Structural Analysis Courses: Computers or Fundamentals

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Introduction

The computer "revolution" that occurred toward the end of the 20^{th} century probably changed forever the background of the student entering engineering programs and the manner in which that student is best suited to learn. Further, the technology revolution has changed the manner in which engineering design is conducted and the needed skills of engineering professionals. This change is being recognized by the professional engineering organizations, which are now considering increased educational requirements for licensure.

One of the major changes brought on by the computer revolution are the tools and computational available for education and professional practice. As the tools and computational resources advance, a perennial question is what should be taught in introductory structural analysis courses. Coupled with that question is what is an engineer, as opposed to an engineering technician, and what do we expect engineers to do in the future. The real question for structural engineering education is "What must a structural engineer know to be prepared for professional practice upon graduation and to successfully adapt to change that is inevitable over the 45-year span of his or her career."

The easy answer to this question is that we must teach the fundamentals of structural analysis and that the student must assimilate those fundamentals. The difficult question that naturally follows this question is "What are the fundamentals of structural analysis that an engineer should know." In this paper, two aspects of this latter question are explored in an effort to provide an answer. First, the authors will attempt to distinguish between the skills, attitudes, and knowledge necessary for an engineer and those necessary for an engineering technician. This distinction will be based on the definitions of the Accreditation Board for Engineering and Technology, the body of knowledge for professional practice prepared by the American Society of Civil Engineers, and the expectations of employers. Second, given the characteristics expected of an engineer, the authors will attempt to provide a coherent set of fundamentals for structural analysis that a graduating engineer should know. This set of fundamentals will reflect the fact that most structural analysis is conducted with the use of computers, but that the computer is only a tool in the process rather than the process itself, as some students and practitioners have come to believe.

This paper states the summary opinion of the authors and serves as the opening statement of the authors in a panel discussion on this subject. It is not intended to be an all encompassing review of the content of structural analysis courses. The authors also recognize that their opinion is not the only opinion on this subject—there are almost as many opinions as there are structural engineering educators, and each opinion has a strong and loyal following.

A New or Old Question

The question of what should be taught in a structural analysis course for engineers was likely first asked in the 1930's shortly after Hardy Cross developed moment distribution for the analysis of frames. This procedure was much simpler than the other methods for structural analysis available at that time. With the simplicity and universality of moment distribution, why were other methods for structural analysis needed and why should they be taught when there is so much else that needs to be taught.

During the lifespan of the authors, this same question has been asked numerous times—each time there is an advance in computational technology. It occurred when major computer programs for structural analysis, such as STRESS and STRUDL, were first introduced during the 1960's. With these tools readily available, why were "hand methods" for performing structural analysis taught? This question was asked by students and educators alike, even as practitioners used computers for structural analysis more and more. With the advent of the personal computer as being the dominant engineering tool, and with the plethora of excellent structural analysis software available today, this question is even more relevant than it was during the 1960's and 1970's.

The bottom line is that the question being asked today is not a new question, nor is it a question that has ever been resolved. One can come to this conclusion by looking at the table of contents of the many structural analysis books available today. Invariably each presents all of the classical and approximate methods of structural analysis. A review of the contents of the previous editions of these textbooks shows that the subject matter presented has changed very little over the last 40 years, despite significant change in professional practice. Is this a reflection of engineering education or is it a reflection of the need of the engineering profession. The authors of this paper contend that it is a reflection of engineering education in that what needs to be taught in structural analysis today has not been resolved, nor was it resolved as methods and tools changed in the past. Perhaps now, with the significant change brought on by the personal computer, the content of the courses should be evaluated and changed—brought into line with current practice.

Engineer versus Engineering Technician

When discussing what should be contained in a structural analysis course, one also needs to discuss the intended audience for that course, the career choice of the individuals taking that course. The focus of the authors—because of the nature of the institution and departments by whom they are employed—is the education of engineers, not engineering technicians. Simply stated, engineering and engineering technology can be described as follows:

- **Engineers** have a broad understanding of the fundamental principles that can be applied to the conceptualization and design of new and innovative systems. Furthermore, engineers have an understanding of the impact of design options on the performance of the entire system.
- **Engineering Technicians** apply engineering principles to the routine design of components in a system conceptualized by an engineer—the focus is on the application of established design principles developed by engineers.

As the focus of the authors is engineering, the structural analysis courses engineering students complete must provide the student with the ability to understand the issues related to the design of systems as well as the design of components.

