have emerged to repair such damage by auto-delivery of reactive liquid agents to the crack plane from ruptured micro-channels [2]. Upon making contact in the damage zone, the complementary chemistries react and polymerize to restore mechanical integrity of the structural host. However, difficulties in achieving appreciable *in situ* mixing of two-part agents, polymerization times on the order of hours/days, and propensity for flow blockages from cross-contamination are existing research challenges limiting adoption of this technology.

Here we describe the development of a self-healing structural epoxy that overcomes such challenges by sequestering a one-part photo-chemistry within microvasculature and employing embedded polymer optical fibers (POFs) to delivery sufficient light (upon fracture) for *in situ* polymerization (**Fig. 1**). This new strategy exhibits sub-hour chemical kinetics to restore 90% of mode-I fracture toughness (K_{IC}), exceeding state-of-the-art two-part self-healing systems [2,3] both in terms of K_{IC} recovery (~1.5x) and significantly faster (~50x). The latest self-healing advancement is well-poised to replace routine inspection with rapid auto-repair of structural polymers/composites while enhancing in-service safety and reliability.

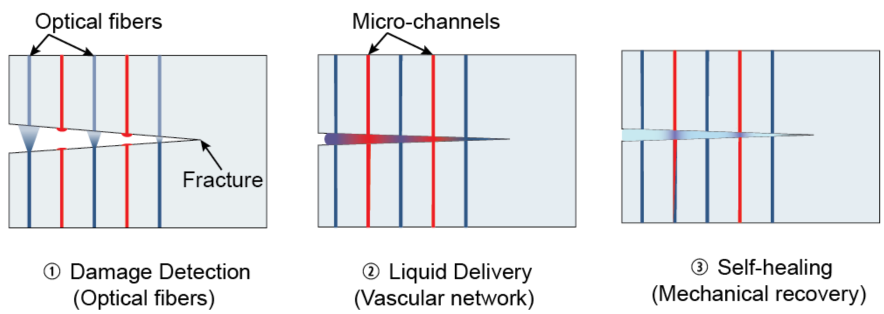


Figure 1 - Opto-vascular self-healing strategy: (1) Internal fracture of optical fibers (blue) releasing light and detecting damage. **(2)** Simultaneous rupture of micro-channels (red) for delivery of one-part liquid photochemistry. **(3)** Resulting photo-polymerization for rapid (sub-hour), *in situ* recovery.

Keywords (brittle fracture, self-healing, microvasculature, optical fibers)

References

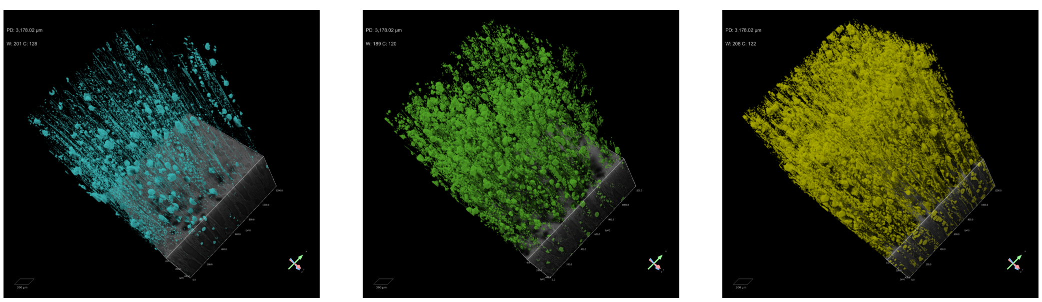
[1] Kim, J.-K and Sham, M.-L. "Impact and Delamination Failure of Woven-Fabric Composites," *Composite Science and Technology*, **60**, 745-761 (2000).
[2] Patrick, J.F., M.J. Robb, N.R. Sottos, J.S. Moore, and White, S.R. “Polymers with autonomous life-cycle control,” *Nature*, **540**, 63-370 (2016).
[3] Hart, K.R., Lankford, S.M., Freund, I.A., Patrick, J.F., Krull, B.P., Wetzel, E.D., Sottos, N.R., White, S.R. "Repeated Healing of Delamination Damage in Vascular Composites by Pressurized Delivery of Reactive Agents," *Composites Science and Technology*, **151**, 1-9 (2017).

Can the Deposition of $CaCO_3$ Increase the Mechanical Properties of Wood?

