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Preparing Community College Students for Earthquake Engineering Research through State-of-the-Art Real-Time Hybrid Simulation

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Amelito Enriquez is a professor of Engineering and Mathematics at Cañada College in Redwood City, CA. He received a BS in Geodetic Engineering from the University of the Philippines, his MS in Geodetic Science from the Ohio State University, and his PhD in Mechanical Engineering from the University of California, Irvine. His research interests include technology-enhanced instruction and increasing the representation of female, minority and other underrepresented groups in mathematics, science and engineering.

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Oskar Granados is currently a sophomore at Cañada College in Redwood City, CA, majoring in Mechanical Engineering. His research interest include renewable energy, astrophysics, waste management, the smart grid, and structural analysis. Over time, he hopes to get involved in the engineering industry workforce, research and development, and pursuit a teaching career to pass on the tradition of American education to communities who lack access to higher education.

Maryam Khan
Manuel Alexis Ramirez, San Diego State University

I feel honored to be part of the ASEE conference. I never thought opportunities like this would be available for me. Coming from Peru and with a language barrier to overcome, for me it was certainly tough when I started my education in California. Nonetheless, I knew that if I aimed for excellence my work on school was going to be worth it. I am now on my junior year at San Diego State University majoring in Aerospace Engineering. During the Summer of 2016, I had the privilege to be the lead intern at the ASPIRES program at San Francisco State University. The experience I gained there has helped me throughout my classes and projects at SDSU. I look forward to go to graduate school in the upcoming years.

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Nathan Carlson is currently a sophomore at Cañada College in Redwood City CA, majoring in Mechanical Engineering. His previous research worked with structural testing and he hopes to pursue a career in the field of aeronautics.

Preparing Community College Students for Earthquake Engineering Research through State-of-the-Art Real-Time Hybrid Simulation

Abstract

Earthquake has posed a great danger for the human society. Future earthquake disaster prevention and preparation require that young professional civil engineers are trained and recruited into the next generation workforce for the purpose of public safety. With support from the US Department of Education through the Hispanic-Serving Institution Science, Technology, Engineering, and Mathematics (HSI STEM) program, four community college engineering students participated in a ten-week summer research internship program at San Francisco State University in summer 2016. This paper presents a summer intern project that prepares community college students for future earthquake engineering research. Real Time Hybrid Simulation (RTHS) provides a viable alternative to evaluate the structural response under the earthquakes in size limited laboratories. The explicitness of the unconditionally stable CR algorithm makes RTHS of large civil engineering structures possible. However, it is impossible to know the exact mass, damping, and stiffness of the experimental and analytical substructures. During the ten weeks internship, the four community college students utilized MATLAB and Simulink to explore how the variation of the parameters affects the stability and accuracy of RTHS using these two integration algorithms. This research internship program integrates state-of-the-art earthquake engineering research with the development of project management, time management and teamwork skills, thus helping strengthen students' knowledge in earthquake engineering and preparing them for successful academic and professional careers. The internship program therefore provides valuable mentorship for community college students during their transition to a four-year college.

1. Introduction

Community colleges serve as the gateway to higher education for large numbers of students especially in California. The California community college system, with its 112 community colleges and 71-off campus centers enrolling approximately 2.6 million students is in a prime position to grow the future STEM workforce [1]. However, for science and engineering fields, lower success and retention rates are observed at both community college and university levels resulting in underrepresentation of minority groups in these fields. Cañada College, located in the San Francisco Bay Area, is a Hispanic-serving community college, and is one of three colleges in the San Mateo Community College District. During the 2015-16 academic year, the student body is genuinely multi-cultural with a total of 10,075 unique students, of which Hispanic students is the largest single group at 45.2%; white students comprise 26.8%, Asians 12.3%, African-Americans 2.8%, American Indian/Alaska Natives 0.2%, Filipinos 4.1%, Pacific Islanders 1.4%, multi-ethnic 4.2%. Approximately 18% attend college full time, taking 12 or more units per semester. Like all California community colleges, Cañada College is an open-enrollment institution, designed to welcome students of all backgrounds. Cañada College's Engineering Program is a transfer program that offers a comprehensive set of lower-division engineering courses needed to transfer to any four-year engineering program in any field of engineering.

