AC 2007-2315: DEVELOPMENT OF AN INNOVATIVE STRUCTURAL TESTING LABORATORY TO ENHANCE EXPERIENTIAL LEARNING

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Development of an Innovative Structural Testing Laboratory to Enhance Experiential Learning

Abstract

At the advent of the third millennium, more demand has been placed on the civil engineering profession to tackle the complex activities of renovating aging infrastructures. The structural design of such facilities has to be multidisciplinary and robust so that integration with advanced technological developments can occur. To prepare the next generation of engineers so that they can meet these challenges, the School of Engineering and Computer Science at the University of the Pacific has committed to build an innovative structural testing lab to support the civil and mechanical engineering programs.

This paper addresses the development of a new lab that is to be used collaboratively by students, faculty, and industry. This lab is planned to support experiential learning and traditional classroom pedagogy including lab instruction. Currently, the civil engineering curriculum covers four areas: construction, environmental, hydraulics, and structures. Three of which are supported by hands-on labs except for the structural engineering area. The new lab will support structural engineering and integrate teaching and research in structural and construction engineering.

This paper also summarizes the lessons learned and the innovative aspects of the planning and design phases of this laboratory. This lab facility will be providing valuable information about the economics and technical challenges to support its mixed use of teaching and research. Students will benefit from this facility by having education in an applied structural and materials testing environment.

The lab features a unique layout and spacing arrangement of anchors to fully take advantage of the limited floor area. We are currently in the process of procuring the structural testing equipment, which will include innovative systems to integrate teaching and research. Upon its completion, this lab will become a benchmark for integration of teaching and research in the United States.

The lab is also needed to support two tiers of courses; one tier includes the engineering science courses statics and strength of materials; and the other tier includes engineering analysis and design courses, such as structural analysis, steel and concrete design, earthquake engineering, materials for construction, heavy construction, and the capstone/synthesis course. This lab will boost instruction in structural engineering, construction, materials science, and mechanical engineering; and will cultivate research and collaboration with industry partners for technology transfer and to bring solutions from lab to practice. Undergraduate and graduate students and researchers will be able to invent, plan, assemble, build, test, study, analyze, learn, and discover innovative solutions to some of the most pressing problems facing our aging infrastructure. This will significantly enhance integration of the pedagogy and scholarship in the civil and mechanical engineering programs.

Key words: Anchors, strong floor, pedagogy, construction engineering, structural engineering, technology transfer, and integration.
Introduction

The School of Engineering and Computer Science at the University of the Pacific has undergraduate facilities and laboratories that you would expect to find at one of the best engineering and computer science universities. They include over 12 instructional laboratories, 24-hour student computer facilities, undergraduate research laboratories, the Cooperative Education Center, and Multicultural Engineering Program (MEP) Center.

Currently, the civil engineering curriculum covers four areas: construction, environmental, hydraulics, and structures. Three of which are supported by hands-on labs except for the structural engineering area. The new lab will support structural engineering and integrate teaching and research in structural and construction engineering. This paper addresses the development of a new lab that is to be used collaboratively by students, faculty, and industry. This lab is planned to support experiential learning and traditional classroom pedagogy including lab instruction.

The conceptual planning phase of this lab started several years ago. The School of Engineering and Computer Science established a financing strategy to support the various developmental stages of this ambitious project. In early 2005, major planning activities were undertaken by the Dean and Faculty to provide and collect all information relevant to the construction and operations of this lab. In summer 2005, the initial planning was completed after major discussions and collaboration with major structural labs including the ones at UC Berkeley, University of Nevada Reno, UC San Diego, Simpson Strong Ties, MTS, and others. During this process, lessons learned from other labs helped create a final plan to develop a unique state-of-the-art facility with many strengths and long-term benefits to the School.

By the end of Summer 2005, a structural design firm was hired to perform the structural calculations of the strong floor and all its ancillaries. The design phase took several months and major modifications and fine-tuning of the original design were adapted. Several constraints posed a number of threats and opportunities for this project. These constraints ranged from spatial limitations in terms of height and area to other access issues and special pedagogical and research needs that were integrated in the design specifications. One of the major aspects of this lab is the evolution of the design of the anchors and their layout. Anchors had to go through a comprehensive design process with multiple iterations of reviews and adjustments. To design the most effective anchors and to provide the necessary strength and utility for future experiments, concerns about fabrication, construtability, and certainly cost arose. The evolution of the anchor design and fabrication will be discussed in detail in the following sections.

