AC 2011-2159: BRINGING CURRENT RESEARCH TO THE CLASSROOM USING LINKED COLUMN FRAMED SYSTEM IN AN UNDERGRADUATE STRUCTURES LAB

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Abstract

This paper describes a hands-on and demonstration-driven learning opportunity at the undergraduate level for students to understand and experience the design philosophy of relying on "plastic deformation" of structural members in seismic design of buildings. This research was brought to a junior level structural analysis, design, and experimentation classroom at a predominantly undergraduate institution with i) design project, ii) scaled demonstration models developed by students and iii) structural testing of scaled-down models. The design project introduces newly researched novel structural system as an alternative to moment frame, as a lateral load carrying system in a typical multistory building. The students built scaled structural models of the Linked Column Framed (LCF) system, a recently developed structural frame system, using vinyl materials for gravity members and metal replaceable clips for the yielding links as an instructional tool to explain the general concepts of ductility and the mechanism behind the new seismic resisting system. These models were placed on a small instructional shake table and excited by earthquake records. The tests were developed to demonstrate how the LCF structure deforms at pre-designated weak but replaceable links (via inexpensive paper clips of the models), while retaining the gravity load carrying capacity of the frames.

Students are able to grasp the concepts of not just the new lateral load resisting system (Linked Column Frame), but also learn to understand the intended inelastic response of structures caused by seismic shaking through a hands-on model in general. Through the multistory building design project, undergraduate students see the big picture of how a new lateral load resisting system can be used as an alternative to a conventional lateral load carrying system. This paper documents details of the course as well as the course assessments conducted.

Introduction

The objective of this paper is to demonstrate how a NSF/Network for Earthquake Engineering Simulation Research (NEESR) project on performance-based structural design for earthquake loading was brought to civil engineering undergraduate classroom at a predominantly undergraduate institution, California State University at Los Angeles. This learning experience was achieved, through a design project, hands-on demonstration models, and experimentation on a small instructional shake table. The NSF/NEESR funded research project focuses on the development of a new structural steel system that is free of diagonal bracings and capable of rapid return to occupancy after a seismic event. This lateral system is referred to as the Linked Column Framed (LCF) system and consists of dual columns with replaceable link beams and a secondary moment frame. The inelastic lateral behavior of the system is provided by having the links yield primarily in shear under predetermined levels of lateral demands. This protects the
columns and beams that carry the gravity loads. The rapid return to occupancy is then achieved by replacing the damaged links. To demonstrate the viability of the system, large scale seismic testing will be conducted at a NEES Laboratory following extensive modeling and component testing.

Students learning initiatives in earthquake engineering have been pursued by many academics such as Einde[1]. Parallel to these, research is continually working on advancing the state of earthquake engineering knowledge and applications through cutting edge research. One such initiative is the research in Linked Column Frame (LCF) system [2,3] as an alternative to the traditional moment frame system for lateral resisting frames for earthquake loads. Currently, there is a tremendous demand for bringing civil engineering research results to undergraduate classrooms. This paper addresses the initiative associated with the LCF research project. The NSF/NEES funded research project focuses on the development of a new structural steel system that is free of diagonal bracings and capable of rapid return to occupancy after a seismic event. The lateral system referred to as Linked Column Framed (LCF) system consists of dual columns with replaceable link beams and a secondary moment frame. The inelastic behavior of the system is provided by having the links yield primarily in shear under predetermined levels of lateral demands. This protects the columns and beams that carry the gravity loads. The rapid return to occupancy is then achieved by replacing the damaged links. The paper addresses how the concepts of this multi-university state-of-the-art research were brought to a junior level civil engineering classroom.

The Course

The successful development and implementation of learning experience at a predominantly undergraduate institution, California State University at Los Angeles, were made possible with close collaboration of the two partner research institutions, Portland State University and University of Washington, where majority of the research on LCF system has been conducted. The course selected to introduce research related concepts was a junior level civil engineering laboratory course, CE382 “Computer Aided Structural Analysis, Design and Experimentation Laboratory.” The prerequisites for the course are i) Strength of Materials Laboratory and ii) Introduction to Structural Design. The catalog description for the course includes “Computer Aided Structural Analysis and Design using structural simulation software as encountered in practice. Computer aided structural experimentation and comparison of structural experimentation with structural analysis software.” This is a 3 hour laboratory course that includes the use of software and experimentation. The software used for structural analysis and design is SAP 2000 [4] simulation program.

The student learning outcomes for the course are knowledge of engineering principles (abet a), knowledge of current design specifications, and knowledge of computer aided structural analysis and design. In addition, skills outcomes for the course are the ability to identify, formulate, and solve structural engineering problems (abet e), ability to plan and design a system, component or
process that meets desired needs (abet c), ability to use techniques, skills, and modern engineering tools necessary for engineering practice, including computer tools and information technology (abet k), and the ability to design and conduct experiments as well as to analyze and interpret data (abet b).

The course topics include computer aided structural analysis of trusses, structural design of trusses, computer aided structural analysis of 2D-frames for gravity and lateral loads and load combinations, computer aided structural design of 2D-frames, setting up of an experiment on a small shake table and dynamic experimentation, computer aided structural dynamic analysis with time history, and verification of computer aided analysis results with experimentation.