In 2015 Cañada College's Engineering Department collaborated with San Francisco State University School of Engineering to develop and implement the *Accelerated STEM Pathways through Internships, Research, Engagement, and Support* (ASPIRES) project, which is funded by a three-year grant from the Department of Education Minority Science and Engineering Improvement Program (MSEIP). ASPIRES addresses identified barriers to student success using high-impact educational practices that have been shown to enhance interest, increase participation, and improve outcomes for underrepresented minority students in STEM.

Among the main objectives of ASPIRES is to develop an internship program model that is suitable for community college students and provides multiple exposures to undergraduate research opportunities. The ASPIRES internship program has three levels targeting students at different stages in their academic careers. The ASPIRES Summer Group Research Internship Program is the second level ten-week program for sophomore students who have no previous research experience and have at least one more year of courses to complete at Cañada College before transferring to a four-year university. In addition to allowing students to participate in the program as part-time interns, the group setting wherein students work with their peers and faculty they know will give students the supportive learning environment needed to succeed in their first internship experience. A collaborative learning environment has been shown to positively impact minority students—improving cognitive development and reducing students' feeling of isolation. The ASPIRES Group Research Internship program consists of five research groups, each consisting of one full-time student intern and three part-time student interns supervised by one San Francisco State University graduate student and mentored by an engineering faculty. This paper presents the outcomes of the civil engineering intern group.

2. Civil Engineering Project

Earthquake engineering is concerned with design and analysis of structures to withstand earthquakes at specific locations. Civil engineers need to find ways to build more efficient and cost-effective buildings that have the capability to resist various natural hazards such as earthquakes and high winds. Recent earthquakes in California and Japan have caused significant impact on human society (20 killed, $20B in direct losses during the 1994 Northridge earthquake, and 5500 killed, $147B in direct losses during the 1995 Kobe earthquake). Similar earthquakes of magnitude 6.0 or greater can have a more profound impact on the greater San Francisco Bay Area. Earthquake engineering research is important to explore new lateral force resisting systems and to improve existing design methodology for more economical and efficient structural design. Being a cost-effective experimental method for large-scale civil engineering systems, real-time hybrid simulation (RTHS) has started to see increased applications in seismic hazards mitigation. RTHS combines physical testing and numerical simulation to achieve system-level responses for modern performance-based design. As shown in Figure 1, the critical and/or complex components of a structural system that may be difficult to model numerically are built as physical specimens and tested as the *experimental substructures*. The rest of the structural system, which is generally simple to model and analyze, is analytically modeled as the *numerical substructure*. RTHS therefore has attracted considerable research interests in the last two decades [2-3]. One of recent advances is the development of structural property dependent *integration algorithms* and their application to RTHS. Explicit integration algorithms are often preferred than implicit ones to avoid back and forth actuator movements necessary for the iterative solution of implicit integration algorithms. Unlike the Newmark explicit method, the structural property dependent algorithms [4] have unconditional stability in addition to its explicitness. The structural property dependent algorithm hase greatly advanced the implementation and application of RTHS for earthquake engineering research [5].

