Characterization of Dynamic Soil-Pile Interaction by Random Vibration

Mohammad K. Fotouhi (Ph.D. Student) and Jeramy C. Ashlock (Advisor), Iowa State University

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Background

Dynamic soil-structure interaction (SSI) has been recognized as a fundamental consideration in the design and assessment of buildings, bridges, highways and dams to withstand dynamic loads such as earthquakes, explosions or vibrations from machinery. This importance has been reflected in modern design building codes and rehabilitation regulations. Different analytical and numerical models have been proposed to represent the complex response of the soil-foundation system. In order to calibrate and validate these models, a database of full scale and model testing are required. Experimental and computational capabilities are being developed in this investigation to provide realistic multi-modal dynamic modeling of full-scale pile foundations over a wide range of frequencies. The research goals are:

- ➢Validating the Hybrid Multi-Mode dynamic test to supersede two separate vertical and coupled horizontal-rocking tests.
- ➢Employing random vibration theory for efficient experimental and analytical characterization.
- ➢Determining the optimal testing techniques and forcing intensities.
- ➢Developing 3D computational continuum models and calibrating them against the dynamic response.
- ➢Validating and improving existing approximate analytical relations for impedance functions.

Experiment Overview and Results

•A total of 109 full-scale vibration tests were performed on HP 10x42 piles with 20 ft embedment using random vibration methods and a newly developed servo-hydraulic inertial shaker testing system

•**Pile U (unimproved soil):** tested in the natural soft clay soil profile

•**Pile I (improved soil):** surrounded by a 48" diameter, 13 ft deep cement deep soil mixed (CDSM) improved zone within the soft clay layer

•Three excitation techniques were examined using a range of forcing intensities to determine optimal testing configuration;

Random (R), Chaotic Impulse (C) and Swept-sine (S)

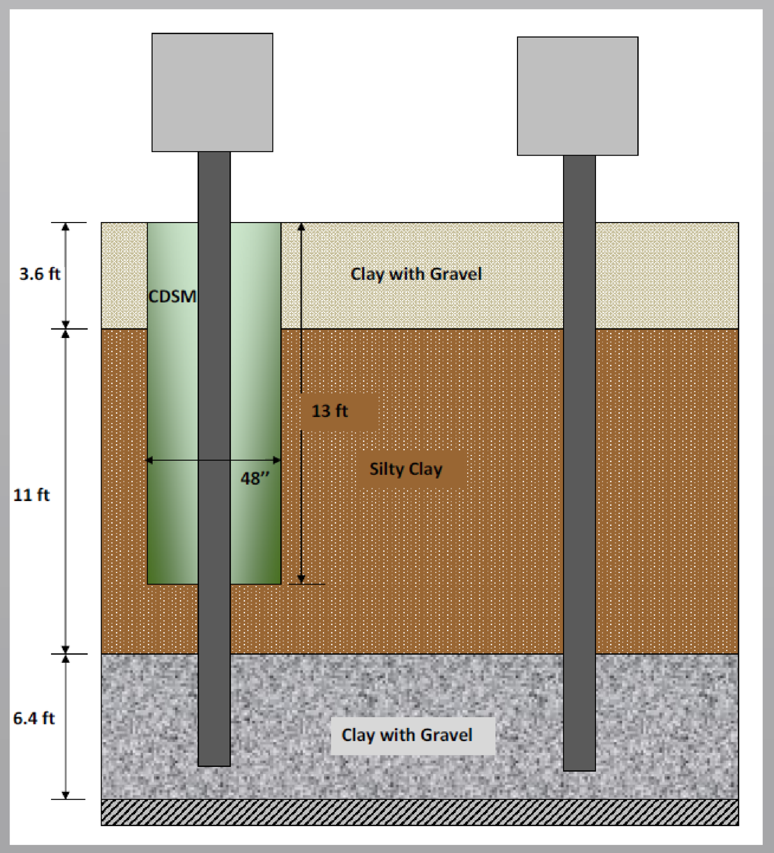
•**Test naming convention: (Pile)-(Test type)-(Excitation type & level)** e.g., test **I-VC-R1** = test on Pile I in VC configuration with Random loading at intensity level 1.

