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Integrating Structural Engineering Research into Internship Experiences for Community College Students

Dr. Cheng Chen, San Francisco State University

Dr. Cheng Chen is currently an associate professor in the school of engineering at San Francisco State University. His research interests include earthquake engineering, structural reliability and fire structural engineering.

Dr. Amelito G Enriquez, Canada College

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.

Dr. Wenshen Pong P.E., San Francisco State University

Wenshen Pong received his Ph.D. in Structural Engineering from the State University of New York at Buffalo. He joined the School of Engineering at San Francisco State University in 1998. He teaches courses in Civil/Structural Engineering.

Dr. Pong is a registered Professional Engineer in California. He is a member of the American Society of Civil Engineers and the Structural Engineers Association of California. He has published over fifty technical papers in the areas of Structural Control and Earthquake Engineering. Dr. Pong has been the Director of the School of Engineering at SFSU with 20 full-time faculty and over 25 part-time faculty since 2009.

Dr. Zhaoshuo Jiang P.E., San Francisco State University

Zhaoshuo Jiang graduated from the University of Connecticut with a Ph.D. degree in Civil Engineering. Before joining San Francisco State University as an assistant professor, he worked as a structural engineering professional at Skidmore, Owings & Merrill (SOM) LLP. As a licensed professional engineer in the states of Connecticut and California, Dr. Jiang has been involved in the design of a variety of low-rise and high-rise projects. His current research interests mainly focus on Smart Structures Technology, Structural Control and Health Monitoring and Innovative Engineering Education.

Prof. Hamid Mahmoodi, San Francisco State University

Hamid Mahmoodi received his Ph.D. degree in electrical and computer engineering from Purdue University, West Lafayette, IN, in 2005. He is currently a professor of electrical and computer engineering in the School of Engineering at San Francisco State University. His research interests include low-power, reliable, and high-performance circuit design in nano-electronic technologies. He has published more than one hundred technical papers in journals and conferences and holds five U.S. patents. He was a co-recipient of the 2008 SRC Inventor Recognition Award, the 2006 IEEE Circuits and Systems Society VLSI Transactions Best Paper Award, 2005 SRC Technical Excellence Award, and the Best Paper Award of the 2004 International Conference on Computer Design. He has served on technical program committees of Custom Integrated Circuits Conference, International Symposium on Low Power Electronics Design, and International Symposium on Quality Electronics Design.

Dr. Hao Jiang, San Francisco State University

Hao Jiang received the B.S. degree in materials sciences from Tsinghua University, China, in 1994 and the Ph.D. degree in electrical engineering from the University of California, San Diego, in 2000.

Hao Jiang has been with San Francisco State University since August 2007 as an assistant professor in electrical engineering. Prior joining SFSU, he worked for Broadcom Corporation, Jazz Semiconductor and Conexant Systems Inc. His research interests are in the general area of analog integrated circuits, particularly in ultra-low-power circuits for biomedical applications.

Dr. Kwok Siong Teh, San Francisco State University

Kwok Siong Teh received his B.S., M.S., Ph.D. degrees in Mechanical Engineering from the University of Illinois Urbana-Champaign, University of Michigan at Ann Arbor, and University of California at Berke-

Christopher Amaro is currently a junior at Cal Poly San Luis Obispo, in San Luis Obispo California, majoring in civil engineering. His research interests include water resources and structures. Christopher hopes to obtain his P.E. after graduation and work in the private sector.

Adam Albert Davies, ASPIRES

Adam Davies is a student of mechanical engineering at Cañada College. Who goals are to transfer to a University and continue higher education.

Priscila Joy Silva Chaix, Cañada College

Priscila Silva is currently a student at Cañada College majoring in Mechanical Engineering. Her interest include AI technology and mechatronics and hopes to pursue a career in Mechanical Engineering.

Jesus Caballero, Canada College

Jesus A. Caballero is a third year student at Canada College in Redwood City, CA. He is currently studying Mechanical Engineering. Jesus is interested in further researching 3 Dimensional printing and mechatronics, and hopes to work in an Electronics Industry.

Mr. Juvenal Marin Sanchez, San Jose State University

Juvenal Marin Sanchez is currently a junior at San Jose State University that is majoring in civil engineering with an emphasis on structural engineering. His educational interests include structural mechanics and earthquake engineering. Mr. Marin Sanchez also collaborated with other community college students on a summer research internship held at San Francisco State University. The internship was during the 2017 summer, and was research based on magneto rheological dampers for seismic mitigation.