This is a relatively new course, and it has been traditionally taught with a roof truss example and a moment frame example. This analysis includes gravity and lateral loads. In addition, the design includes an experiment on a shake table for a single degree one-bay-one-story metal frame. For the first time in Fall 2010, with the objective of applying research concepts to classroom through this course and to explain the difficult concept of plastic deformation in earthquake engineering, a linked column frame (LCF) was introduced to the course as a project example. This dealt with two prong approaches:

i) Analysis and design: For a three story building, both moment frames and Linked Column frames (LCF) were used as alternative design for lateral load carrying system and the results were compared. This provided students with an insight into LCF frames as well as the frame’s advantages and disadvantages.

ii) A student-built scaled-down vinyl model of a LCF frame was tested on a small instructional shake table to demonstrate the natural period of the structure, concept of resonance due to shake table excitation with different frequencies, and acceleration amplification of story floors due to shake table excitation of sample scaled earthquakes such as Kobe, and to demonstrate how earthquake engineering design relies on plastic deformation. Figure 1 depicts the SAP2000 model used for analysis and design. It also shows how the scaled down LCF frame corresponds to a real LCF frame. The instructional structural model was used with an educational shake table to demonstrate behavior of a performance based designed lateral load resisting frame system to support student learning. The linked column frame system is an alternative lateral resisting system intended to rapidly return to occupancy through link replacements following a major earthquake.

With the above objectives, the course project dealt with three parts:

i) For a three story building with gravity and lateral loads, analysis and design of a lateral load carrying traditional moment resisting frame will be used in a computer aided design (SAP 2000.) A sample student work on moment resisting framed model is depicted in Figure 2.
ii) For the same building and loads, analysis and design of a lateral load carrying linked column frame (LCF) will be used in a computer aided design (SAP 2000). This will be compared with traditional moment frame. A sample of a student’s work on the LCF model is depicted in Figure 3.
Experimentation on a shake table using a scaled down sample model of a LCF of vinyl material was used to demonstrate resonance, study acceleration amplification at the story floors due to earthquake excitations, and to observe any plastic behavior of sacrificial links in the LCF system. The model used on the shake table is shown in Figure 4. Also shown in Figure 5 is a sample plot of acceleration amplification curves for various floors compared to shake table accelerations of scaled Kobe earthquake on the instructional shake table. Figure 6 depicts an visual demonstration of the “plastic deformation” concept for the weak links after an earthquake activity on the LCF model as the links that started as undeformed straight before the earthquake now have permanent deformation. The link that connects two closely spaced columns provides the students a visual clue of permanent plastic deformation.
Figure 5: Plot of acceleration vs. time for different floor levels of the instructional model

Figure 6: Observed inelastic deformation at weak link after the experimentation
Course Assessment

Two practicing professional engineers with P.E. licenses assessed the three part student project reports based on the student learning outcomes for the project. Out of 21 student projects in the class, the first four in the class roster were selected for assessment. Both evaluators assessed all the four student project reports. The weighted average scores (similar to GPA calculations) for each outcome were calculated. A summary of assessment results are as follows for the sample of four students in the class. On a scale of 0 to 4 the assessed students reports received weighted average ratings of 3.0 or higher for knowledge outcome, knowledge of computer aided structural analysis and design, and skills outcome use of modern engineering tools such as computer tools (abet outcome k). Since part of the course centers around computer aided structural analysis and design these indicate positive assessment for the course. Also the assessed reports received ratings of between 2.5 to 3.0 for knowledge outcomes structural engineering principles (abet outcome a) and structural design specifications. Also results were between 2.5 to 3.00 for skills outcomes ability to identify and solve structural engineering problems (abet outcome e), and ability to design and conduct experiments (abet outcome b). These indicate success but should be improved. The knowledge outcome knowledge of structural design specifications and skills outcome ability to plan and design a component or a process (abet outcome c) received a rating of 2.50. These two outcomes were selected as areas of possible improvement for the course as the course also centers on design aspects.

The comments made by the evaluators, state that the student strengths were the recognition of lighter steel sections and better drift controls for LCFs as opposed to moment resisting frames, and good understanding of the concept of resonance in structural dynamics through the experimentation. They also commented on the need to expand on discussion on replacement ability of weak links after a major earthquake, and difference between the moment frames and LCF frames. A very important suggestion they made is to have the experimental component and the analysis and design component of the project to be on the same laboratory model. The current project deals with a practical large scale building design example for the analysis and design component and a small laboratory model and experimentation to understand the concepts behind design practice.

Based on the course assessment results the project component of the course has been modified for the offering in Winter 2011. The modified design project for the course deals with the same experimental model, and the students would perform computer structural simulations on the same model as the experimental model. This will allow the students to have a better understanding of theoretical concepts, and structural behavior as they are able to compare computer structural simulations with experimental results in the laboratory. This change is expected to improve the ratings on course outcomes that received marginal assessment scores such as ability to design components and processors, design specifications, design and conduct experiments, and ability to identify and solve structural engineering problems, listed above.
Conclusions

The paper presented a first time implementation of the Linked Column Frame (LCF) structural system concept as a project in a computer aided structural analysis, and design and experimentation classroom at a predominantly undergraduate institution. Using the project assessment by practicing engineers, the project has been modified in the future course offerings. Through this project course, a broader learning opportunity for the students to understand and experience the earthquake design philosophy of relying on "plastic deformation" in seismic design of structures with hands on experience has been achieved. Also, the scaled model demonstrate the fundamental concepts behind the research project, advantages of using controlled inelastic behavior of structures, and the ability to rapidly return to occupancy following a major earthquake via sacrificial link replacement.

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