The lab features a unique layout and spacing arrangement of anchors to fully take advantage of the limited floor area. We are currently in the process of procuring the structural testing equipment, which will include innovative systems to integrate teaching and research. Upon its completion, this lab will become a benchmark for integration of teaching and research in civil engineering.
Functional Components of the Structural and Construction Laboratory

The lab is planned and designed while having the following strategic goal in mind: “To provide students and local/regional engineering/building/construction industry with superior technology and world-class testing and research capability.” It contains three modules. Module 1 has the MTS facility, versatile structural testing facility, and scaled bridge testing and monitoring systems. The second module has the virtual construction simulation models using automated remote monitoring system with 3-D/Walkthru capability and heavy construction equipment. The third module contains the damage assessment and concrete repair facility in addition to destructive/nondestructive testing tools of scaled systems. Figure 1 illustrates the three components at the conceptual level. The emphasis in this paper will be on module 1 as it relates the structural testing facility.

Figure 1: Conceptual Design of Laboratory Components
Pedagogical, Research, and Industry Interaction

In Civil Engineering at the University of the Pacific, undergraduate students are always looking for educational undertakings that connect theory and practice by finding solutions to real engineering challenges. This task helps to achieve the learning objectives of the underlying lab as described above. The structural and construction research laboratory will be engaged in research that will support the various pedagogical activities within the department in the areas of structural testing and experimental mechanics. The variety of testing that will be undertaken involve full- and small-scale tests of steel, concrete, masonry, and composite structural components. Various advanced equipment such as MTS frames and controllers will support such functions. Other facilities will include 1000 square feet of 4-foot thick high strength concrete that is heavily reinforced, hydraulic testing systems, MTS testing machines, reaction blocks, frames, different sizes portable hydraulic rams, a gantry crane, and a forklift. The previous testing equipment will be supported by a computerized data monitoring and acquisition systems.

The laboratory is planned to provide a satisfactory learning experience while meeting an existing need and reaching a deeper understanding of the interplay between pedagogy, research, and industry. Hands-on experience in the structural testing area will help engineering students, primarily in civil and mechanical to develop a holistic view of and initial competency in structural engineering design. This is achieved by following a full learning cycle of conception and envisaging, designing, fabrication and testing of structural components that will eventually aid in complex real life applications. This lab is located next to a machine shop that is used for a variety of applications in manufacturing and design of mechanical systems. The lab is planned and executed while keeping in mind that all facilities are available to instill a spirit of innovation from conception to application, and to foster prolific linkage between industry and research. However, the latter two paradigms will strongly support the pedagogical objectives via a number of classes and learning modules that are based on active balance of lectures and experiential tasks.

As a result, feedback from faculty within and outside the university as well as input from industry professionals yielded valuable input on how to best equip and manage the lab operations and to sustain its funding. On the pedagogical side, the lab will support two tiers of courses as shown in Figure 2. One tier includes the engineering science courses such as statics (ENGR 20), dynamics (ENGR 120), and mechanics of materials (ENGR 121). The other tier includes engineering analysis and design courses, such as structural analysis (CIVL 100), steel (CIVL 165), concrete design (CIVL 166), earthquake engineering (CIVL 167), heavy construction methods (CIVL 151), and the capstone/synthesis course (CIVL 180). Several other courses will benefit from this lab including research seminar (CIVL 197), special topics (CIVL 193), experimental methods (MECH 110), engineering design/senior project (MECH 141), and a variety of independent study courses (CIVL 191). Given these pedagogical benefits, this lab will boost instruction in structural engineering, construction, materials science, and mechanical engineering; and will cultivate research and collaboration with industry partners for technology transfer and to bring solutions from lab to practice.
This lab will support a wide spectrum of important structural tests such as static & fatigue testing, static deflection testing, dynamic testing, block loading, bridge loading, impulse loading, cyclic loading, tension and compression, bending and buckling tests, compression ASTM C39, flexure ASTM C78, sorptivity, abrasion ASTM C779, linear & torsional loading, scaling ASTM C672, biaxial fatigue testing, pseudodynamic and low frequency testing, and others. Please see Figure 2 for a full list of testing.