Dr. Xiaorong Zhang, San Francisco State University

Xiaorong Zhang received the B.S. degree in computer science from Huazhong University of Science and Technology, China, in 2006, the M.S. and the Ph.D. degrees in computer engineering from University of Rhode Island, Kingston, in 2009 and 2013 respectively. She is currently an Assistant Professor in the School of Engineering at San Francisco State University. Her research interests include embedded systems, wearable technologies, neural-machine interface, and cyber-physical systems.

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Christopher Amaro, Priscila Silva, Adam Davies, Juvenal Marin, Jesus Caballero, Amelito G. Enriquez
Cañada College, Redwood City, CA

Junjian Liang, Cheng Chen, Wenshen Pong, Hamid Shahnasser, Zhaoshuo Jiang, Hamid Mahmoodi, Hao Jiang, Kwok-Siong Teh and Xiaorong Zhang
School of Engineering, San Francisco State University, San Francisco, CA

E-mail: chcsfsu@sfsu.edu

Abstract

With support from the US Department of Education through the Minority Science and Engineering Improvement Program (MSEIP), five community college engineering students participated in a ten-week summer research internship program at San Francisco State University (SFSU) in summer 2017. A popular seismic damping device, magneto-rheological damper, was investigated by the interns during the internship. By analyzing different numerical models of the dampers, existing large-scale damper tests were studied and the damper response under external excitation is reproduced using the computing program software. UQ Lab was then applied to experimental results to explore the uncertainties inherent to the damper modeling. The probabilistic distributions of model parameters were derived and studied for their effect on real-world applications. This paper presents the summer intern project findings. Through the integration of state-of-the-art structural and earthquake engineering research into the internship, this program also enables the development of project management, time management, and teamwork skills, strengthens students' knowledge in structural and earthquake engineering, and prepares 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

The primary goal of structural and earthquake engineering is to enhance the seismic resiliency of communities through improved engineering and management tools for critical infrastructure systems. The magnitude of 5 earthquakes occurred more than 1500 times each year from 2000 to 2016 and the cumulative death over these 16 years is more than 800,000 [1]. Recent earthquakes in Mexico City, 7.1-magnitude quake on September 21, 2017, had a strong shake for 20 seconds, toppled buildings, damaged public infrastructure and killed more than 220 people [2]. It was four times stronger than the 6.7-magnitude Northridge earthquake in 1994, a Los Angeles-area disaster along a previously undetected fault that took more than 60 lives and caused about $44 billion in damage [3]. Similar earthquakes of magnitude 6.0 or greater can have a more profound impact on the greater San Francisco Bay Area [1]. The control of structural vibrations produced by the earthquake can be done by various means and methods by providing active or passive counter forces. Structural control devices have been shown to be effective in reducing structural displacements during earthquakes [4]. Semi-active devices provide controllability, stability (in a bounded-input bounded-out sense), and requires low power supply; therefore, presenting an appealing option for seismic hazard mitigation.

Community colleges such as Cañada College serve as the gateway to higher education for large numbers of students especially in California. 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. The *Accelerated STEM Pathways through Internships, Research, Engagement, and Support* (ASPIRES) program between San Francisco State University and Cañada College attempts to address some of these barriers to the successful transfer of community college engineering students to a four-year institution, including inadequate preparation for college-level courses, especially in mathematics, low success rates in foundational math courses, lack of practical context in the traditional engineering curriculum, and inadequate relevant internship opportunities for lower-division engineering students. In this paper, we will present a collaborative training program between SFSU and Cañada College funded by the Department of Education (DoE) through the Minority Science and Engineering Improvement Program (MSEIP). This program aims to strengthen community college students' foundation in the academic fields of science, technology, engineering and mathematics. Five community college students participated in this program in 2017 and performed research in the earthquake-engineering field. The internship experience enabled the interns to realize how trained civil engineers in the field will have to collaborate with other members on their team. Trained civil engineers will need to make weekly meetings with their supervisor to discuss their progress on their design and provide feedback on what they can improve. They will need to make a detailed plan that they must follow until their deadline when the building must be constructed. The research project could not have been completed by one engineer because it takes teamwork and collaboration on everyone's part to get the project done.

2. Civil Engineering Project

As part of a grant-funded initiative titled *Accelerated STEM Pathways through Internships, Research, Engagement, and Support* (ASPIRES), a ten-week summer group research internship program was held at San Francisco State University in summer 2017. There were six research groups in the program, each group consisting of four to five community college students, mentored by a graduate student and an engineering faculty. One of the groups consisted of five interns who did a structural and earthquake engineering project involving Magneto-Rheological (MR) dampers.