•For Transfer and Coherence functions, acceleration A_{mm} of shaker's moving mass was taken as the stimulus, with all other pile-cap and soil accelerations treated as response quantities

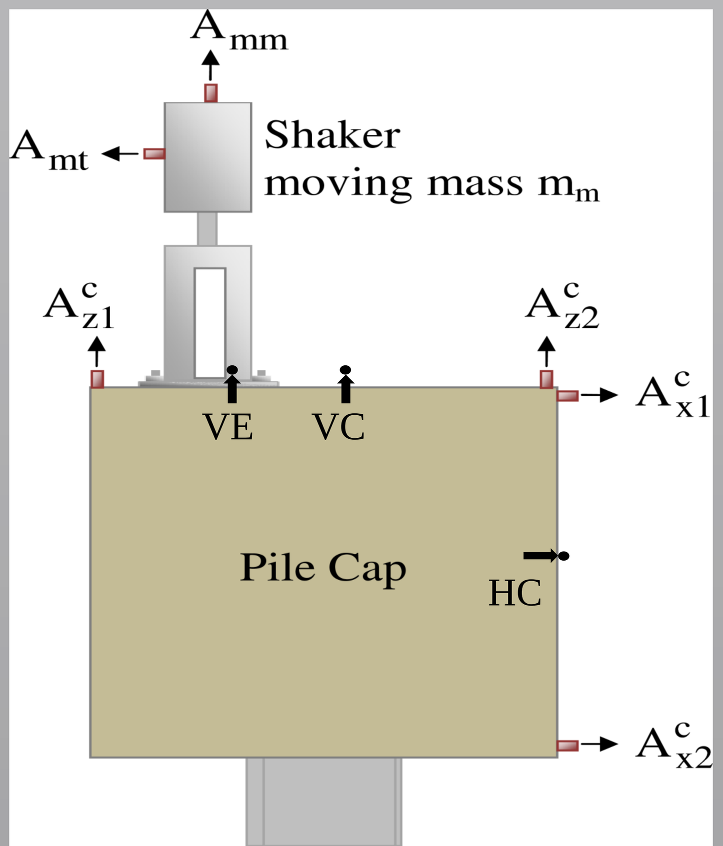
- **XFER** $= \dfrac{\text{response type}}{\text{stimulus type}}$ e.g.,   **VC/VE** $= \dfrac{\text{VC acceleration of pile cap}}{A_{mm} \text{ of shaker in VE position}}$

(a) **VC** test (b) **HC** test (c) **VE** test

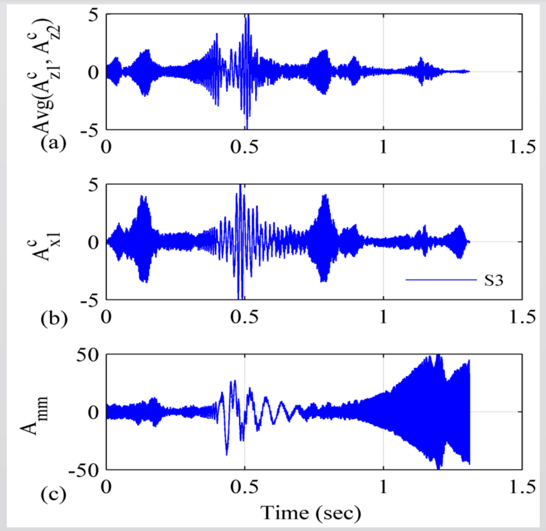
Inertial shaker configurations for the three test types



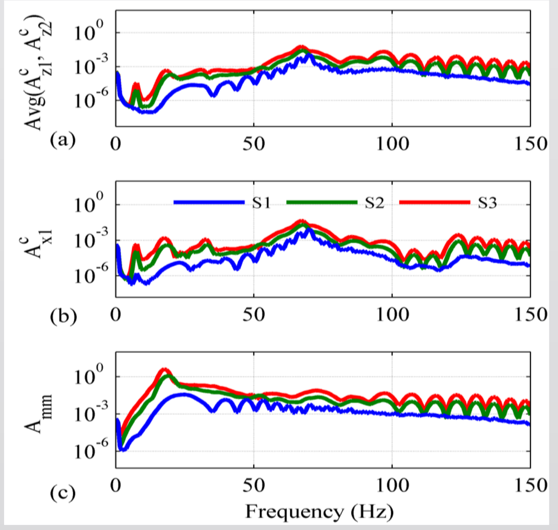
A section shows the piles set up in the soil media and CDSM around the pile