With the industry support in the region, undergraduate and graduate students and researchers will be able to invent, plan, assemble, build, test, study, analyze, learn, and discover innovative solutions to some of the most pressing problems facing our aging infrastructure. This will significantly enhance integration of the pedagogy and scholarship in the civil and mechanical engineering programs.

Figure 2: Overall Schematic of the Lab Pedagogical and Research Interactions
Lab Description and Design Issues

All design criteria and specifications were discussed and agreed upon with the designer. The crucial component of this laboratory is the strong floor that measures about 25 by 40 feet, and whose thickness is 4 feet. A decision was made to increase the thickness from 3 feet to 4 feet for long-term use and enhancement of strength. As a result, stiffness may be increased significantly, and deflection can be reduced by approximately 70% according to the designer. Such thickness increase will add modestly to the cost and therefore it was economically justified based on the long-term benefits reaped. Figure 3 illustrates the general layout of the strong floor in relation to the surrounding facilities and other access limitations.

![Figure 3: General Area Layout and Spatial Limitations](image)

The design strength of the strong floor concrete is 5000 psi. The lab will uphold static testing of actuators’ capacity of 100 to 220 kips. On the other hand, dynamic testing will require large pumps and cooling system. However, the strong floor should be able to handle dynamic loading. A variety of crane options were discussed and a decision to buy gantry crane was reached. Other facilities include a staging area, a rollup door with a
man-door, reaction blocks, pump station area, cooling tower; and most importantly anchors with all fitting, couplings, and caps.

Structures will be bolted to the surface of the strong floor, and then powerful hydraulic actuators will be used to exert forces on them. There are 280 holes that are carefully placed in the strong floor. The holes will have anchors embedded to allow the bolting of testing machines and structures being tested. The evolution of the anchors’ design and fabrication, as well as their innovative features are described in the following sections.

The reaction blocks are essential to provide the necessary support between the testing facility and the strong floor. Each has to be designed not to exceed 4 tons and its dimensions are 3 x3 x 6 ft, or not to exceed 2.5 tons with dimensions of 2 x 2 x 4 ft. There will be a need for at least 4 reaction blocks. A special form is to be designed by the design firm and to be later ordered through a precast yard in the region.

Various crane scenarios are discussed based on dimensions and height limitations. Three are evaluated: Bridge Crane (on beams supported by columns), Gantry crane (sliding on tracks attached on the strong floor), and a jib crane (or two). The latter can cover a radius of 12-15 ft, and thus two can be used. A gantry crane of 5-ton capacity will be used along with a forklift to support the various loading functions of this lab.

**Innovative Aspects**

Besides the experimental design and pedagogical aspects of this laboratory, a number of unique features are embedded to support all its objectives. These features can be summarized in terms of its layout and spacing of anchors, innovative anchor bolt design and fabrication, and its special equipment.

To maximize the use of the limited space available for the laboratory and its associated facilities, the placement and location of the anchors become crucial for bolting the testing equipment, structural members, and any reaction blocks. Various anchor spacing strategies were considered, and these included 1 ft, 1.5ft, 2 ft, and variable spacing of anchors. If the spacing were left at 1 ft, which provides more flexibility for testing and placement at all locations, the number of required anchors to cover the entire strong floor would have been approximately 790 anchors. On the other hand, if the spacing were kept at 2 feet with even distribution, the number of needed anchors would have been close to 200, but with somewhat lesser flexibility. A compromised layout that contains a pattern of four with spacing of 1 and 2 ft was finally adapted in each module. This layout allowed the use of 279 anchors, which provided a flexible utility with a significantly lower cost. Anchors are being fabricated and assembled by a major steel company that is internationally known. Because the design does not allow for use of any available (off-the-shelf) product, and due to their distinctive and proprietary design and strength, their cost was quite high.
The anchor bolts are considered among the most innovative components of the lab structure. They are initially designed to be 1-1/4” to 1-1/2” Grade 150. Anchors are intended to bolt testing equipment and structural members being tested with the strong floor. Therefore, they help transfer the stresses to the strong floor, but they don’t add much to the strength of the strong floor itself. The design has evolved from a primitive 1-1/2” threaded anchor rod with a 3” pipe sleeves with a nut assembly to screw in the anchor at the bottom. This design did only require the presence of the pipe sleeve and nut assembly embedded in the 4-ft strong floor without the need to have the anchor in place. Anchors will be supplied by the owner (lab operator) when needed. This design had several shortcomings, one of which was that if concrete chunks or debris were to fall in the pipe sleeve, or if the nut assembly were misused or broken; the hole is lost for good and became useless. Figure 5 illustrates the development and evolution of the design concept.
Figure 5: Evolution of Conceptual Design of the Anchor Bolt
Elaborate discussions with both leading industry organizations and major university research lab allowed the design to evolve from the above mentioned one to a one that is far superior. The anchor design was finally issued as shop drawing for fabrication and assembly as shown in Figure 6 below. This assembly is a complete system where all components including anchor bolt housed within a 3” SCH40 pipe. The system has an upper assembly that contains a lid with a threaded end as well as a DSI coupler with a transition plate. The lower assembly contains a cap plate, hexnut, and a 6”x7”x2-1/2” 6 x 7” plate. This design is premised on the notion that if the stresses were to increase and cause failure, breakage would occur at the coupler, which represents the weakest point of the anchor system. Such approach will permit the replacement of the broken part near the upper portion of the strong floor surface and without having to lose the entire anchor permanently.