A Magneto-Rheological (MR) damper could operate in the large temperature range, and could produce large control forces at low velocities with a high dynamic range (the ratio between maximum force and minimum force at any given time) utilizing its low power consumption and high-efficiency characteristics. The MR damper, therefore, presents a promising type of seismic control device. Figure 1 shows the schematic of large-scale semi-active damper. However, setting up physical experiments could be very expensive and time-consuming. Multiple numerical models have been studied and developed to simulate the MR damper behavior [5-12]. For the Summer 2017 ASPIRES Program the civil engineering research group investigated four different numerical models of MR dampers including hyperbolic tangent, Bouc-Wen, non-parametric algebraic and viscous plus Dahl models, which are described as following.

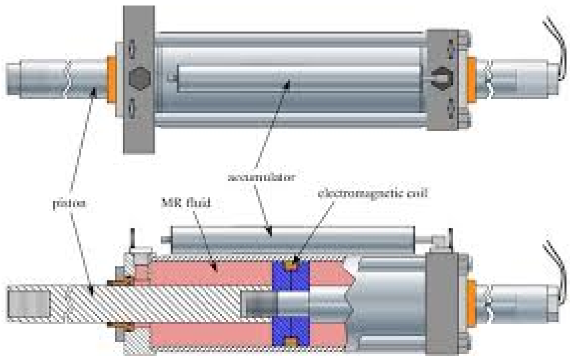

Figure 1. Schematic of Large-Scale MR damper

Hyperbolic Tangent Model: The hyperbolic tangent model was proposed by Gavin, et al. [5] for an 8 kN electro-rheological fluid damper. The hyperbolic tangent model includes two dashpot elements, two spring elements, an inertial mass element, and a Coulomb friction element. The model can be described using the following equations:

$$\begin{bmatrix} \dot{x}_0 \\ \ddot{x}_0 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ \dfrac{-k_0 - k_1}{m_0} & \dfrac{-c_0 - c_1}{m_0} \end{bmatrix} \begin{bmatrix} x_0 \\ \dot{x}_0 \end{bmatrix} + \begin{bmatrix} 0 & 1 \\ k_1/m_0 & c_1/m_0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \end{bmatrix} + \begin{bmatrix} 0 \\ -1/m_0 \end{bmatrix} f_0 \tanh\left(\dot{x}_0/V_{ref}\right) \quad \text{(1a)}$$

$$f = \begin{bmatrix} -k_1 & -c_1 \end{bmatrix} \begin{bmatrix} x_0 \\ \dot{x}_0 \end{bmatrix} + \begin{bmatrix} k_1 & c_1 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \end{bmatrix} \quad \text{(1b)}$$

where m_0 represents the inertia of both the fluid and the moving position; k_0 and $k_1$represent the post-yield and pre-yield visco-elastic stiffness, respectively; c_0 and c_1 represent the post-yield and pre-yield visco-elastic viscous damping, respectively; x and $\dot{x}$ represent the displacement and velocity of damper input; x_0, $\dot{x}_0$, and $\ddot{x}_0$ represent displacement, velocity, and acceleration of damper piston end relative to the inertial mass; the Coulomb friction is a function of the velocity across the element such that $f(\dot{x}_0) = f_0 \tanh\left(\dot{x}_0/V_{ref}\right)$, where the parameter f_0 is the yield force and V_{ref} is a reference velocity; and f is the output force of the MR damper.

Bouc-Wen Model: Bouc-Wen model was first introduced by Bouc [6] and later improved [7]. Dyke, et al. [8] first introduced the Bouc-Wen model to emulate the MR damper behavior. The Bouc-Wen model could be described using the following equations:

$$f = \alpha z + c_0(\dot{x} - \dot{y}) + k_0(x - y) + k_1(x - x_0) \quad \text{(2a)}$$

$$f = c_1\dot{y} + k_1(x - x_0) \quad \text{(2b)}$$

$$\dot{z} = -\gamma|\dot{x} - \dot{y}| \cdot z \cdot |z|^{n-1} - \beta(\dot{x} - \dot{y})|z|^n + A(\dot{x} - \dot{y}) \quad \text{(2c)}$$

$$\dot{y} = \frac{1}{(c_0 + c_1)}\left[\alpha z + c_0\dot{x} + k_0(x - y)\right] \quad \text{(2d)}$$

where k_0 and c_0 represent the stiffness and viscous damping at large velocities, respectively; k_1 represents the accumulator stiffness; c_1 represents damping at low velocities due to bleed or blow-by of the MR fluid between the damper piston and cylinder; x_0 represents the initial displacement of spring k_1; x and $\dot{x}$ represent the displacement and velocity of damper input; y, $\dot{y}$, z, and $\dot{z}$ are evolutionary variables in the function; and f is the output force of the MR damper.

