Research Statement

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Overview

My research uses applied mathematics to solve problems in structural engineering and in how engineers learn mathematics. Across four journal papers and conference papers at ASEE, SPIE and the U.S. National Conference on Earthquake Engineering, I have built material models, matrix algorithms and neural networks for structures under earthquake loading. I have also studied, with colleagues at the University of Virginia, how grading and instruction shape engineering students' success in mathematics. Both lines of work ask the same question: which mathematical structure makes a hard problem tractable, stable and teachable?

1. Seismic resilience with shape memory alloys

Conventional steel frames survive earthquakes by yielding, which leaves permanent residual drift and costly repairs. I designed a super-elastic memory alloy re-centering damper (SMARD) that pairs high-performance NiTiHfPd bars with friction springs. The bars dissipate energy through a flag-shaped loop and return the frame to plumb. Uniaxial tests from −35 °C to 25 °C and 0.05 to 1.0 Hz fed a material model. Nonlinear time-history analyses of 6- and 9-story special moment frames under 44 ground motions showed large reductions in peak and residual response (Smart Materials and Structures, 2022; SPIE 2022). In related work on tension-only NiTi braces, median residual drift under the strongest records fell from 4.31% to 0.69% (11NCEE, 2018).

2. Graph-theoretical algorithms for structural computation

Structures that mix stiff and flexible members produce ill-conditioned flexibility matrices, and round-off error then corrupts the analysis. I treat the structure as a graph and choose its cycle basis, built from shortest route trees, so the matrix is sparse, banded and well conditioned before it is ever formed. My paper proposes five topological algorithms and tests them on five structures, including a 4-story 3D steel frame. There, a stiffness-weighted cycle selection cut the digits lost to round-off from 7.25 to 5.14 (Engineering Computations, 2022). This extends my earlier work on graph methods for well-conditioned flexibility matrices (Journal of Civil Engineering, Ferdowsi University of Mashhad, 2011).

3. Neural networks for hysteresis

Materials such as shape memory alloys respond with hysteresis that depends on loading history and rate, which no single classical model captures. With M. Farrokh and M. Shafiei Dizaji, I developed the Extended Preisach Neural Network (EPNN). Its first hidden layer uses deteriorating-stop neurons that reproduce non-congruent loops. A second sigmoidal layer learns asymmetric, non-Masing behavior, and feeding in the input's rate of change captures rate dependence. A hybrid genetic and sub-gradient algorithm trains the network, which matched experimental hysteresis from several engineering fields (Neural Processing Letters, 2022).

4. Mathematics education for engineering students

In three ASEE studies with colleagues in UVA's Applied Mathematics Center, I measure what helps engineering students succeed in mathematics. We traced how the move to online teaching during COVID-19 affected applied mathematics courses (2022). Linking survey and registrar data, we found students were more likely to take mathematics courses credit/no-credit than courses in their major, a sign of low confidence in mathematics (2023). After mastery grading came to Calculus I, students reported less test anxiety and more confidence. The students who entered with the lowest diagnostic scores gained most on the common final exam (2024).

Future directions

My next projects join these threads, and each has entry points for undergraduate researchers:

- **Learned material models in structural analysis.** Train EPNN-type networks on SMA test data and use them inside time-history simulations of damped frames, in place of fitted flag-shaped models.
- **Graph methods for large models.** Extend cycle-basis and ordering algorithms to large finite-element and space-frame models, released as open-source tools students can build on.
- **Evidence for inquiry-based learning.** Measure the inquiry-based ODE worksheets I have taught for six years, using the survey and registrar methods from our ASEE studies.
- **Engineering problems as mathematics lessons.** Turn my structural dynamics work, such as spring-mass models and damped oscillators, into discovery modules for calculus and differential equations.

These directions fit NSF programs in engineering education and in structural and materials engineering, and I plan to pursue external funding for them.