![Figure 6: Final Shop Drawing of Anchor Bolt](Image)

Design is Courtesy of DYWIDAG Systems Inc. (DSI)
Challenges to Construction

Interference with existing footings and utilities: The existing footings are 4.5 ft below the surface of the existing slab. Therefore, a 4ft slab can be poured without disturbing the stability of the exiting columns. Backfilling of sand or soil might be done to provide stability and continuity. The shear wall (facing the parking lot) has a footing of about 1 foot in each direction at a depth of about 4feet.

Height Restrictions and Obstructions: Light fixtures had to be removed and raised by nearly 2 feet. This allowed gaining two extra feet clearance out of the 12 feet total height available. Furthermore, a large HVAC vent and pipe inlet/outlet had to be completely removed and relocated to clear about 8 feet of horizontal spacing and 3 feet of height out of the south east corner of the strong floor area.

Levelness: Levelness and flatness of slab are very important and are addressed in the Spec’s. This is essential for future experimentations.

Layers: Strong floor slab will be poured in two layers; the first is 45.5 inches, and then a 2.5-inch layer on top to insure levelness and flatness. A bonding agent will be used to adhere both layers. Also the creep will be extensive with such thickness, therefore, this may warrant pouring two layers.

Spacing of Anchors: Spacing of anchors will be 12 inches instead of 16 inches or 24 inches. This will enhance strength and will ensure that sufficient bolts are available if any were to break. The loading of each anchor is to be 91 kips (tensile capacity).

Design of Anchors: Various options were discussed. Each bolt is 1-1/4 inches. The PVC cap and casing were to be avoided (Based on request from the owner). A simplified design with steel casing and coupling will be adopted. A design similar to couple other university labs in other states will be adopted.

Soil bearing capacity: Soil should be able to withstand loading according to the designer and based on the soil report obtained form the professional soil testing consultant.

Construction and Auxiliary Equipment

Some supporting equipment is planned to be procured near the completion of construction of this lab. A crane setup as well as a forklift will be used. Also, a cooling tower as well as a set of modular pumps will be in place to support the hydraulic system during testing. Reaction blocks will be designed to support experimentation and will be available soon to support the lab functions.
Conclusions:

This lab will become one of the hallmarks for Engineering at the University of the Pacific. Its unique features provide solutions to a number of problems to maximize its benefits. Its distinctive layout and spacing arrangement of anchors will take advantage of the limited floor area so that large scale testing can be conducted. Value engineering was practiced throughout the planning and engineering phase of this project while keeping in mind the primary function and mission of this project; i.e., to provide outstanding experiential and pedagogical opportunities to civil engineering students and a service to the industry. Students will become more proficient in the construction and structural engineering areas as they conduct experiments relevant and supportive to their theoretical learning in these two areas. Many of the unique characteristics of this lab such as anchor design and layout will permit instructors and researchers to cooperate with industry leaders in flexibly conducting experiments that are of great value to the academic community as well as to the practice. This will significantly enhance integration of the pedagogy and scholarship within civil engineering and with other fields such as mechanical engineering. Upon the completion of its construction, this lab will support technology transfer and will enable further interaction between pedagogical means and research instruments mainly in structural and construction engineering.

References


[2] The home of MTS