Non-Parametric Model: A non-parametric algebraic model has been applied on MR damper by Choi, et al. [9], Song, et al. [10], and Scianna, et al. [11]. The non-parametric algebraic model could be described using the following equation

$$f = sign(\dot{x})[1 - (e^{-\alpha|\dot{x}|})] \cdot (m|\dot{x}| + b) \tag{3}$$

where m is the slope and b is the y-intercept parameter; $1 - (e^{-\alpha|\dot{x}|})$ represents the shape description function of force-velocity dependence; α simulates the correlation of hysteretic force-velocity relationship; and f is the output force of the MR damper.

Viscous Plus Dahl Model: The Dahl model proposed by Dahl [12] [13] independently for Coulomb frictional behavior description, and represent hysteresis phenomena by Bouc [6]. The viscous plus Dahl model could be described using the following equations

$$\dot{w} = \rho(\dot{x} - |\dot{x}|w) \tag{4a}$$

$$f = \kappa_x \dot{x} + \kappa_w w \tag{4b}$$

where w and $\dot{w}$ represent the nonlinear behavior of the damper; $\dot{x}$ represents the damper piston velocity; κ_x represents the viscous friction coefficient; κ_w represents the dry friction coefficient; ρ represents current independent parameter; f is the output force of the MR damper.

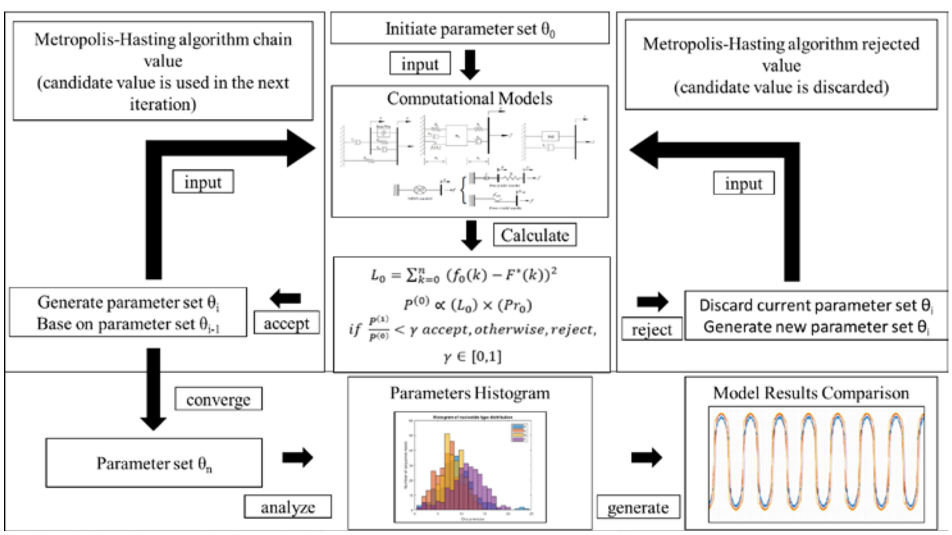

Figure 2. Flowchart of Metropolis-Hasting Algorithm

Probabilistic Estimation of Model Parameters: Bayes' Theorem is a well-known probability event description which is based on existing or known knowledge related to the event. The application of Bayes' Theorem defines the Posterior probability, $P(\theta|D)$, where θ represents the parameter set for given data set D. The Posterior probability could be calculated as $P(\theta|D) = \frac{P(\theta)P(D|\theta)}{P(D)}$, where the Likelihood $P(D|\theta)$ is the probability of realizing an experimental data D given a set of parameters θ; the denominator $P(D)$ is the probability of the evidence and could be considered as a normalizing factor; $P(\theta)$ is the reflected known value of the considered parameters, also called as Prior. The MH algorithm is an improved algorithm based on Markov chain Monte Carlo (MCMC) simulation. The MH algorithm external limitations and targets are set or approximated before the simulation for better efficiency. The Posterior probability is then generated using the MH algorithm. Figure 2 shows a graphical flowchart of the probabilistic approach – MH algorithm as it descripted above.