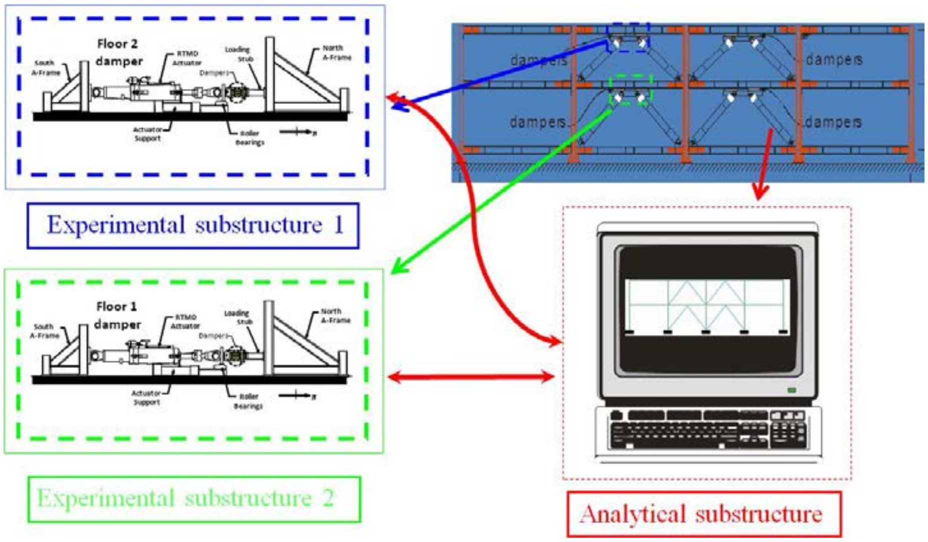

Figure 1: Schematic of RTHS for a Moment Resisting Frame with Energy Dissipation Devices

Shake table, quasi-static, and hybrid simulation tests are the three main experimental methods that are used in laboratory on the seismic performance of structural systems. Although often considered as the most widely accepted testing method, high cost and scaling problems make shake table test difficult, if not impossible, for structural system analysis. On the other hand, although lower in cost, quasi-static tests could not truthfully represent the seismic demands during the earthquakes. On the other hand, RTHS provides a cost-effective experimental technique for large scale testing [2-5]. Due to the fact that structural properties might not be known exactly before the experiment, this poses a great challenge to RTHS using the structural property dependent algorithms. The civil engineering project aims to investigate the effect of estimation error on the stability and accuracy of the RTHS. The research focuses on the single-degree-of-freedom (SDOF) structure as shown in Figure 2, of which the equation of motion can be expressed as

$$m\ddot{x}(t) + c\dot{x}(t) + r(t) = F(t) \tag{1}$$

where m and c are the mass and the inherent viscous damping of the SDOF structure, respectively; r is the restoring force; $\dot{x}(t)$ and $\ddot{x}(t)$ are the velocity and acceleration responses of the SDOF structure, respectively; and $F(t)$ is the external excitation force and can be expressed as $m\ddot{x}_g(t)$, where $\ddot{x}_g(t)$ is the ground motion selected for RTHS.

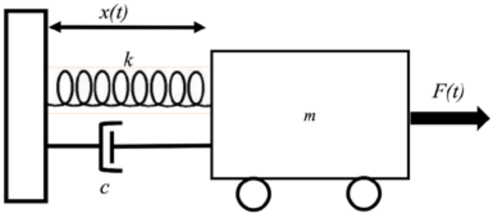

Figure 2. Typical SDOF mass-spring-damper system

When the unconditionally stable explicit CR Integration algorithm is used to solve the equation of motion in Eq. (1), the variations of displacement and velocity over the time step Δt are defined as

$$\dot{x}_{i+1} = \dot{x}_i + \Delta t \cdot \alpha_1 \cdot \ddot{x}_i \tag{2a}$$

$$x_{i+1} = x_i + \Delta t \cdot \dot{x}_i + \Delta t^2 \cdot \alpha_2 \cdot \ddot{x}_i \tag{2b}$$

where α_1 and α_2 are integration parameters; x_i and x_{i+1}, $\dot{x}_i$ and $\dot{x}_{i+1}$, $\ddot{x}_i$ and $\ddot{x}_{i+1}$ are the displacement, velocity and acceleration for the i^{th} and $(i+1)^{th}$ time step, respectively. Eqs. (3a) and (3b) indicate that the CR integration algorithm is explicit for both the displacement and velocity, making it well suited for real-time testing. To attain unconditional stability for the CR integration algorithm for a linear elastic structure, the integration parameters α_1 and α_2 are defined as

$$\alpha_1 = \alpha_2 = \frac{4m}{4 \cdot m + 2 \cdot \Delta t \cdot c + \Delta t^2 \cdot k} \tag{3}$$