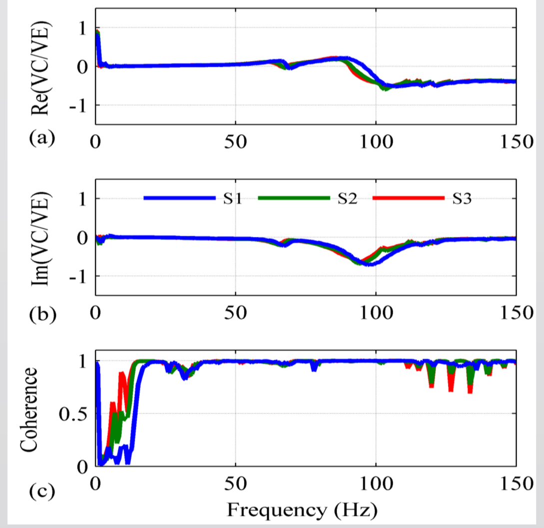
Orientation and notation for accelerometers on shaker and pile cap (shaker in VE test position)



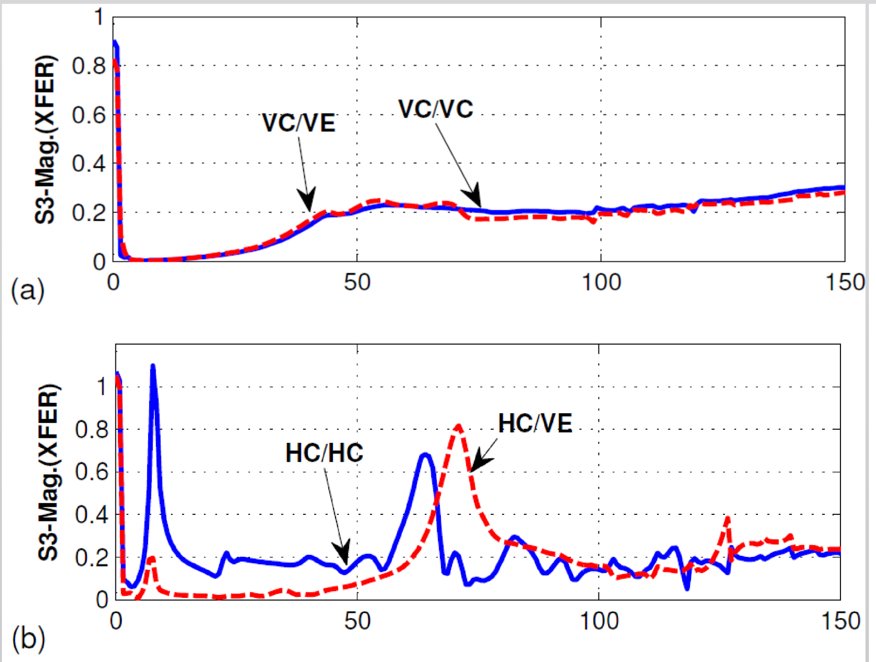
Acceleration time histories (m/s²), Swept-sine excitation, test I-VE-S3



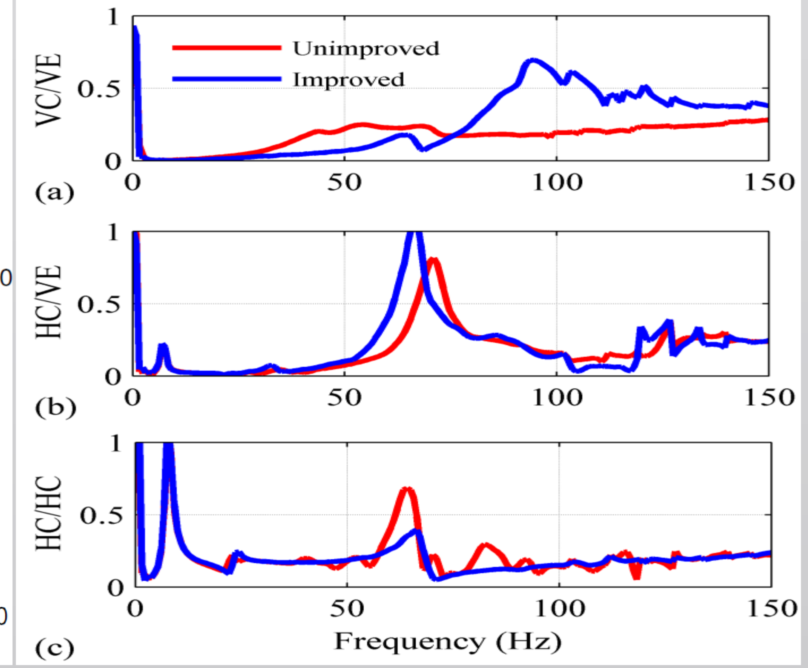
Power spectral densities ((m/s² rms)²/Hz), Swept-sine excitation, tests I-VE-S1, S2 & S3