3. Student Project Findings

After ten weeks of study and research, the civil engineering research group accomplished the scope of the work. The following section presents the result of the project. Figure 3 presents a developed Graphical User Interface (GUI) created by interns using MATLAB. It is an interactive application that could provide a comparison of force vs displacement (hysteresis loop) and force vs velocity for different damper models under different current inputs.

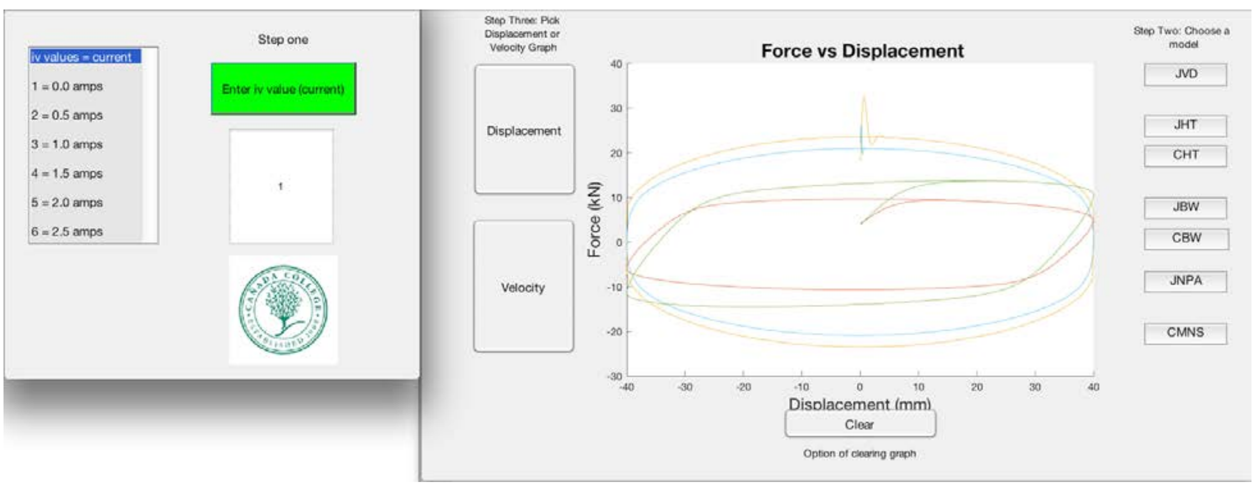

Figure 3. Functioning GUI from interns

Figures 4 (a) to (h) present the results of the simulations for the viscous plus Dahl, the hyperbolic tangent, the non-parametric algebraic and the Bouc-Wen models, for both force-versus-displacement and force–versus-velocity with various current inputs, respectively. Figures 5(a)~(d) present the sensitivity analysis result of the viscous plus Dahl model, non-parametric algebraic model, hyperbolic tangent model and Bouc-Wen model, respectively. The results demonstrate the correlation-based indices of different models for both linear and rank analysis. Figure 5(a) shows k_x as the highest contributed parameter to the viscous plus Dahl model; while k_w and ρ have small negative correlation-based indices, which mean that as kw and ρ increase the output force will decrease. Figure 5(b) presents the non-parametric algebraic model results showing parameter b and m to have relatively higher contribution than alpha. Figure 5(c) presents the ten independent correlation-based indices of Bouc-Wen model. The result shows parameter c_0 show relatively high sensitive; α and A show relatively moderate sensitive; k_0, k_1,

c_1 and x_0 relatively low sensitive; β and γ show negative indices. Figure 5(d) presents c_1 as the relatively high sensitive parameter; the m_0, f_0 and V_{ref} are relatively moderate sensitive parameter; while k_0 and c_0 are relatively low sensitive parameters; and k_1 is the negative indices.