It can be observed that the integration parameters α_1 and α_2 are functions of structural properties. When the exact values of m, c and k are not known a priori, the accuracy of RTHS to replicate actual structural response under earthquakes might be undermined. When the estimated properties (m_{es}, c_{es}, and k_{es}) are used for the integration parameters in Eq. (3) the transfer function which relates the structural displacement to the excitation force can be expressed as

$$G(z) = \frac{X(z)}{F(z)} = \frac{n_2 z^2 + n_1 z + n_0}{d_2 z^2 + d_1 z + d_0} \tag{4}$$

where $X(z)$ and $F(z)$ are discrete z-transforms of the displacement response x_{i+1} and excitation force F_{i+1}, respectively; n_2, n_1, n_0, d_2, d_1 and d_0 are coefficients of the numerator and denominator, respectively, and are listed in Table 1, where m_{est}, c_{est} and k_{est} are the estimated mass, viscous damping and stiffness, respectively.

Table 1. Coefficients for CR integration algorithm with estimated parameters

Numerator		Denominator	
n_2	0	d_2	$k_{est}\Delta t^2 + 2c_{est}\Delta t + 4m_{est}$
n_1	$4\Delta t^2$	d_1	$-8m_{est} + 2k_{est}\Delta t^2$
n_0	0	d_0	$k_{est}\Delta t^2 - 2c_{est}\Delta t + 4m_{est}$

The root-mean-square (RMS) in Eq. (5) is used in this study to quantify the effect of estimated parameter on the accuracy of CR algorithm for RTHS, where x_c is the exact response calculated using the CR algorithm with accurate structural properties and x_m is the response calculated using the CR algorithm with estimated properties.

$$\mathrm{RMS} = 100\% \times \sqrt{\frac{\sum_1^n (x_m - x_c)^2}{n}} \tag{5}$$

where *n* is the total number of recorded data. In this study several computational tools are used to conduct research in a more practical manner. MATLAB and Simulink from the Mathworks [6] are used to program for the computational simulation of RTHS. Maple 18 [7] is also used to solve all symbolic calculations. A total of 100 different ground motions, of which 44 are far-field and 56 are near-fault [8].

3. Student Project Findings

After ten weeks of work, the civil engineering team accomplished the research objective. The following presents representative project outcomes. Figure 3 presents the effect of mass estimation on the CR-algorithm. The error ranges from -50% to 50%. Similar findings can be observed for two different ground motions in Figures 3 (a) and 3(b) for SDOF structures with different natural periods. The accuracy of the CR algorithm decrease with the increase of the error in the mass estimation.

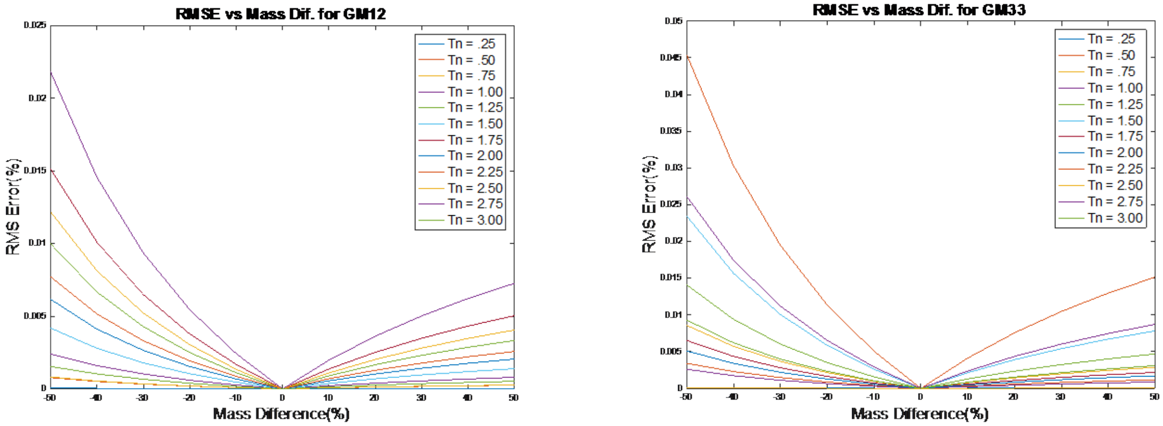

Figure 3. RMS error for mass estimation (a) ground motion 12, (b) ground motion 33

