Structural Analysis for Architectural Engineers

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"Hi Ron, we appreciate your finding time to visit us on the campus and your interest in interviewing our graduates for your firm."

"Professor, that reminds me. You know I'm a graduate of this department and I have been hiring about one new graduate each year. The problem we have is the lengthy training period the new graduates need to become productive. They lack preparation in knowing how the computer and the software are used to do structural analysis. We need to teach them more about loads, how to prepare the information for the computer and how to interpret the output. Why don't you visit our firm and we will discuss this with you and share our ideas?"

Introduction

The introduction of the computer and the development of software for analysis and design has revolutionized every aspect of the structural analysis of buildings. Never before has there been a tool for engineers that has been able to visibly demonstrate how building structures react under various loading conditions with varying geometries. Now, structural analysis using the computer makes it possible to see the effects of various load combinations and framing configurations.

Along with this revolution, practitioners have developed their professional practice beyond the usual content of the required undergraduate course work in structural analysis. In general, the course work content and application methods taught in the classroom for structural analysis lag behind the techniques used in professional practice.

The structural analysis referred to in this paper is concerned with the analytical techniques used during the design process to determine how a building and its individual members resist loads due to the forces of nature (wind, earthquake and snow), the weight of the materials used to build the structure, and the material and people loads it must support. Emphasis is focused on the undergraduate course work.

The objective of this paper is to provide a broad review of the historical development of structural analysis techniques and compare where courses stand today in relation to actual structural engineering practice. The content of textbooks from the late 1800s through today were reviewed to determine how the information was organized and presented.

The content of current structural analysis courses was reviewed in the catalogs of representative engineering programs from all types of institutions in the United States. A review of the curriculum for these same representative programs was also made. As one would suspect, the dominant academic program where these courses are taught is Civil Engineering.

To determine how structural analysis becomes a part of the design process in the practice of professional firms, interviews with practicing engineers were conducted during site visits. This survey included a review of computer equipment, work stations, and software applications.

The paper concludes with recommendations describing the overall content that an undergraduate structural analysis course should have, suggestions for instruction techniques, and recommendations regarding the types of equipment support needed.

Historical and Textbook Development

It is difficult to determine the exact year when the body of knowledge now referred to as structural analysis became a subject of its own. It appears to have been a slowly developing process occurring over many decades. Literature shows that in the late 1800s, design and analysis were integrated and the analysis mainly consisted of evaluating loads. Then the loads were translated into force systems and a related graphical language developed around the turn of the century to solve these force systems.

This is the period when structural systems began to evolve from simple beam-column bays and simple trusses to include fixed framing techniques and expanding geometries. The continued development of structural systems brought the realization that structural systems could be defined as determinate and indeterminate and, over time, this distinction became better defined.

As the graphics of force systems developed into broader applications including influence lines, the knowledge of how structural systems reacted under various types of loads also expanded. The need to further explain and predict how structural members would react when loaded led to the development and application of mathematical techniques. This is apparent in the literature published during the early 1900s.

The problems encountered when applying these involved mathematical techniques included the lengthy amount of work involved and the level of mathematical skill required. To simplify the mathematical procedures, numerous numerical techniques such as moment distribution evolved. There were also numerical techniques linked with graphical analysis, such as the methods used for determining deflections.

The content of textbooks during the 1920s through the 1940s usually included an explanation of force systems, commonly referred to today as statics, graphical and analytical analysis of trusses, including influence lines, and various applications of the mathematical and numerical techniques that had been developed. The content of textbooks published during the 1940s began to expand, particularly in the area of more sophisticated types of structural systems such as frames with lateral restraint, curved beams, and various arches.

By the 1960s, the body of knowledge concerned with structural analysis as applied to buildings had grown significantly. The techniques and their applications were numerous and represented past years of research and contributions by university faculty. These were recognized and accepted by codes and material specifications, and became an important element in the education of engineering students.