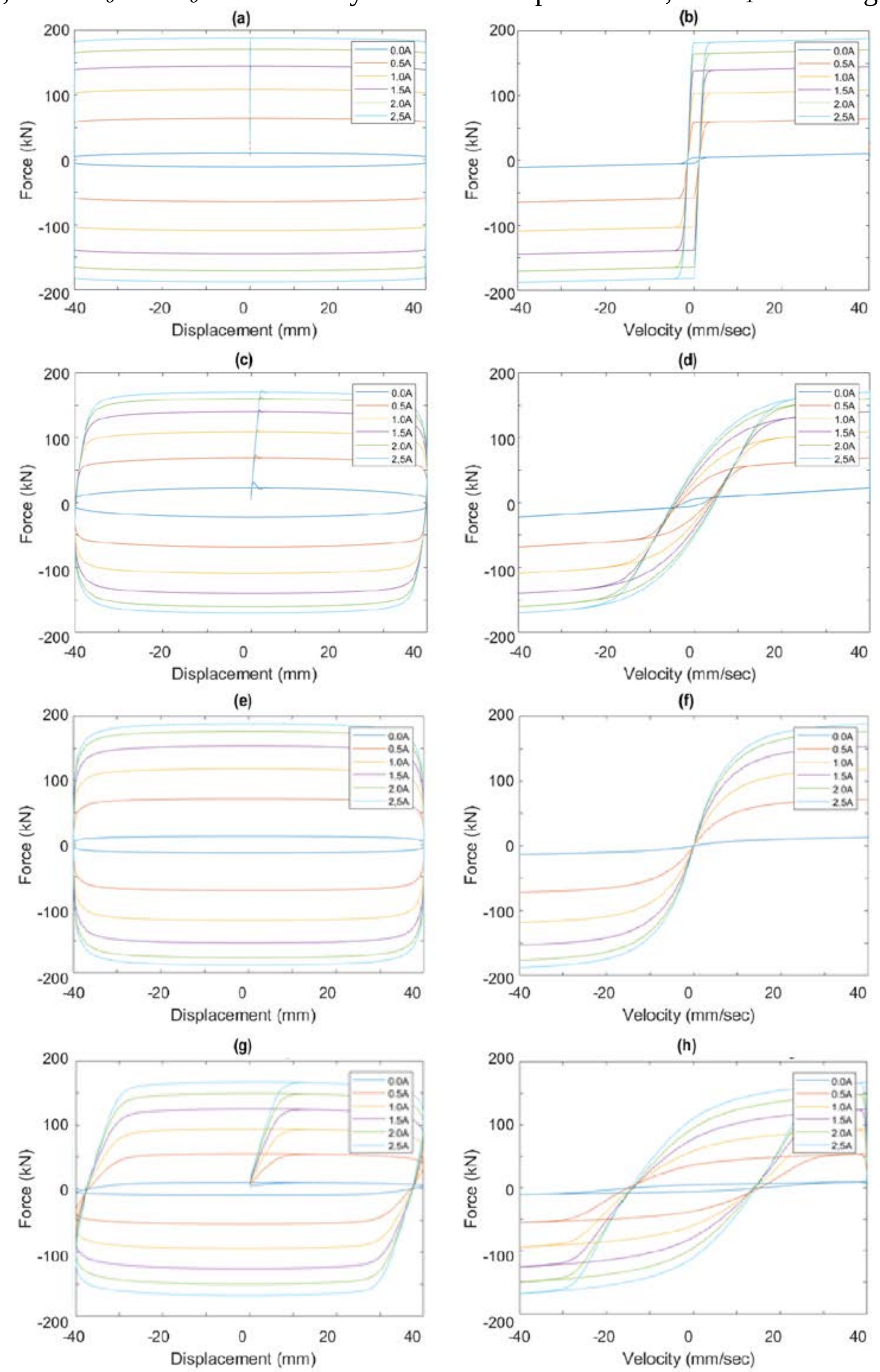

Figure 4 Force-Displacement of (a) Viscous Plus Dahl, (c) Hyperbolic Tangent, (e) Non-Parametric Algebraic, (g) Bouc-Wen Model; Comparison of Force-Velocity with Various

Current Inputs of (b) Viscous Plus Dahl, (d) Hyperbolic Tangent, (f) Non-Parametric Algebraic, (g) Bouc-Wen Model