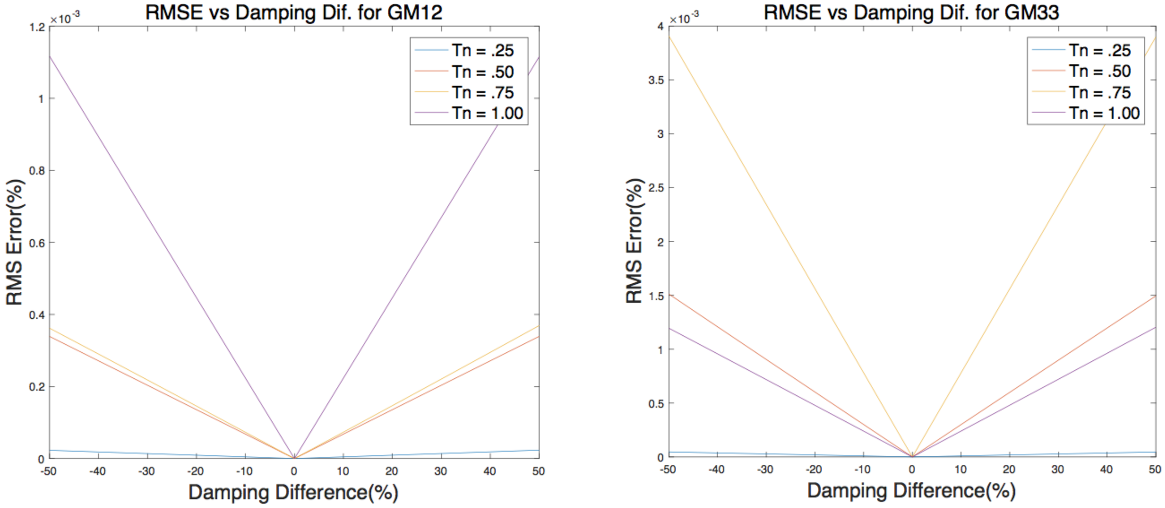

Figure 4. RMS error for viscous damping estimation (a) ground motion 12, (b) ground motion 33

Figure 4 presents the effect of viscous damping estimation on the CR-algorithm for both GM12 and Gm33. The error ranges from -50% to 50%. It can be observed that the RMS error is almost symmetric for overestimation and underestimation. Slight difference in RMS error can also be observed for the two ground motions. Figure 5 presents the effect of stiffness estimation on the CR-algorithm for both GM12 and Gm33. Again, similar findings can be observed.

