Session 1395

Integration of Analysis and Design in the Structural Engineering Curriculum

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Abstract

In the Civil Engineering curriculum, coursework tends to be compartmentalized with the result that students often find it difficult to understand the relationships among concepts covered in different courses. Even within individual courses, students sometimes have difficulty tying together material from different parts of the course. In an attempt to overcome these shortcomings a project is underway at Penn State University to integrate coursework in the areas of structural analysis, structural design, geotechnical engineering, and engineering materials. The general approach is to develop a theme project for which different aspects are covered in several related courses. This paper describes the activities underway to integrate material in our structural analysis and structural design courses, as well as a plan to assess the impact of the approach.

I. Introduction

Undergraduate civil engineering curricula typically cover structural analysis and structural design in different courses. Analysis is often covered first with design being covered in later courses. As a result students often do not see clearly the relationship between analysis and design. Students usually see analysis as being theoretical while design is seen as dealing with practical issues, whereas in fact analysis and design are closely intertwined.

At Penn State we are attempting to integrate various parts of the curriculum by developing project design examples that cover analysis and design of structural components within the context of a complete structural system. This approach has already been implemented in our course on design of concrete structures and we are currently developing the modules for our structural analysis course.

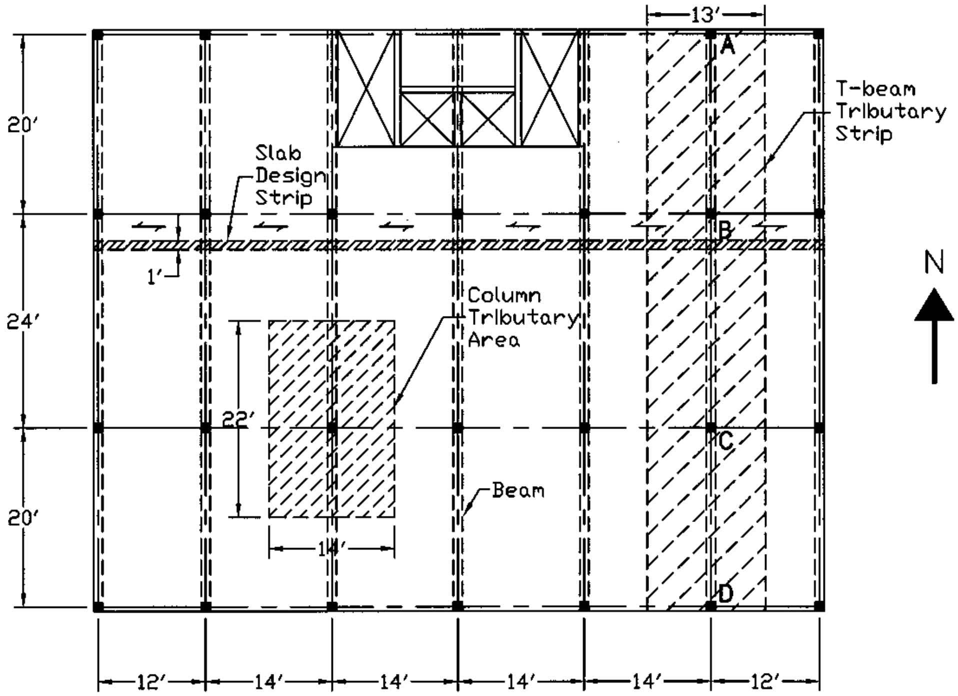
As part of the assessment process, a baseline test has been developed to assess the student's understanding of structural engineering concepts at various stages of their development.