Further, when discussing the content of an engineering education program, one must also be very cognizant of the requirements for professional registration. At present, most states permit registration as a Professional Engineer after graduation from a program of study accredited by the Accreditation Board for Engineering and Technology (ABET), having accumulated four years of professional experience, and having successfully completed registration examinations. In recent years, there has been considerable discussion about the Master's degree being the first professional degree—the degree that would be required to become a Registered Professional Engineer. The American Society of Civil Engineers is one of the lead organizations pushing for this requirement. In Policy Statement 465, ASCE[1] states that:

> *The American Society of Civil Engineers (ASCE) supports the concept of the Master's degree or Equivalent as a prerequisite for licensure and the practice of civil engineering at a professional level.*
>
> *ASCE encourages institutions of higher education, governmental units, employers, civil engineers, and other appropriate organizations to endorse, support, and promote the concept of mandatory post-baccalaureate education for the practice of civil engineering at a professional level. …*

The ASCE has adopted this position for several reasons listed in Policy Statement 465. At the conclusion of that list, the ASCE[1] states:

> *These changes have created a market requiring civil engineers to have simultaneously greater breadth of capability and specialized technical competence than that required of previous generations. For example, many civil engineers must increasingly assume a different primary role from that of designer to that of team leader. …*

The ASCE is of the opinion that advanced education is necessary to achieve the knowledge, skills, and attitudes necessary for professional practice in engineering in the future. To achieve this advanced technical knowledge, the authors believe that engineering students must be taught fundamental principles of behavior in introductory courses so as to have the sound technical base upon which to build the advanced knowledge. The authors do not believe that teaching students only how to analyze structures with a computer is a proper foundation upon which to build advanced technical knowledge. Further, the authors do not believe that it is the basis from which engineers will learn to conceptualize innovative and novel systems, as stated in the definition of an engineer above.

Expectations of Employers

When evaluating the content of any academic, one must consider that which the employing industries expect of the graduates they hire. For many years the authors have heard comments from industry advisory boards and industry colloquiums indicating the expectation that a "graduate should be able to make us money shortly after coming on board." This statement, and similar such statements, requires considerable interpretation otherwise it can lead to significantly erroneous conclusions, and therefore an improper academic program. It can also lead to a transition from engineering education to technical education.

Upon discussions with employers, and subsequent interpretation of the comments made, employers of engineers really expect two things. First, they expect an engineer to be reasonably productive upon joining the organization. This implies that an engineer's education must include practical application of the theoretical principles discussed in the classroom. With a view toward structural analysis, this means that a student must learn how to analyze structural systems using commercially available software and to correctly interpret the results of those analyses.

Second, employers expect graduates to be able to move into positions of leadership within the respective organizations in regards to developing innovative engineering solutions and advancing the engineering. This is especially important with rejuvenation of the aging and deteriorating national infrastructure. For this to occur, structural engineers must receive education in behavior of structural systems, must be able to develop new structural concepts, and must be able to assess the appropriateness of current tools for new applications that occur in the future. This, in the opinion of the authors, requires a firm understanding of fundamental principles. The structural engineer must be able to do more than just analyze structures. They must firmly understand the principles behind the analysis and the limitations of those principles.

Employers do recognize that an engineer's education, indeed the maturing of an engineer, will continue through professional practice. Further employers understand that the needs of industry are not identical. Employers are ready to teach new graduates the industry specific application of principles through experience, but they expect a solid foundation upon which to develop that experience.

These expectations of employers, given the interpretations provided by the authors, is not inconsistent with the thrust of ASCE Policy Statement 465 and the body of knowledge[2] developed by ASCE to support the policy statement. In the author's opinion, solid and thorough education in fundamental theoretical principles and well as practical application of those principles is a thrust of ASCE in this regard.

A First Course in Structural Analysis

Given the previous discussion, the authors offer the following suggestion for the content of a first course in structural analysis. Included with the content suggestions are brief comments as to the rationale for including that content.

1. Loads and Load Distribution in Structural Systems
   Fundamental to structural engineering is an understanding of loads acting on a structural system, the envelope of design forces, and the importance of relevant building codes in regard to minimum acceptable design loads.

2. Virtual work for statically determinate and indeterminate structures
   Through a firm understanding of energy methods students can develop an understanding of the fundamental behavior of structural systems. Most methods of structural analysis are based upon energy methods, or at least have their root in the potential energy in the system. Further, virtual work is used in the development of advanced analysis procedures incorporated in finite element methods.

3. Slope-Deflection method for Statically Indeterminate Structures
   The value of the slope-deflection method of structural analysis is that it provides the students with an easily understood set of simultaneous equations describing the behavior of a structural system. Such a solution reinforces the concept that all pieces of the structure act "in concert" with each other. It also establishes the context for discussions about matrix methods.

4. Moment Distribution
   The value of moment distribution is that it provides a quick means to analyze simple structural systems and can be used as a quick check of computer based analyses. Moment distribution is taught at an "exact/approximate" method analysis. The exactness increases as the number of distribution cycles increases.

5. Introduction to Matrix methods
   Knowledge of matrix methods is fundamental to computer based structural analysis. Such methods need to be incorporated at the introductory level in a first course.

6. Structural analysis and modeling using commercial software.
   The students should be exposed to the practical application of structural analysis, and indeed to the implementation of the theoretical principles discussed in class. Formal lecture periods are not devoted to this topic. Rather, it is incorporated into class throughout the semester as other methods of analysis are discussed. Very effective use can be made of structural analysis software when discussing loads acting on structural systems and the distribution of loads through the systems. Using software, students can easily vary the magnitude and location of loads acting on the system and observe the effects of those changes.

