Warren J. Baker Endowment for Excellence in Project-Based Learning Robert D. Koob Endowment for Student Success

PROPOSAL NARRATIVE

I. Abstract

Existing methods of evaluating buildings after a seismic event rely on destruction of architectural elements such as cladding, partitions, and ceilings in order to inspect structural members. Evaluations are done by visual inspection with no quantitative data. Current faculty and student research focuses on the application of Forced Vibration Testing (FVT) for assessment of buildings after a seismic event. This non-destructive method involves temporary instrumentation to record building behavior.

The Bridge House, located in Poly Canyon, is a structure with removable braces that simulate structural damage. This proposed research will use FVT to investigate damage detection in the Bridge House by adding and removing braces. It is hoped that this research will lead to an accurate method of damage detection that can be applied in the wake of a major seismic event. The findings will become a part of the principal applicant's Master's thesis and will be disseminated in a conference paper and presented at the American Society for Engineering Education (ASEE) Conference in Seattle in June 2015. Further, this research will allow for unique project-based, peer-learning opportunities for undergraduate students enrolled in ARCE 483 and ARCE 412 where undergraduate and graduate students will work collaboratively to test buildings. Funding is sought to cover expenses for required data acquisition equipment and conference travel.

II. Introduction

The Bridge House is a one-story steel structure spanning a forty-eight foot ravine in

Poly Canyon. In 2011, the Bridge House was rehabilitated by students who made facility repairs and added removable braces that simulate damage, and now serves as a dynamic earthquake field laboratory for the ARCE department.


Figure 1: Bridge House after completion (Left), Location of additional braces (Right)

The use of the field laboratory originates from research by ARCE faculty Peter Laursen, Graham Archer, and Cole McDaniel. They have successfully used low-level vibrating shakers and digital data acquisition to predict building dynamic properties. Vibrations due to shaking, while undetectable to humans, are recorded by highly sensitive accelerometers. It is assumed that an intact structure is represented when all braces are engaged. Removing braces simulates damage to the structure, i.e. failed braces. A dis-engaged brace is shown in figure 2.

Figure 2: Close-up of removable brace

The FVT methods pursued by Laursen, Archer and McDaniel have been successfully applied to detect changes in the dynamic behavior [1] [2] [3] [4] [5]. However, in predicting the extent of damage to a building, further research is necessary to establish a robust method. The method developed is unique and allows for quick and cost-

efficient building assessment to determine the safety of a building. The proposed research will be conducted by the applicants with supervision of ARCE faculty members Laursen, Archer and McDaniel.

The FVT research to date is deeply integrated in the Architectural Engineering capstone analysis class, ARCE 483, *Seismic Analysis and Design.* Students create analytical models and predict the building dynamic behavior, and subsequently test the physical structure to compare theoretical results to experimental results

III. **Objective(s)**

(1) To accurately predict structural damage in buildings based upon the FVT procedures.

(2) To share the findings at the ASEE Conference.

(3) To raise awareness of the Forced Vibration Testing method developed for post-earthquake mitigation and recovery.

(4) To integrate practical research into senior ARCE classes.

IV. **Methodology**

Experimental testing is done through the use of low-intensity vibrating shakers and accelerometers When calibrated at resonance for a particular building, the shaker is capable of producing vibrations that, while undetectable to humans, are easily detectable by accelerometers. These accelerations are directly dependent on the health (integrity) of the building's structural system. To predict building damages, removable braces are used. To simulate a brace that has been damaged in a seismic event, the brace is unbolted from the structure. Testing is performed by applying the shaker at the roof of the Bridge House. Acceleration measurements are recorded at multiple locations on the building. Acceleration measurements at 9 locations need to be investigated simultaneously. After data is recorded, the process is repeated with a new brace configuration.

Figure 3: Shaker, accelerometer, data acquisition, & computer

The accelerations and relative displacements found during testing will be used to create an experimental representation of the building. By comparison to theoretical computer models, a confidence metric will be established that will reveal which braces are most likely to be "damaged" (or dis-engaged) in the structure.

V. Timeline

November 2014	Design of test procedures
December 2014	Acquire equipment, Create computer model of building
January 2015	Perform experimentation on building, Preliminary data processing
February 2015	Perform experimentation on building
March 2015	Perform experimentation on building
April 2015	Finish experimentation
May 2015	Final data processing
June 2015	Attend ASEE Conference
September 2015	Create report to Baker and Koob Learn by Doing Endowment
October 2015	Submit and finalize report

VI. Final Products and Dissemination

The research outlined above will be published. In addition to publication, this research will contribute future advancement of "Damage Detection Using Forced Vibration Testing" as developed by Laursen, Archer, and McDaniel. Research to date has been successful in detecting building damage. However, further testing and development are needed to establish legitimacy for post-earthquake evaluation. It is hoped that this method will be applied for damage detection in the wake of the next large seismic event in California.

This research will also contribute to the principal applicant's thesis in partial fulfilment of a Master of Science in Architecture with a Specialization in Architectural

Engineering. This applicant's anticipated graduation and thesis completion is Fall 2015.