Acceleration transfer functions and Coherence Swept-sine excitation, tests I-VE-S1, S2 & S3



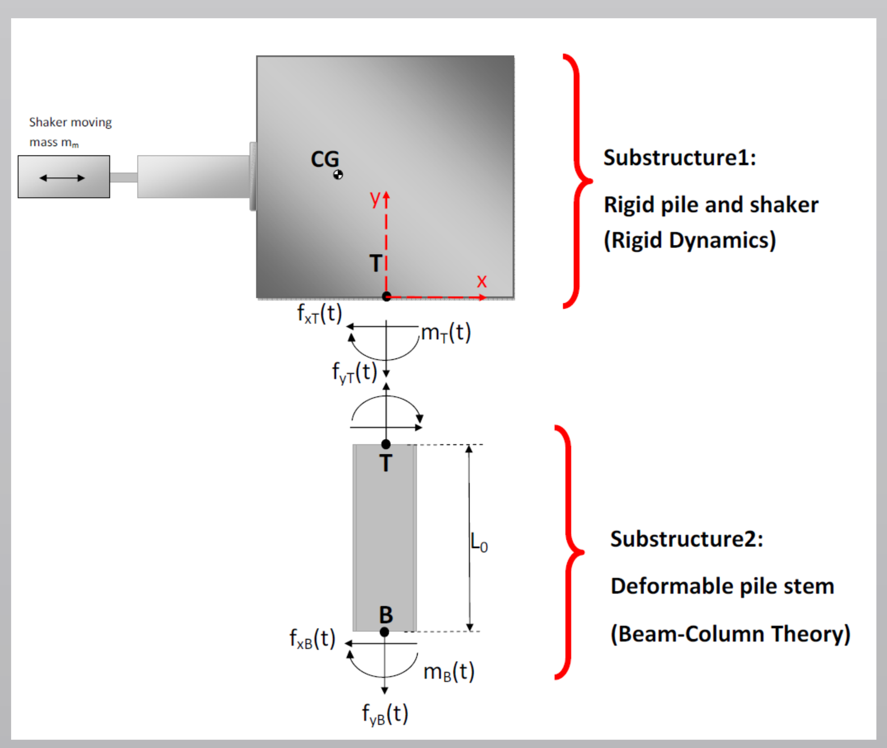
Comparison of VE test to combination of VC and HC tests (swept-sine excitation) (a) VC response from VC and VE tests, (b) HC response from HC and VE tests