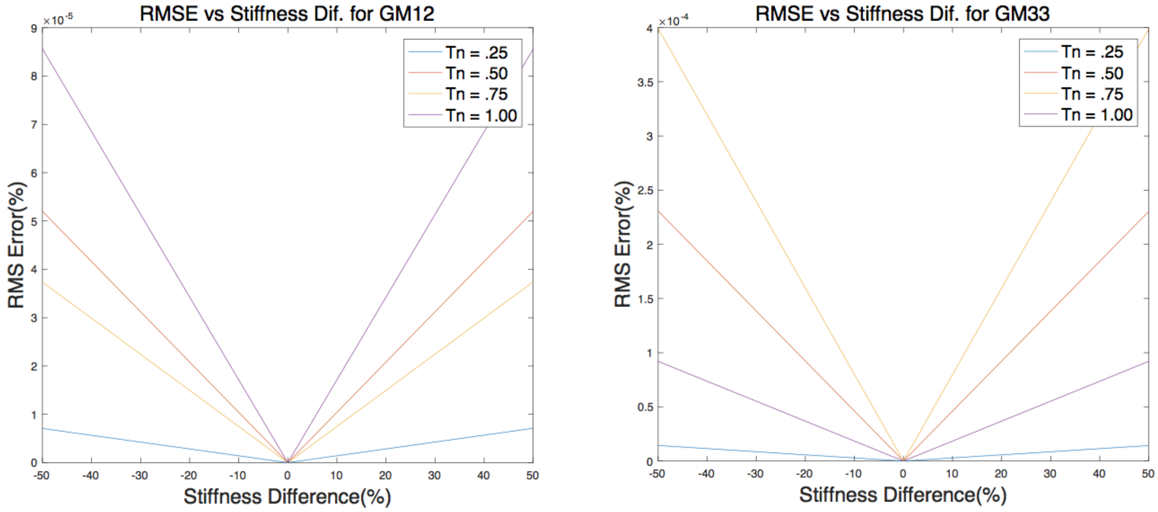

Figure 5. RMS error for stiffness estimation (a) ground motion 12, (b) ground motion 33

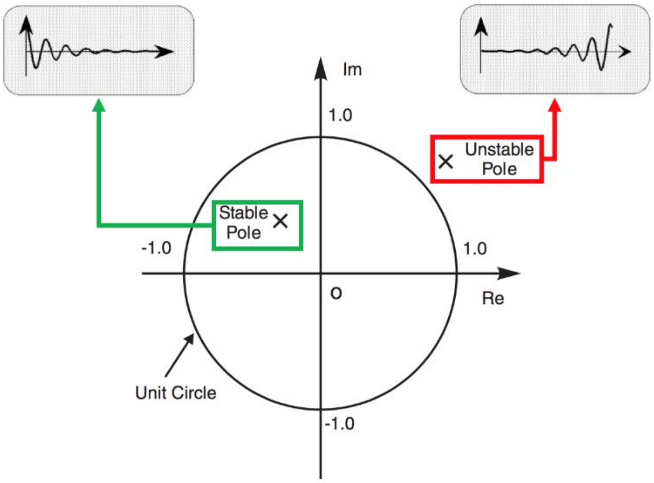

Figure 6. Pole stability in the discrete z-domain

The stability of the CR algorithm with estimated parameters is evaluated through the pole of the transfer function in Eq. (4). When the poles are inside the unit circle, as shown in Figure 6, the discrete transfer function in Eq. (4) is stable, implying the CR algorithm is stable with the estimated parameters. Otherwise, it is not stable. Figures 7(a) and 7(b) present the pole locations for the discrete transfer function in Eq. (4) with underestimation and overestimation of the mass for the SDOF structure with four different natural periods. It can be observed that with a 50% of error in mass estimation, the CR algorithm is stable. Figures 7(a) and 7(b) present the pole locations for the discrete transfer function in Eq. (4) with 50% underestimation and overestimation of the viscous damping. The root locus analysis also shows the stability when the damping coefficient is overestimated and underestimated. The poles are observed to be located inside the unit circle, being stable as well as when there is an overestimation of 50%.