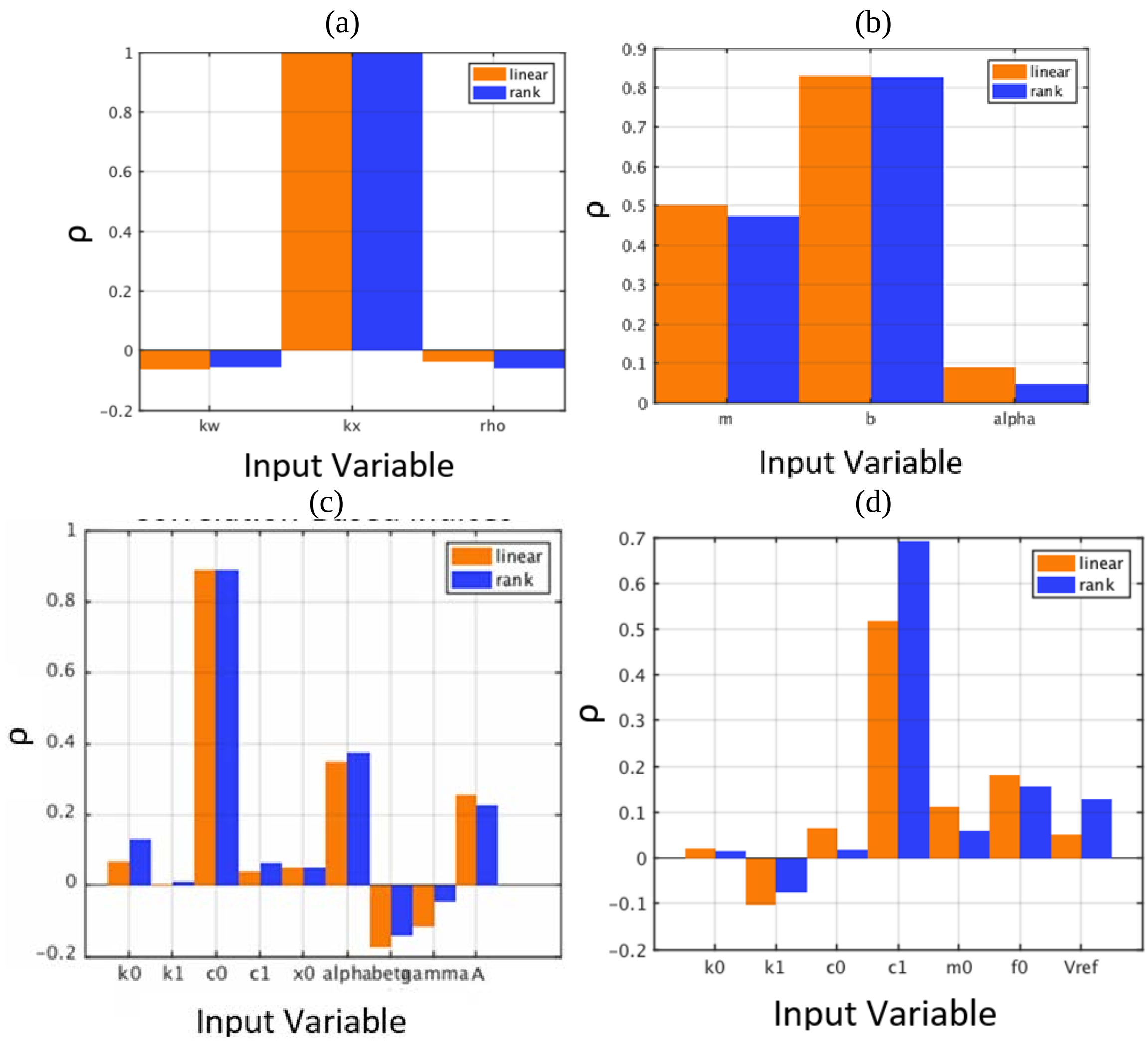

Figure 5. Correlation-Based Indices for (a) Viscous Plus Dahl (b) Non-Parametric Algebraic (c) Hyperbolic Tangent and (d) Bouc-Wen Model

Figure 6 presents the non-parametric algebraic model output force comparison using deterministic parameters [14] (red line), probabilistic mean parameters identified by Caicedo *et al.* [15] (green line), probabilistic mean parameters identified by Liang *et al.* [16] (blue line) and experimental data (purple line). It can be observed that probabilistic mean parameter is closer to experimental data in this case.