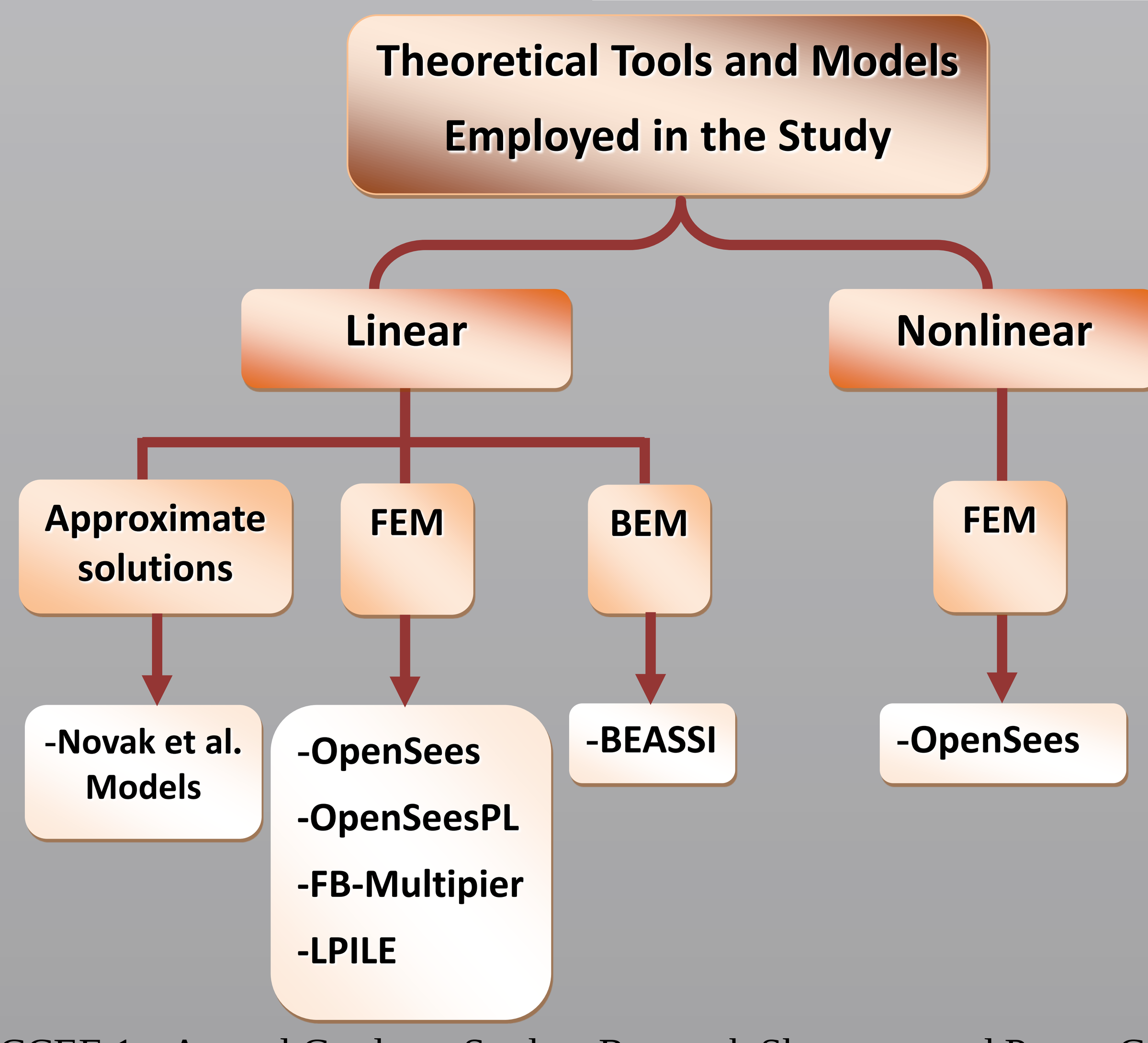


Comparison of transfer functions for pile in unimproved vs. improved soil (swept-sine excitation at intensity level 3)

Theoretical Approach

The soil stiffness and impedances are calculated using computational continuum models for the pile and soil domains, with beam-column theory for the un-embedded portion of the pile and rigid body dynamics for the pile cap. The computational continuum model results will later be verified using other tools.





Novak et al. approximate solution

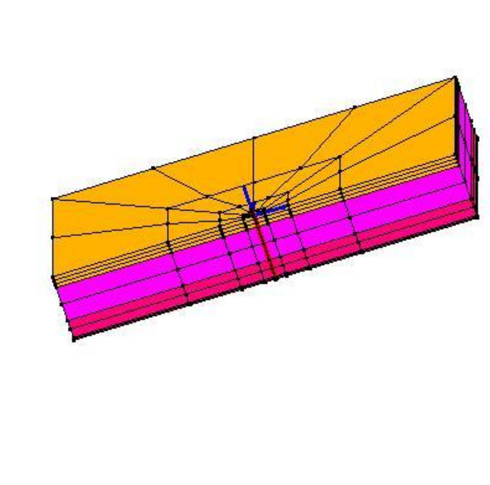
The main advantage of this model is its **negligible computing costs** and relative simplicity. It contains the following steps:

•Finding complex soil reactions for Plane Strain case (Novak and Nogami,1978).
•Finding the reaction of soil acting on the tip of the pile (Veletsos and Verbic,1973).
•Constructing the complex frequency parameters and dimensionless functions.
•Constructing the element stiffness matrices for vertical, horizontal and rotational vibration.
•Assembling the total stiffness matrices of pile for vertical, horizontal and rotational vibration.
•Finding the stiffness of the pile at the head by solving the matrix equation.