H. Choi[1*], L. E. Dalton[1], M. Pour-Ghaz[1], I. Peszlen[2]

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

According to a 2019 report by United States Census Bureau, 90% of American homes are wood-frame structures [1]; the estimated property loss from house fires in 2019 was $7.7 billion and the reported civilian deaths was 2,770 [2]. It has been shown that the deposition of calcium carbonate in wood can increase its fire retardancy without the use of chemical treatment [3,4]. Since wood is an organic anisotropic solid, we hypothesize that the deposition of calcium carbonate in wood not only will enhance its mechanical properties but will also result in an organic-inorganic composite with self-adapting properties. In this presentation, we discuss the developed calcium carbonate deposition methods and the resulting 3D morphologies quantified using X-ray computed tomography. We also present the results of dynamic mechanical analysis used to quantify the impact of calcium carbonate deposition on the mechanical properties of two types of wood.



(a) (b) (c)

Graphical abstract title: Deposited $CaCO_3$ after each cycle of solution-exchange cycles (aqueous $CaCl_2$ + aqueous K_2CO_3): (a) after 1 cycle, (b) after 2 cycles, and (c) after 3 cycles.

Keywords Pine, Beech, Calcium carbonate, Dynamic mechanical analysis, Thermogravimetric analysis

References

[1] Cornish C. Characteristics of New Housing. *US Census Bureau (MCD)*: https://www.census.gov/construction/chars/highlights.html.

[2] Ahrens M., & Maheshwari R. Home structure fires. *National Fire Protection Association*, Fire Analysis and Research Division (2020). Available online: https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Building-and-life-safety/oshomefirestables.pdf.

[3] Merk, V., Chanana, M., Gierlinger, N., Hirt, A. M., & Burgert, I. Hybrid wood materials with magnetic anisotropy dictated by the hierarchical cell structure. *ACS applied materials & interfaces*, ***6***(12), 9760-9767 (2014).

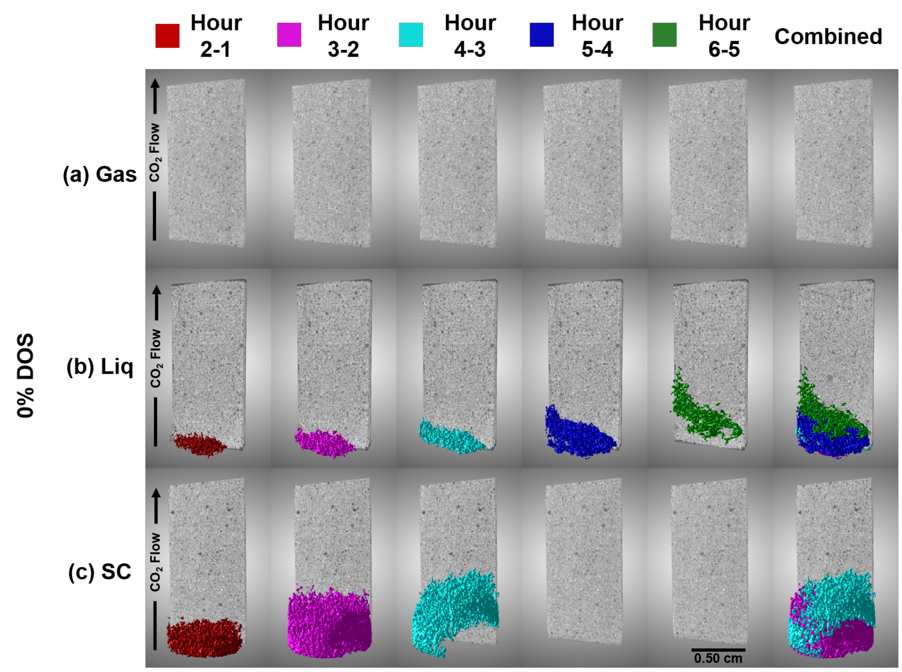
[4] Merk, V., Chanana, M., Keplinger, T., Gaan, S., & Burgert, I. Hybrid wood materials with improved fire retardance by bio-inspired mineralisation on the nano-and submicron level. *Green Chemistry*, ***17***(3), 1423-1428 (2015).