Lastly, the research done on the Bridge House will further be integrated into the Architectural Engineering department curriculum, notably ARCE 412 and ARCE 483. The Bridge House acts as a dynamic field laboratory where students are able to test the structure, change the building, and discover how these changes impact building behavior. This one of-a-kind building is unique to Cal Poly and embodies our Learn-By-Doing philosophy. This research will both utilize the opportunities this building provides and enhance the understanding of building dynamic behavior of future Architectural Engineering students.

VII. Budget Justification

$2000 is budgeted for conference and travel fees for the ASSE Conference in Seattle in June 2015: $700 for conference fees and $1300 for transportation and accommodation.

$3000 is budgeted for new equipment: $1700 for a data acquisition unit made by *National Instruments*, $1100 for two accelerometers made by *PCB*, and $200 for cables and misc. hardware. The equipment will complement 2 data acquisition units and 7 accelerometers already in our possession, as it is essential to record 9 accelerations simultaneously to obtain concurrent real-time data. In addition, the equipment will further be utilized for undergraduate learn-by-doing activities.

[1] Ramos, P., "System Identification of a Long-Span Building Structure." Master's Thesis. California Polytechnic State University, San Luis Obispo, 2011. digitalcommons.calpoly.edu/theses/944.
[2] Gerbo, E., "Structural Damage Detection Utilizing Experimental Mode Shapes." Master's Thesis. California Polytechnic State University, San Luis Obispo, 2014. digitalcommons.calpoly.edu/theses/1247.
[3] Archer G.C., McDaniel C.C. "An Experimental Study of Damage Detection Using Removable Braces." Tenth U.S. National Conference on Earthquake Engineering, 2014.
[4] Archer G.C., McDaniel C.C. "Determination of Building Modal Parameters Using Low-Level Excitation", presented at the Architectural Engineering Conference, Oakland 2011.
[5] Rendon A.R., Archer G.C., McDaniel C.C.. "Ultra-Low Forced Vibration Testing of a Large Building", presented at 15th World Conference on Earthquake Engineering, Lisbon 2012.

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CAL POLY

PROPOSAL BUDGET

Student Applicant(s): William Rosenblatt, Joshua Raney, Simon Jardel-menno	
Faculty Advisor: Peter Laursen	
Project Title: Poly Canyon Bridge House - Damage Detection Using Forced Vibration Testing	**Requested Baker Endowment Funding**
Travel *subtotal*	$
Travel: In-state	$
Travel: Out-of-state	**$2000**
Travel: International	$
Operating Expenses *subtotal*	$
Non-computer Supplies & Materials	$
Computer Supplies & Materials	**$3000**
Software/Software Licenses	$
Printing/Duplication	$
Postage/Shipping	$
Registration	$
Membership Dues & Subscriptions	$
Multimedia Services	$
Advertising	$
Journal Publication Costs	$
Contractual Services *subtotal*	$
Contracted Services	$
Equipment Rental/Lease Agreements	$
Service/Maintenance Agreements	$
TOTAL	**$5000**

CalPoly Department of Architectural Engineering

Memo

To: Whom it may concern

From: Prof. Peter T. Laursen

CC:

Date: October 24, 2014

Re: Letter of support for William Rosenblatt et al.

This memo serves as a letter of support for Rosenblatt's team's funding application to the Warren J. Baker Endowment for Excellence in Project-Based Learning and Robert D. Koob Endowment for Student Success.

Having taught William in several courses at CalPoly, including mechanics of structural members and structural analysis, I have found him to be an intelligent and dedicated student. His questions in class and in my office hours were insightful and well thought out. In every class William has had with me, he has performed very well.

As such, William is currently pursuing a Master's of Architecture degree and I am pleased to be the advisor. Graham Archer and Cole McDaniel are his co-advisors. His research is in system identification and damage detection. To that end, he will be the lead researcher in conducting forced vibration testing on the Bridge House structure in Poly Canyon. In early winter, the students expect to begin to apply a Forced Vibration Testing protocol to the structure to investigate using mode shapes alone to predict damage detection. William, being the lead of the collaborative team-based project, is resourceful and generally only comes to me with solutions – not problems. He learns quickly, is motivated and has a voracious appetite for learning. ARCE student Simon Menno and ARCH student Joshua Raney will be participating in the research as a part of their structural electives.

The ultimate goal for using Forced Vibration Testing for Damage Detection is to assess the structural integrity of buildings after a seismic event. This non-destructive method involves temporary instrumentation to record building behavior. I believe the proposed research will contribute significantly to legitimizing this inexpensive method for building damage detection readily deployable in the wake of the next large seismic event in California. A project like this has the potential to alter the current methods of building inspection because the equipment is inexpensive, mobile and rapidly deployable, and the method is expected to produce robust results within days.

William strongly feels that the findings should be disseminated to a broader audience. In addition to documenting this research in his Master's thesis, he anticipates writing a paper for and attending the ASEE conference in Seattle next June. I strongly support the request for funding for instrumentation and conference attendance from the Warren J. Baker Endowment for Excellence in Project-Based Learning and Robert D. Koob Endowment for Student Success.

Sincerely,

Peter T Laursen

Peter Laursen, PhD
Associate Professor
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