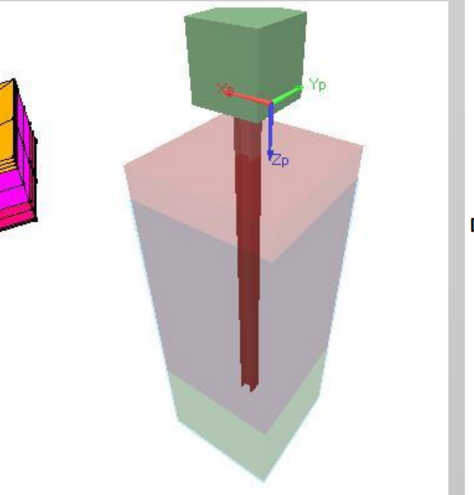
BEASSI

BEASSI is an advanced **3D BEM** program written in **Fortran** featuring:

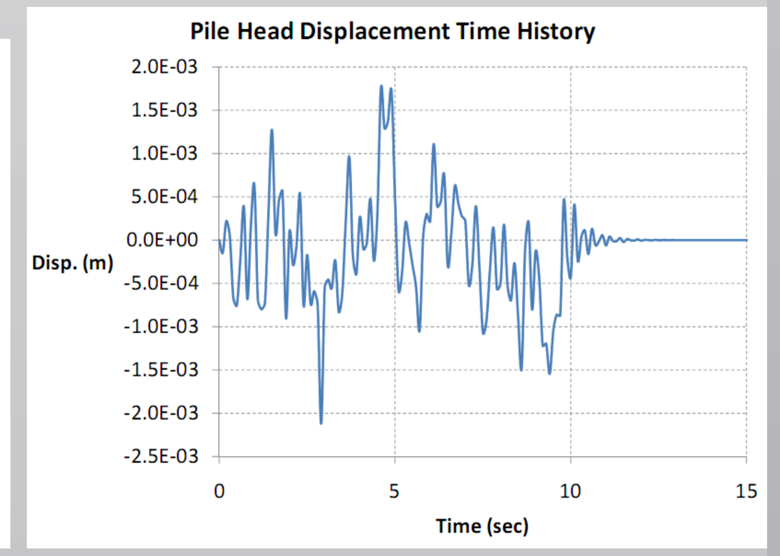
•Regularized multi-domain formulation
•A library of layered viscoelastic half-space fundamental solutions
•Families of singular and adaptive gradient (AG) elements
•Boundary element-compatible structural beam-column elements for the pile domain
•An adaptive integration algorithm to ensure accuracy of the coefficient matrices



Model of the pile-soil system in OpenSeesPL



Model of the pile-soil-pile cap system in FB-Multipier



Response of the Pile-Soil System modeled in OpenSees to a Horizontal 10KN pink noise loading at the pile head

Findings and Remarks

- Shapes of measured transfer functions were as anticipated
- VE tests successfully generated significant horizontal-rocking motions
- CDSM improved soil zone provided significantly stiffer vertical response, but fundamental peak frequency of horizontal-rocking response was unchanged.
- After comparison of the modeling capabilities of a number of software packages, we selected OpenSees to carry out subsequent analysis. This program allows for greater parameter control, customizable meshing, makes available linear and non-linear elements for pile and soil behavior, and provides a variety of pre-defined soil constitutive models that can be modified. OpenSees is an open source academic software package that is coupled to convenient support resources, and that displays better overall stability in comparison to its counterparts.
- Data from this Payload project is currently being analyzed to provide the first full-scale verification of other numerous experimental studies, calibrations for the Impedance Modification Factor (IMF) approach, and refinement of advanced computational continuum boundary element models

Acknowledgements

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- ISU undergraduate students Robbie Jaeger and Theodore Bechtum for programming the dynamic signal analyzer

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