During the next couple of decades, there were only minor additions to the field of analysis techniques and methods. Most of the emphasis was placed on how the material could be better and more efficiently taught, how the content was to be formed into courses, and where it would appear in an undergraduate curriculum. However, one significant analysis technique did appear during this time. This technique focused on the stiffness matrix and the realization that the computer could aid in the analysis of structural systems by quickly manipulating large matrices.

A review of the current content of textbooks and the typical content of undergraduate courses indicates that the majority of the old - or what are now commonly referred to as the "classical"- analysis techniques continue to be included and taught as a major part of the undergraduate curriculum.

Codes and Design Specifications

The amount of information and related criteria about loading has significantly expanded during the past couple of decades. Governmental agencies, research from the universities and the private sector, code groups, and material and component qualification by laboratories have all contributed to this body of knowledge. During past decades, the Uniform Building Code only contained a few pages about loading requirements. Now this type of code typically contains an entire chapter about loading requirements, and ANSI/ASCE has an entire document devoted to loading criteria.

Conclusions from the reviews made while preparing this paper indicate loading information is now more involved and comprehensive. Loading requirements have grown to such an extent that loading fundamentals now need to be incorporated into the undergraduate course work. This includes definitions, applications, and methods for calculations. The importance of this body of knowledge is also reflected in the design specifications, such as the LRFD Manual of Steel Construction.

Professional Practice

It is difficult to find structural engineers in practice who are not utilizing the computer. Software that uses the stiffness matrix method is used by structural engineers to complete nearly every structural analysis task. Information from the surveys performed for this study indicate that the computer is used for the analysis and design of virtually every structural system, including frames, beams and columns, plates, diaphragms, shear walls, footings, and all types of trussed systems. In some applications, the software determines member sizes in addition to calculating the forces they must resist.

The usual procedure in a consulting firm is to determine the types of loads and magnitudes required by the various codes along with the code-required design criteria. Loading requirements are usually prepared using hand calculations. This becomes input data for the computer model. Some firms also have developed computer programs to help determine loading criteria.

The information from the surveys of professional firms indicates that very few engineers execute hand calculations using the classical analysis methods. Most of the manual or hand calculations are performed during the detailed design phase to design connections and special details.

The prevalence of computer models used in analysis and design makes statics and the fundamental knowledge of the strength of materials very important resources for checking and analyzing the results generated by the computer.

Engineers in practice now accept and depend on the computer as a source of correct and complete information. In past years, there was always some skepticism about the dependability of the results generated by computer software. There were questions about the programs' accuracy and whether a complete analysis using all possible combinations had been executed. As a profession, we now understand more about the computer, the analysis methods used by the software packages, and how to interpret the results. Professional's in firms now use these computer systems constantly and have developed a sense of what the results should be based on the input information.

Professional firms now expect their employees to be computer literate and understand how to use structural analysis and design programs and how to interpret the results. To more adequately prepare graduates to meet this new challenge, we propose undergraduate structural analysis be brought up to date with current office practice.

Proposed Course Description

The proposed Structural Analysis and Loading class will follow classes in mechanics of materials and statics and will be interactive in its design. The class will be a combination lab/recitation class to facilitate more interaction among the students and between the students and the instructor. Ideally, each student would have a computer, but one computer could be shared by two students. Simple models will be used along with analytical methods to illustrate general concepts and key principles of structural systems. The focus will be on structural systems as a whole and how they interact with loads.

The class will begin with the definition of loads and code forces showing how structures are loaded, where the loads come from, and how the loads interact with the structure. Concepts of gravity loads and how they are calculated will be covered first. The class will then move on to lateral loads, learning where they originate, how they are calculated, and how they are distributed to the structural frame. During these sessions, the student will be introduced to several prevalent codes and standards and will learn how to interpret the loading information presented in these documents. Standards will include those used in the later design classes to give the students early exposure to the standards and enhance their familiarity with the codes and standards they will be using later. This also will help to link the structural analysis class more directly to the subsequent design classes. Frame configurations and their interaction with different types of loading will be introduced, which will lead into structural analysis.