Supercritical, Lquid, and Gas CO_2 Reactive Transport and Carbonate Formation in Portland Cement-based Mortar

L. E. Dalton[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 study, we investigate carbonate formation and reactive transport in variably saturated portland cement mortars when high concentrations of gas, liquid, or supercritical CO_2 flow through their pore network. X-ray computed tomography completed during CO_2 flow is used to quantify the microstructural evolution as the mortar carbonates. After *in situ* tests, higher resolution scans, thermogravimetric analysis, and desorption isotherm analysis are performed to further quantify microstructural changes. We found that at dry conditions supercritical CO_2 moves more rapidly through the pore space (shown in the attached Figure) and precipitates more carbonates than liquid or gas CO_2 [1]. However, when the pore space is at 50 to 100% degree of saturation (DOS), supercritical CO_2 did not react with hydration products more rapidly nor did it result in more carbonate formation during exposure compared to gas or liquid CO_2. Lastly, the amount of phases other than $Ca(OH)_2$ that contributes to $CaCO_3$ formation is correlated to the DOS where with an increase in DOS results in an increase in other phases (unhydrated cement and C-S-H) that contribute to $CaCO_3$ formation.



Graphical abstract title: 0% DOS specimen carbonation evolution during CO_2 exposure: (a) gas CO_2 (Gas), (b) liquid CO_2 (Liq), and (c) scCO_2 (SC)

Keywords (supercritical CO_2, carbonates, x-ray, micro computed tomography)

References

[1] Dalton, L. E., Crandall, D., & Pour-Ghaz, M. (2022). Supercritical, liquid, and gas CO2 reactive transport and carbonate formation in a portland cement mortar. Under review in *International Journal of Greenhouse Gases*.

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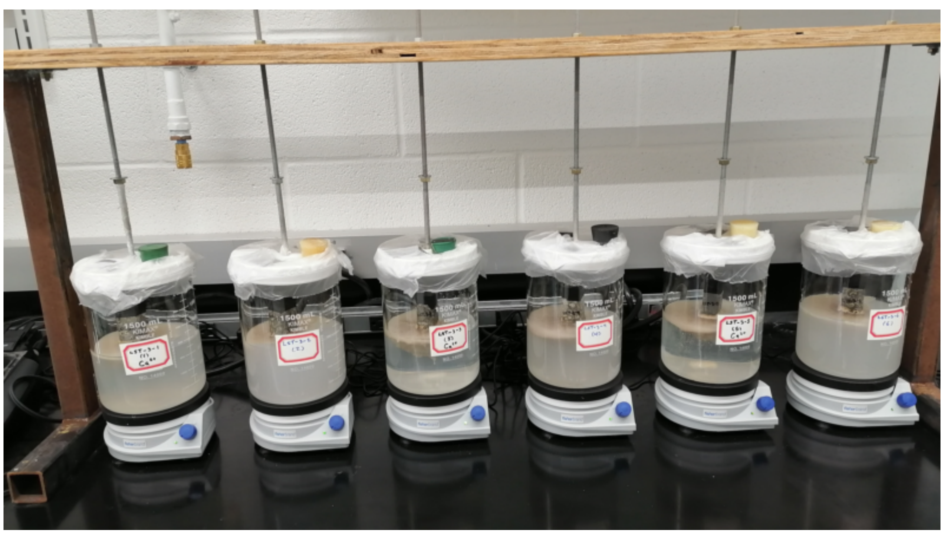
2022 Structural Engineering and Mechanics (SEM) Symposium

Fat, Oil, and Grease (FOG) Formation and Adhesion to Concrete treated with Soy Methyl Ester (SME)

J. Pazmino[1*], M. Pour-Ghaz[1,] J. Ducoste[1]

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

Concrete sewer collection system is one of the fundamental parts of the infrastructure in a community by carrying wastewater to a safe disposal location. Sewer systems are designed for a define capacity of flow. If a blockages interrupt the inner flow of the sewer system, will have risk of flooding and generates Sanitary Sewer Overflows (SSOs). Blockages in the sewer line has many factors can cause this phenomena; one of them are Fat, Oil, and Grease (FOG) deposition inside the sewer pipe surface. Research studies have shown that FOG deposition mechanism is complex and formed by a saponification reaction between long-chain free fatty acids (LCFFAs) and, calcium ion present in wastewater and from concrete corrosion that release calcium hydroxide [1]. One alternative to reduce the leaching of calcium hydroxide from the cement paste is using a water reducing sealant to enhance the durability of this material. In this research we assess the mechanism of FOG formation in concrete surfaces coated with Soy Methyl Ester (SME), a biodegradable product of soybean oil that is hydrophobic [2, 3]. SME characteristics may reduce the adhesion and formation of FOG in concrete sewer systems.