II. Structural Design

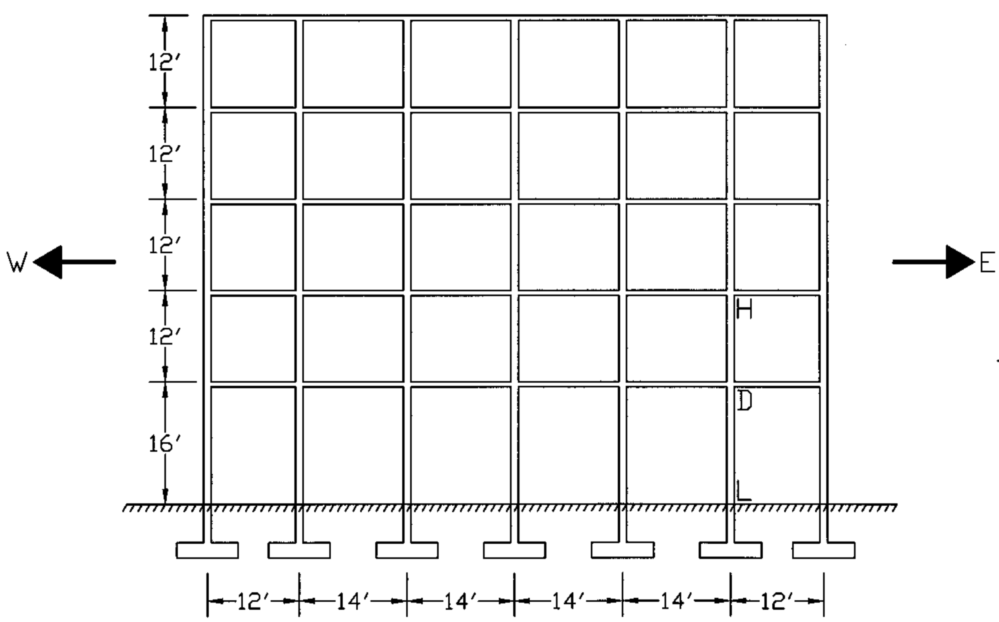
Design in civil engineering usually means developing a scheme from the conceptual phase through the detailing phase to produce a set of drawings and specifications that can be used by a general contractor to actualize the final product in the construction phase. In addition to the drawings and specifications, the work product of the design engineer will include an extensive set of design calculations that will be subject to close scrutiny in the future should a problem develop with the end product. Because civil engineering designs involve large scale products such as bridges, building structures, and dams, it is difficult to develop realistic student design projects where the students can actually construct a prototype based on their design, particularly when class sizes are relatively large. This introduces somewhat different challenges to the teaching of civil engineering design compared to disciplines such as mechanical or electrical engineering design. Visits to local construction sites are helpful in providing students with exposure to construction projects. Students can be exposed to the practicalities of the construction process through construction and testing of small scale structural members or structural models in the laboratory. However, the primary objective of a structural design course is to provide the students with an experience that will enable them to enter a design office and have an understanding of the process by which a complete set of design calculations, drawings and specifications is produced. In addition, because the design process in large projects involves a team effort with input from experts in different fields, students need to understand how the design process works in the broad sense.

The approach being used to integrate these various facets of the design process is to use a theme project in related courses at various stages of the curriculum. The initial effort has been to develop the theme project in the introductory reinforced concrete design course. A detailed design example has been developed for a five-story reinforced concrete office building. At various stages of the course this design example is used to demonstrate the concepts developed in class, such as calculation of design loads, or shear design of floor beams. The students are not provided with the complete design example. In the version provided to the students some of the material is deleted, with the details to be completed in class. This approach forces the students to remain actively involved in the development of the design example. Figure 1 shows a floor plan and elevation of the building used in the design example.

The detailed design example covered in class provides a template for the students' own semester-long design projects that are developed in parallel. Because this course is usually the first course in which the students are introduced to the design process in some detail, assigned projects are less open-ended than the design projects conducted in the senior elective design course for which this course is a prerequisite. Students work in pairs on different but similar projects. This ensures that all students address all the design issues that need to be tackled. However, working in pairs allows some active learning processes to take place, such as teaching each other by explaining how they arrived at their designs using formal in-class exercises. They are also required to check each other’s calculations, an extremely important part of design office practice often overlooked in design courses. The project assigned to the students typically involves a building with a framing arrangement similar to that used in the design example but with different design loads and span arrangements. Each group of two develops a complete design, one of the students assuming an orthogonal framing scheme to that used by the other student. At the end of the course each student has a complete set of design calculations and sketches illustrating their designs.



Plan View



Elevation View

Figure 1: Integrated Building Project Layout

The experience gained by the students in these and related courses will provide considerable flexibility in the degree of open-endedness that can be incorporated in future technical elective project design-based courses.

III. Structural Analysis

In the current phase of the planned curriculum development the analysis portion of the theme project is being incorporated into the structural analysis course, which is a prerequisite to the design course. Many of the concepts of structural analysis can be demonstrated by application to the theme building project including the significance of certain simplifications that are introduced in design. The intent is to clearly tie the significance of analysis to the design process to offset the tendency of students to see analysis as a theoretical exercise with little relevance to practice.