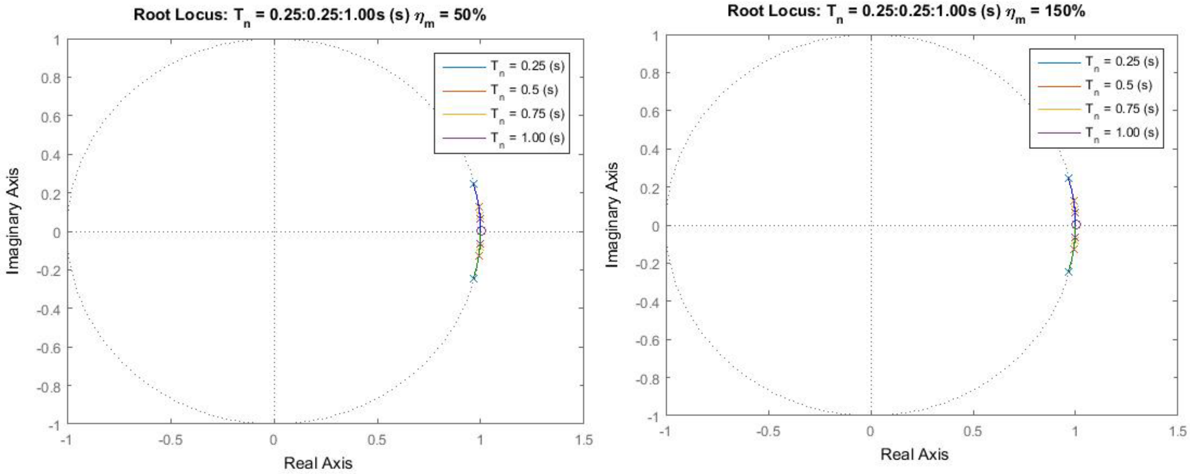

Figure 7. Stability for (a) mass underestimation; (b) mass overestimation

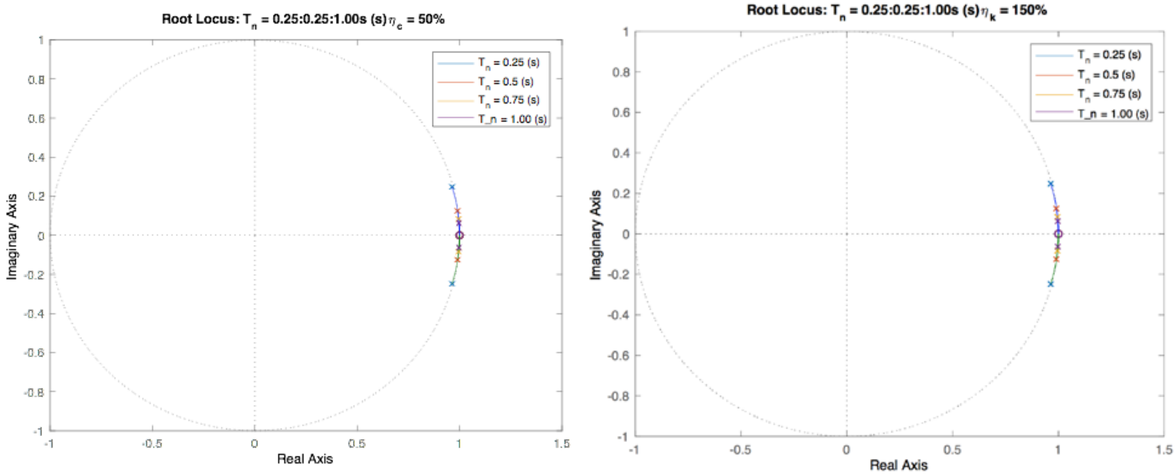

Figure 8. Stability for (a) damping underestimation; (b) damping overestimation

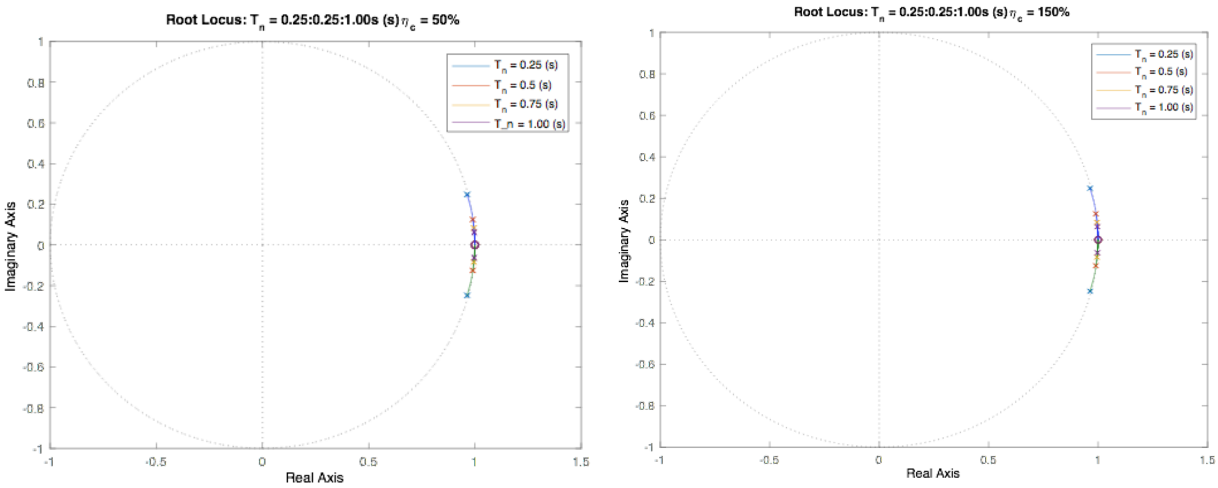

Figure 9. Stability for (a) stiffness underestimation; (b) stiffness overestimation