Graphical abstract title: FOG formation test on concrete samples in the laboratory.

Keywords (Fat, Oil, and Grease (FOG), Concrete sealant, Soy Methyl Ester (SME))

References

[1] He, X., de los Reyes, F. L., Leming, M. L., Dean, L. O., Lappi, S. E., & Ducoste, J. J. (2013). Mechanisms of Fat, Oil and Grease (FOG) deposit formation in sewer lines. Water Research, 47(13), 4451–4459. https://doi.org/10.1016/J.WATRES.2013.05.002.
[2] Coates, K.C. “Evaluation of Soy Methyl Ester Polystyrene Blends for Use in Concrete Master’s thesis, Purdue University, West Lafayette, 2008.
[3] Golias, M. “The Use of Soy Methyl Ester-Polystyrene Sealants and Internal Curing to Enhance Concrete Durability”. Master’s thesis, Purdue University, West Lafayette, Indiana, 2010.

Behavior of Dapped Ends in Thin-Stemmed Prestressed Concrete Beams

M. Qambar[1*], G. W. Lucier[1], G. T. Proestos[1], R. Seracino[1]

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

Daps are a common end-condition in which the bottom section of a member is blocked out and is allowed to rest on a ledge or corbel. This detail reduces the floor-to-floor height of a structure, and can allow for significant gains in structural efficiency and economic savings. However, this block-out creates a geometric discontinuity in the end region which results in concentrated stresses, particularly at the re-entrant corner. In addition, the reaction does not act to confine the bottom of the beam, reducing the shear strength of the global section. Recent research on this end condition in precast members with thin stems has paid particular attention to developing efficient and effective reinforcement schemes, and now forms the basis of standard industry design guidance [1]. However, further investigation is required to determine the impact of various parameters on the strength of the dapped end in a thin stemmed member, including the amount of precompression present in the nib, the effects of lightweight concrete, and impacts of hanger steel bend radius on the captured node of the critical compression strut.

This presentation summarizes research from the past 18 months, including validation of finite-element models using data from literature. Validated FEMs were then used to guide the design of 11 full-scale test specimens to investigate selected parameters. These beams are now being produced at prestressing plants and tested in the Constructed Facilities Laboratory to assess the end region behavior experimentally.

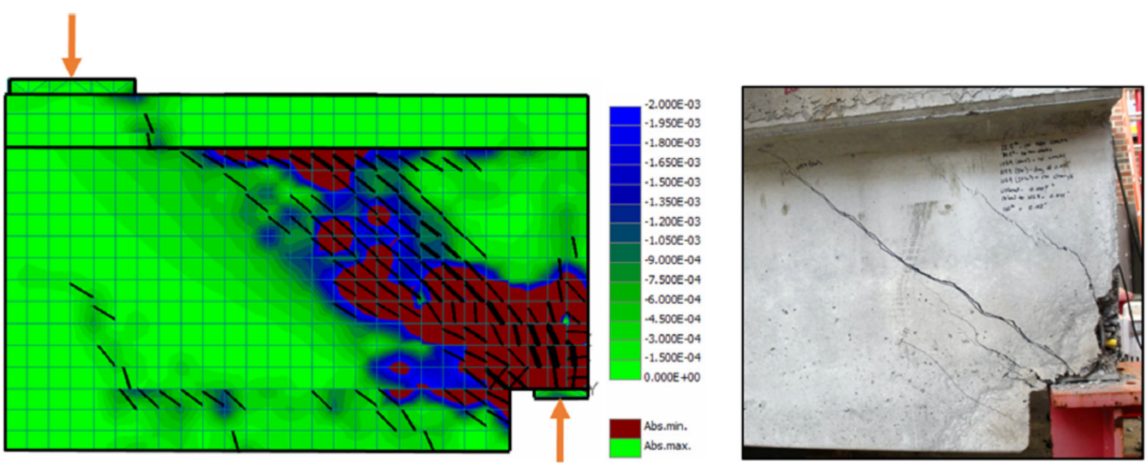


Figure: FEM predicted principal compressive strains and crack widths (left) for a dapped experimental specimen (right).