Several course modules have been developed in which a portion of the frame is isolated for analysis. An example of a two-story substructure model of the frame is shown in Figure 2. These modules demonstrate concepts such as modeling at the boundaries, load transfer mechanisms, calculation of design loads applied to various components and various techniques of indeterminate structural analysis. Member forces calculated by rigorous analysis are also compared with results obtained by simplified methods such as the moment coefficients provided in the ACI Building Code[1].

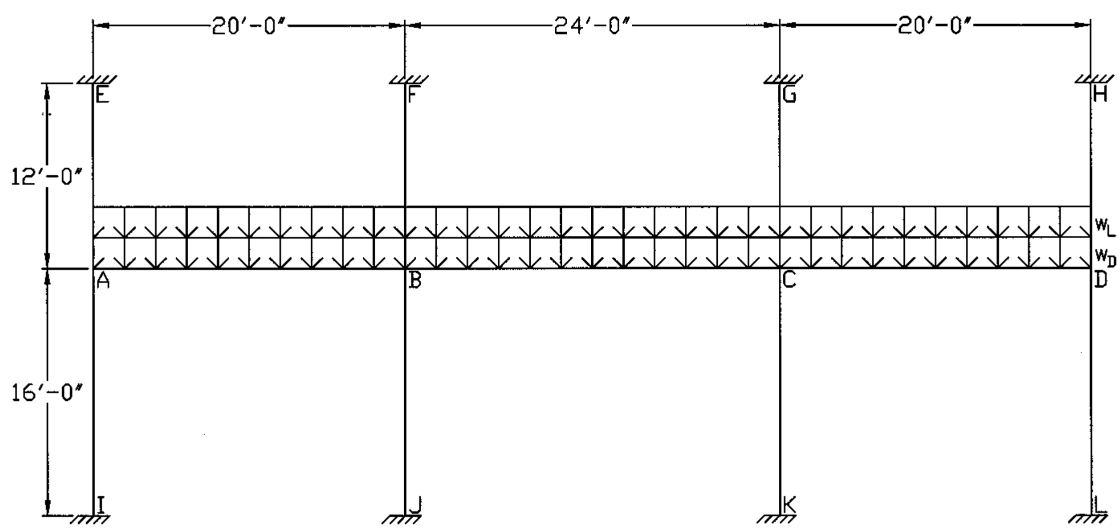


Figure 2: Frame Substructure Model

The course modules are used during class as example problems for load calculations, modeling techniques, and several techniques of indeterminate analysis. Students are provided with a packet covering the examples with the solutions to be filled in during class discussion. The use of the course module prepares the students for their final semester project to analyze a frame on the Penn State campus. The students determine loads and the representative model for the frame. They analyze the frame with the commercial structural analysis package, STAAD Pro, and compare their results to hand calculations by the methods learned in class. An honors section to the structural analysis course will be added in the fall semester of 2001. The students in this section will meet weekly to discuss topics in greater detail, focusing on an interaction of structural analysis and design. The final project for this course will be expanded from the standard class project.

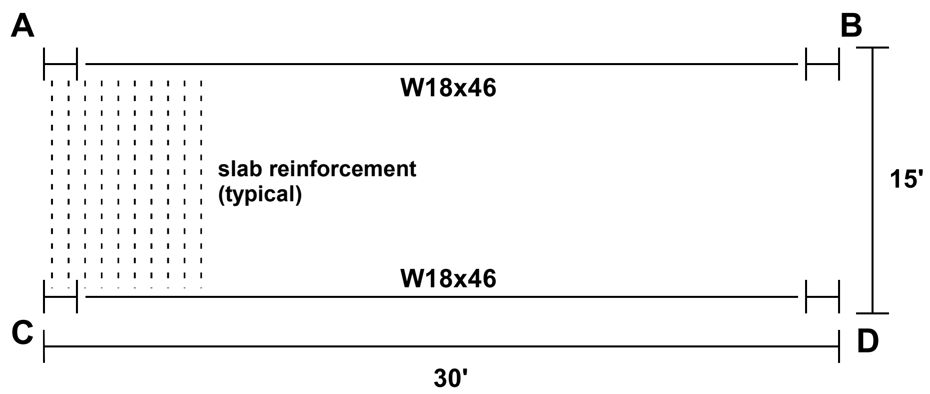
IV. Assessment

Engineering Instructional Services (EIS) at Penn State provides consulting and development of assessment and evaluation of educational activities within the College of Engineering[2]. An assessment program is currently being developed in cooperation with EIS. A baseline test has been developed to assess the development of the student's understanding of structural concepts as he or she progresses through the curriculum. Two simple structures as shown in Figures 3 and 4 are presented to the students. The students are asked to draw models for analysis of these structures showing the loads carried by individual members and assumptions regarding support conditions. These examples are intended to demonstrate the level of understanding of load transfer mechanisms and the ability to develop structural models for analysis of realistic structures. The structural analysis class is the student's first exposure to structures in the curriculum. At this level the students are not expected to be familiar with typical design drawings and the problems are presented as clearly as possible, while letting the student visualize the 3 dimensional structure. One problem has steel framing while the other is concrete. Figure 3 represents a one-way system, and the direction of the reinforcement in the deck is included to help the student understand the system. Figure 4 represents the more complex two-way system.