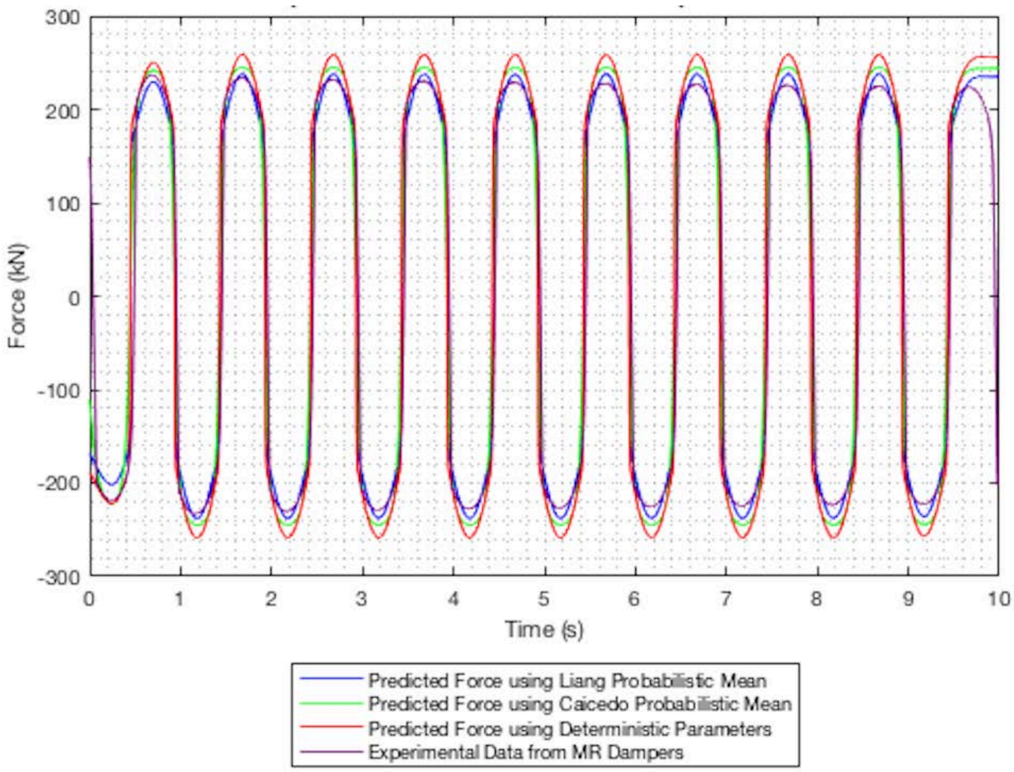

Figure 6: Non-Parametric Algebraic Model Output Force Comparison

4. Project Assessment

To obtain a quantitative assessment of the project and further improve the project in the future, an exit survey was conducted for all student participants. Students were asked to rate their level of agreement with each question in a five point scale: 1 – Not at all useful; 2 – A little; 3 – Some; 4 – Quite a bit; 5 – A lot. 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?

Activity	**Average Rating**
Gain hands-on experience in research	4.09
Gain skills needed to successfully complete a BS degree	3.88
Clarify whether I wanted to pursue a STEM research career	4.06
Have a good intellectual challenge	4.34
Read and understand a scientific report	4.03
Write a scientific report	3.97
Ask good questions related to the scientific process	3.97
Work with others to plan and conduct scientific experiments	4.09
Talk to professors about science	4.00

Think like a scientist	4.03

Question: Tell us how much you agree with each of the following statements.

Activity	**Average Rating**
I was able to conduct the scientific research that is part of my summer internship.	4.28
I am confident I will transfer to a four year institution.	4.78
I am confident I will complete a BS in a STEM field.	4.69
I can imagine myself continuing after my BS to pursue a Master’s Degree.	4.38
I have skill in interpreting results.	4.22
I have tolerance for obstacles faced in the research process.	4.38
I am ready for more demanding research.	4.28
I understand how scientists work on real problems.	4.13
I understand that scientific assertions require supporting evidence.	4.53
I have the ability to analyze data and other information.	4.25
I understand science.	4.28
I have skill in how to give an effective oral presentation.	4.31
I have skill in science writing.	4.16
I have self-confidence.	4.22
I have the ability to work independently.	4.50
I am part of a learning community.	4.34
I have a clear understanding of the career opportunities in science.	4.28

When asked the question "what do you like most about the NASA CIPAIR Internship Program?' Typical response from the civil engineering group students are: “I like the fact that we work in a group on a research project. We gain the experience and knowledge of working as a group.” “The problem that we were given was a graduate level problem for student civil engineers. This project helps us advance our skills in civil engineering.” These specific feedbacks from interns more convincingly prove that the ten-week internship benefits the interns by not only better understanding their future career but also engaging them in a collaborative environment.

5. Summary and Conclusion

The ASPIRES 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 proved to increase student motivation and persistence – especially as they struggle through the first two years of the engineering curriculum.

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conclusions and recommendations expressed in this paper are those of the author and do not necessarily reflect those of the sponsors.

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