Keywords: (shear, prestressed concrete, dapped ends)

References

[1] Botros, A. W., Klein, G. J., Lucier, G. W., Rizkalla, S. H., and Zia, P. 2017. “Dapped ends of prestressed concrete thin-stemmed members: Part 1, experimental testing and behavior.” *PCI Journal* 62 (2): 61-82.

Experimental Validation of Performance-based Limit-state for the Seismic Fragility Assessment of T-joint in a Piping System

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Observations from past earthquake-related failures of piping in non-nuclear facilities such as hospitals and industrial plants have highlighted that such failures take place primarily at the location of joints in the entire system. Several experimental and analytical studies have been performed in the past decade to evaluate the seismic fragility of piping systems. Almost all the studies conducted in the recent past characterize the limit-state for the first leakage in terms of maximum rotation that follows the ASME's "twice-the-elastic-slope" criterion. However, a recent analytical study by Dubey et. al (2020) uses nonlinear simulations for cyclic loading on T-joint piping components to establish a new limit-state. It is based on the concept of "low-cycle fatigue" and uses the accumulation of plastic rotation in each cycle to determine a new failure criterion. In this study, we present the experimental verification of this new limit state from a set of experimental results conducted to verify the failure criterion based on the accumulation of plastic rotation.

Data from laboratory experiments on T-joint components for both the monotonic and cyclic loadings are considered in this study. For cyclic loading, data from multiple tests at different but constant amplitudes of cyclic loading is considered. Then, the nonlinear behavior of T-joints is simulated using nonlinear analyses. A comparison of simulation and experimental results is used to validate the low-cycle fatigue-based limit-state. Figure 1 shows the experimental set-up of a T-joint component.

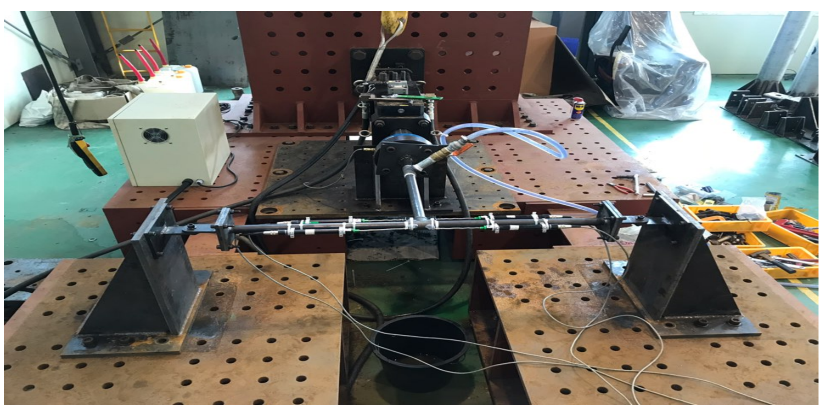

Figure 1: Experimental Set-up

Keywords (simulation, piping T-joint, cyclic loading, non-linear behavior, limit-state)

References

[1] Dubey, A., Gupta, A., Cho, S., (2020), "Characterization of limit state for seismic fragility assessment of T-joint in piping system" ASME Journal of Pressure Vessel Technology, Volume 142, pages 051901 (1-4).