The structural analysis portion of the proposed class builds on the foundation laid in the first portion of the class, beginning with the application of some key historical analysis methods such as simple beam theory, virtual work, and the stiffness method. Once the students have a general feel for structural behavior and analysis, the methods used by most computer programs to do structural analysis will be discussed, including the theories used and their basic assumptions and limitations. At this point, the students will begin working on computers and will learn how to build computer models. The computer work will start with simple two-dimensional models and progress to more complex three-dimensional models. This will give the student a deeper understanding of how structures behave under different types of loading and which factors most affect the results. The computer provides a very visual explanation of structural behavior by showing stress gradients, deformations and displacements, and by allowing the student to view the structure in three dimensions from any angle. Once the student can build models and create input files, the computer output will be reviewed and verified. The class will conclude by providing instruction in how to read and interpret the computer output and how to apply it in structural design. This will then lead directly into the subsequent structural design classes the student will take.

Proposed Course Outline

The proposed course objectives are to present the material graduates will need to know to perform structural analysis and design in a professional office and to provide the graduates with a basic understanding of structural system behavior.

A. Loading and Code Forces (References: UBC, SBC, BOCA, AISC, ACI, NDS and ANSI/ASCE 7)
   This section teaches the student where loads come from and how they are applied to the structural frame.

   1. Gravity loads
      a. Dead loads
      b. Snow loads
      c. Live loads
      d. Impact loads
      e. Tributary widths and tributary areas
         1. How loads are carried by the structure, load path
            Use physical and computer models to illustrate

   2. Lateral loads
      a. Wind
         1. How wind creates forces on buildings
            Use models to illustrate
            Show films of strong winds on buildings and point out different types of behavior
         2. Code wind forces
            Basis for code wind forces
            How to calculate wind pressures

Primary system
Parts and components
How to apply wind loads to the structure
3. Use computer models to show how stiffness and the configuration of a structural system affect the load distribution and where stress concentrations occur.

b. Seismic
1. Cause of earthquakes
2. How earthquakes affect buildings
Use simple models made of flexible rods and heavy metal washers to illustrate vibration modes
Test models of different structural systems on a shaking table
Show pictures of structures damaged in earthquakes and discuss the causes and modes of failure
3. Code seismic forces
Basis for code seismic forces
How to calculate the seismic forces on a building
Primary system
Parts and components
How to apply seismic forces to the structure
4. Use computer models to show how stiffness and the configuration of a structural system and the type of earthquake affect the response

3. Code required load combinations for design

4. Configurations of frames and the frames' interaction with loads
Use physical and computer models to illustrate

B. Structural Analysis

This section gives the student background in historical analysis methods and then moves on to computer analysis and models, illustrating how they are used in design offices.

1. Historical methods of structural analysis
a. Simple beam theory- relationships between load, shear, and bending moment
1. Moving loads
b. Deflections
c. Free body diagrams
d. Method of sections
e. Method of joints
f. Virtual work
g. Stiffness method
h. Introduction to finite elements

2. Structural models
a Elastic analysis

b. Plastic analysis
. c. Common simplifications and assumptions

3. Computer analysis
    a. Analysis methods used in programs
    b. Building computer models
        1. Input information
        2. Model assumptions
        3. Two-dimensional models
            Use previous hand problems to begin calculations on computer and verify results
        4. Three-dimensional models
            A. Second-order effects
    c. Interpreting computer output
    d. Applying computer output in design

Conclusions

The objective of this review was to determine how the usual undergraduate academic course work in structural analysis compares with the fundamental knowledge and methods professionals use in practice. The conclusion reached during this study is that undergraduate structural analysis courses focus on "classical" analysis methods using manual calculations, while professionals predominately use computers to perform analysis and design of structures.
The knowledge needed to effectively use structural analysis programs is generally not sufficiently covered in current undergraduate courses, creating an unnecessarily large gap bewteen education and practice.

The recommendations address this gap by outlining course work which focuses on load criteria, structural system behavior, and computer modelling to better prepare our architectural engineering graduates for the profession.

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