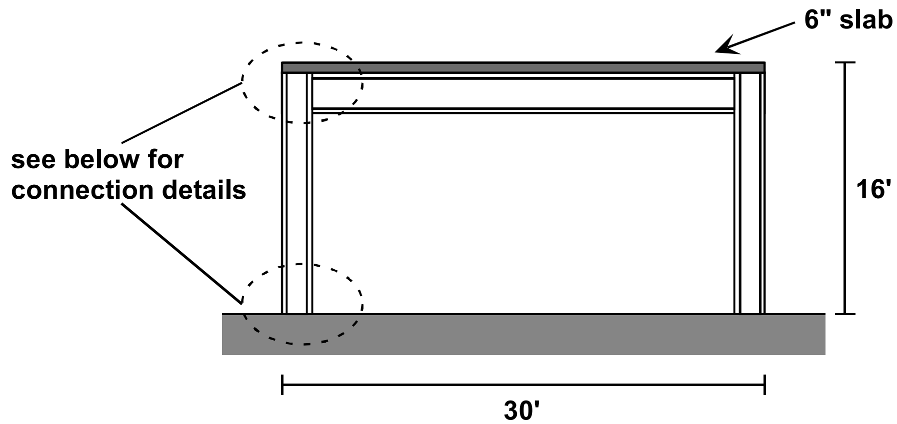
The test has been administered to students in the first analysis course on a trial basis. As anticipated, at this early stage of development, students generally perform quite poorly. The following general observations where made from the initial testing:

- Most students were very concerned with trying to analyze the structure without first considering the load path and developing a proper model
- Little thought was given to dimensions (centerline dimensions versus outer dimensions)
- Students had some concept of tributary area, but trouble applying the concept when given a full 3-D system
- Students had difficulties transforming loads in pounds/ft^2 to proper pounds/ft loads
- Most were perplexed by the two-way system, or simply ignored the frames in one direction
- Modeling of the slab was not considered

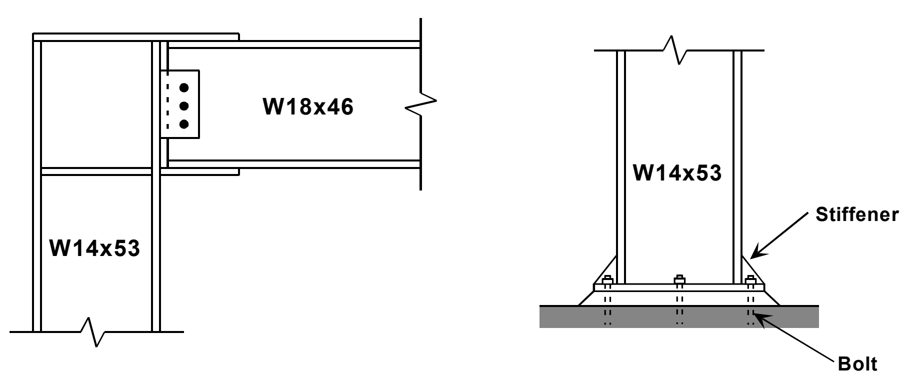
The test will be applied again as students continue through the program and the students' progress will be monitored. The test will also be used to compare the development of students exposed to the integrated approach with those in sections taught in the traditional format to assess the extent of improved understanding gained by those students exposed to the new format.