Bond-Slip Failure of RC Bridge Columns under Seismic Loads

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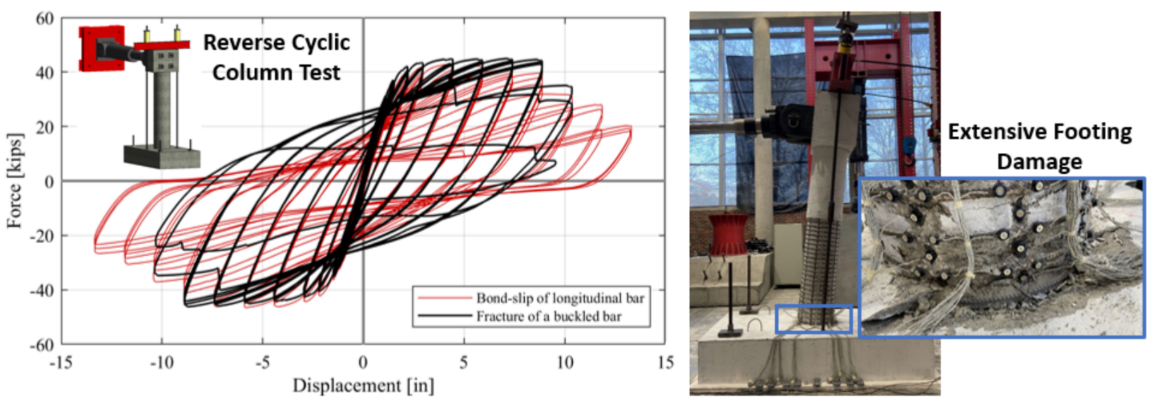
The damage of seismic members occurs in locations of inelastic deformation, known as plastic hinges, which act to dissipate energy. Through mindful detailing for the anticipated seismic demands, these locations are designed to fail in flexure through plastic rotation of the hinge [1]. In an extensive experimental program, large-scale reverse cyclic tests have been conducted on bridge columns reinforced with Grade 80 steel to quantify the seismic performance. The typical failure mode of these tests has been the fracture of previously buckled longitudinal reinforcing bars. Conversely, out of the 16 tests, one column experienced a bond-slip failure due to extensive concrete crushing at the foundation level. The longitudinal bars debonded from the concrete in the damaged area, causing them to become less restrained and slip as the column was cyclically loaded. As a result, the column was able to displace significantly, but the force required to deform the column decreased at every cycle. This study explores the implications of bond-slip failures on the seismic performance of columns reinforced with Grade 80 steel.



Hysteretic Response of Column Tests & Bond-Slip Damage: Comparison of two identical tests with different types of Grade 80 steel that resulted in different failure mechanisms.

Keywords (seismic, RC column, bond-slip, grade 80 steel, large-scale)

References

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BIM Interoperability Solutions for Model Data Exchange and Structural Analysis of Building-Piping Systems

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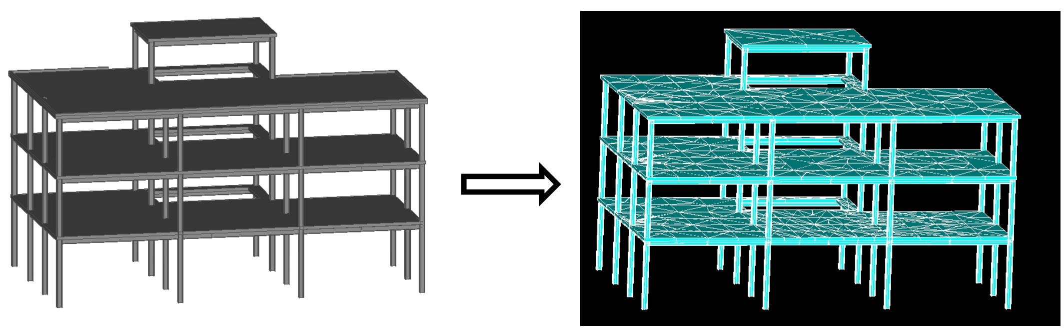
Designing of piping systems for nuclear power plants involves engineers from multiple disciplines and close coordination with contractors who build the plant. Any design changes during construction need to be carefully communicated and managed with all stakeholders in order to assess risks associated with the design change, such as risk assessment through structural analysis of coupled building-piping systems. Therefore, there is a need in the industry to facilitate quick and accurate model exchange between design software, namely building information models (BIM) of building and piping systems, and structural analysis software. Currently, there is a lack of foundational methods for interoperability between BIM and finite element model (FEM) domains, particularly for piping elements. Therefore, this study presents novel BIM-to-FEM digital data conversion solutions that are implemented and tested in a developed BIM interoperability support tool for structural building and piping systems [1]. The BIM interoperability support tool allows for streamlined model data exchange and creation of a finite element model for building-piping coupled analysis for use in risk assessment.



(a) AVEVA E3D Building Model (b) ANSYS Finite Element Model

Graphical abstract title: Automatic data exchange and conversion of (a) sample building structure from AVEVA E3D in the Building Information Model domain to (b) ANSYS Mechanical APDL in the Finite Element Model domain.

Keywords Building Information Modeling (BIM) interoperability; Structural analysis; Piping design; Model data exchange; Digital engineering

References

[1] Crowder, N., Lee, J., Gupta, A., Han, K., Bodda, S., Ritter, C. (2021). Digital Engineering for Integrated Modeling and Simulation for Building-Piping Systems through Interoperability Solutions. Under review in *Nuclear Science and Engineering.*