Figures 8(a) and 8(b) present the pole locations for the discrete transfer function in Eq. (4) with 50% underestimation and overestimation of the viscous damping. The root locus analysis also shows the stability when the damping coefficient is overestimated and underestimated. The poles are observed to be located inside the unit circle, being stable as well as when there is an overestimation of 50%. Figures 9(a) and 9(b) present the pole locations for the discrete transfer function in Eq. (4) with 50% underestimation and overestimation of the viscous damping. The root locus analysis also shows a stable system when the stiffness coefficient is overestimated as well as underestimated.

4. Project Assessment and Future Improvement

The internship experience enabled the interns to realize how earthquake engineering researchers will have to collaborate with other members on their team. They will need to make weekly meetings with their supervisor to discuss their progress and provide feedback on what they can improve. They will need to make a detailed, tentative plan that they must follow until their deadline when the building must be constructed. One engineer could not have completed the research project because it takes teamwork and collaboration on everyone’s part to get the project done.

To obtain a quantitative assessment of the project and further improve the project in the future, an exit survey was conducted for all twelve student-participants. Students were asked to rate their level of agreement with each question in a five point scale. The tables below present the students' response to some of the survey questions. The survey was conducted anonymously to help student express their opinions honestly.

Question: As a result of your participation in the program, how much did you learn about each of the following? (1 – Not at all useful; 2 – A little; 3 – Some; 4 – Quite a bit; 5 – A lot)

Activity	Average Rating
Gain hands-on experience in research	4.46
Solidify my choice of major	4.18
Gain skills needed to successfully complete a BS degree	4.21
Clarify whether graduate school would be a good choice for me	4.04
Clarify whether I wanted to pursue a STEM research career	4.36
Have a good intellectual challenge	4.54
Read and understand a scientific report	4.25
Write a scientific report	4.04
Ask good questions related to the scientific process	4.18
Set up a scientific experiment	4.07
Work with others to plan and conduct scientific experiments	4.61
Talk to professors about science	4.25
Think like a scientist	4.18

Question: Tell us how much you agree with each of the following statements. (1 – Not at all useful; 2 – A little; 3 – Some; 4 – Quite a bit; 5 – A lot)

Activity	Average Rating
I was able to conduct the scientific research that is part of my summer internship.	4.43
I am confident I will transfer to a four-year institution.	4.89
I am confident I will complete a BS in a STEM field.	4.89
I have a clear career path.	4.14
I have skill in interpreting results.	4.32
I have tolerance for obstacles faced in the research process.	4.39
I am ready for more demanding research.	4.14
I understand how knowledge is constructed.	4.21
I understand the research process in my field.	3.86
I have the ability to integrate theory and practice.	4.07
I understand how scientists work on real problems.	4.28
I understand that scientific assertions require supporting evidence.	4.43
I have the ability to analyze data and other information.	4.39
I understand science.	4.00
I have an ability to read and understand primary literature.	4.07
I have skill in how to give an effective oral presentation.	4.22
I have skill in science writing.	3.89
I understand how scientists think.	3.89
I have the ability to work independently.	4.25
I am part of a learning community.	4.50
I have a clear understanding of the career opportunities in science.	4.43

5. Summary and Conclusion

The HSI-STEM program has been very successful in helping students understand civil engineering topics and the engineering profession. Responses from the student participants are very positive. Among the students who solidified their choice of an engineering career and decided to major in one of the engineering fields, the program has provided context to their study of engineering – a strategy that has been proven to increase student motivation and persistence – especially as they struggle through the first two years of the engineering curriculum.

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