Plan View

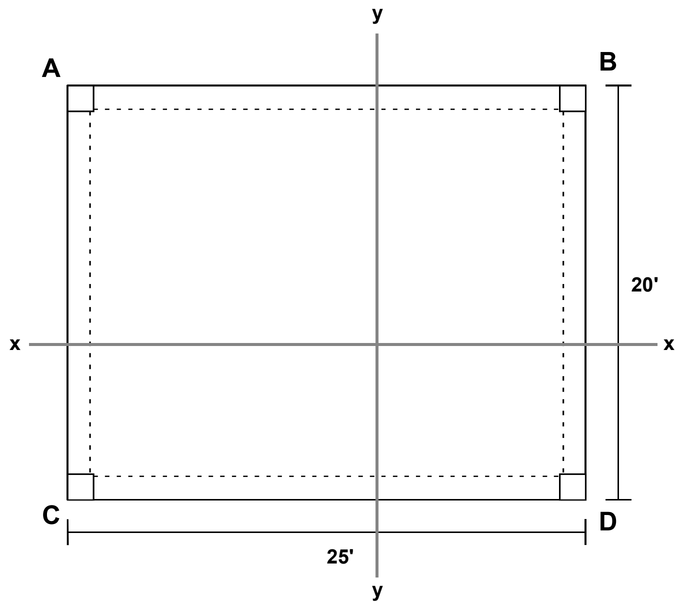


Elevation View

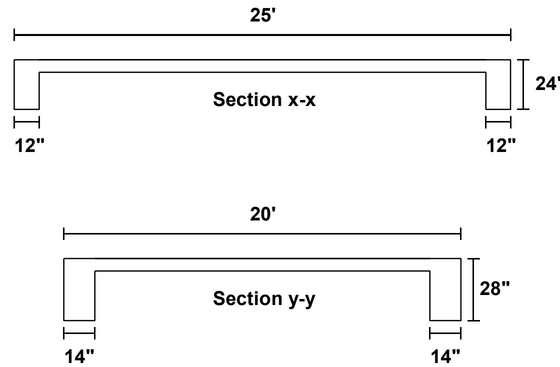


Connections

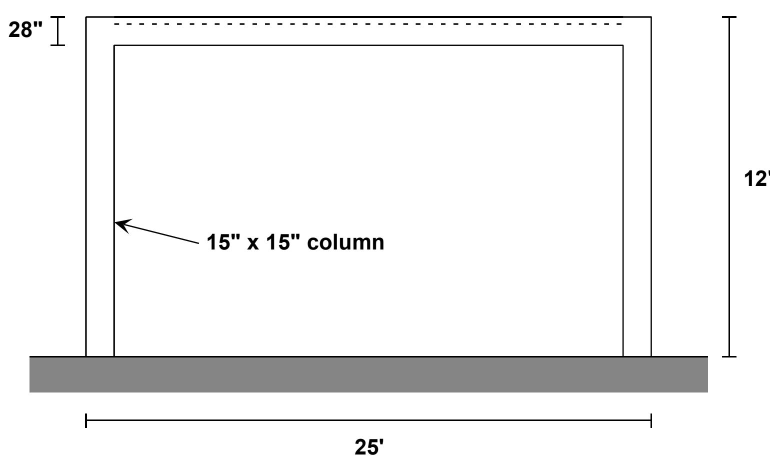
Figure 3: Baseline Test – One-Way System



Plan View



Beam Dimensions



Elevation View

Figure 4: Baseline Test – Two-Way System

V. Future Development

At this time the building project has been incorporated into the structural analysis and concrete design courses. The theme project will also be incorporated into the steel design, materials, geotechnical, and matrix structural analysis courses over the next two semesters.

In the steel design course, the same building structure will designed using steel framing systems and will be incorporated in much the same way as presently done in the reinforced concrete design course. In the materials course, students will focus on specifying concrete mix designs for the concrete building structure. In the geotechnical course, the loads from the concrete building will be used to design footings. The building module in the matrix analysis course will be an extension of the module in the basic structural analysis course, including computer modeling of the building.

VI. Summary

A theme project has been developed to integrate analysis, design, materials, and geotechnical courses in the Civil Engineering curriculum. Modules have been completed for the structural analysis course and concrete design course. The first group of students has just completed the structural analysis course of the integrated curriculum. A baseline test has been administered to this group of students to access their progress through the curriculum. Additional class modules will be introduced each semester with expected full integration by the beginning of spring semester 2002.

VII. Bibliography

1. **ACI Committee 318**, *Building Code Requirements for Reinforced Concrete and Commentary (ACI 318-99 and ACI 318-99R)*, American Concrete Institute, Farmington Hills, Michigan, June 1999.
2. **Marra, R.M, Palmer, B., and Litzinger, T.A.,** "The Effects of a First-Year Engineering Design Course on Student Intellectual Development as Measured by the Perry Scheme," *Journal of Engineering Education,* January 2000, pp. 39-45.

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