This content matter represents that of the first course in structural analysis taught in the Department of Civil and Construction Engineering at Western Michigan. The syllabus for that course is presented in Appendix 1. This course is taken by both the civil engineering and the construction engineering majors. Students interested in structural engineering would take additional structural analysis courses dealing with fnite element methods and structural dynamics at some point in their formal education.

The authors recognize the importance of using computers and computational software in education to provide students with practical knowledge of their use. However, learning and understanding the fundamentals of structural analysis cannot be ignored. Further, by teaching the content outlined above, when students use software they will:

1. have a better understanding and utilizing of these software,
2. be better able to interpret the computed results,
3. be able to perform quick checks and validation of the results, and
4. be able to develop and enhance computer-based tools.

A Philosophical Comment

When finalizing their position on this subject, and completing this paper, the authors received a copy of *Structure*.[3] Upon leafing through this publication, numerous phrases and statements caused the authors to reflect upon that which is necessary in the future. These statements include "Celebrating 100 Years of Concrete Innovation," "Concrete Diaphragm Wall Construction," "What do you do when it is not economically feasible to 'anchor' an earth support wall into stiff soils to gain fixity?" and "Lateral Wall Movement and Adjacent Construction." The introspection that occurred was along the line "Are we providing our students with the fundamental knowledge necessary to learn to address these and similar evolving issues after they have graduated and as they progress through their engineering career?" Through this introspection the authors reaffirmed their position, and that of the department, regarding two aspects of engineering education. These aspects are:

1. The focus of the educational process for engineers must be on "why" systems behave in a particular manner and on providing the necessary skills and knowledge to interpret that behavior. This concept is diametrically opposed to teaching "how." Further the authors believe that education does not end upon graduation. Rather it continues throughout an engineer's professional career. Engineering students must learn how to learn outside the classroom and after graduation, and must be given the tools by which this learning can occur.

2. Practical application of the fundamental principles discussed must be incorporated into the educational process. This is necessary so that graduates can be effective shortly after graduation.

Conclusions and Observations

There is no question that the computational resources available to students and practicing engineers alike have significantly changed in the last 25 years, and that these changes have brought on the need to evaluate the content of all courses in structural engineering education, and in structural analysis courses in particular. The authors firmly believe that fundamentals of structural behavior must continue to be taught. They believe this for two reasons. First, without an understanding of the fundamentals of structural behavior, there is no means available to evaluate if the computations from the computer are correct for the intended structure. Second, without a firm understanding of the fundamental principles, the tools used will not continue to advance—there will be nobody available to advance existing tools and develop new tools. To advance the tools used for system analysis, the engineer must have a firm understanding of the principles of system behavior, not simply knowledge of how to enter data into a computer.

References

1. American Society of Civil Engineers (2001) "*Academic Prerequisites for Licensure and Professional Practice,*" ASCE Policy Statement 465.

2. American Society of Engineers (2003) "Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future," Body of Knowledge Committee of the Committee on the Academic Prerequisites for Professional Practice.

3. National Council of Structural Engineers Organizations (2004) *Structure*, Volume 11, Number 1.

Biographical Sketches

JAMES K. NELSON is Professor and Chair of Civil and Construction Engineering at Western Michigan University and was previously chair of civil engineering at Clemson University. At Western Michigan University, Dr. Nelson has led the faculty in implementing a curriculum for civil engineering that is based on Policy Statement 465 and the Body of Knowledge for Professional Practice prepared by the American Society of Civil Engineers. Dr. Nelson has co-authored undergraduate textbooks dealing with structural analysis, structural steel design, and reinforced concrete design. In addition, he has developed software for three structural analysis and design textbooks, and is one of two authors of software for masonry design that has become widely used in industry.

SHERIF YEHIA is an Assistant Professor of Civil and Construction Engineering at Western Michigan University. His principle teaching and research responsibilities are in the area of structural engineering. Before joining the faculty at Western Michigan University, Dr. Yehia was the assistant director of the Structures and Materials Laboratory at the University of Nebraska. He has over 15 years of academic and research experience in structural engineering.

Appendix 1—Syllabus for Structural Analysis Course Taught at Western Michigan University

Civil and Construction Engineering

CCE 386—Structural Analysis

Course Syllabus

Course Description:

Introduction to structural systems; structural requirements; structural systems and specification of loads; analysis of statically determinate and indeterminate structures using equations of equilibrium, moment distribution, and energy methods; determination of design forces in the structural components including shearing force and bending moment diagrams; and brief introduction to the direct stiffness method. (3 hours credit)

Course Objectives:

- To learn how to estimate the magnitude of the loads acting on a structural system
- To learn how to determine the distribution of the applied loads through a structural system and the forces that occur in each component in the structure
- To learn how to calculate structural deflections

Prerequisite Requirements:

ME 257—Mechanics of Materials

Textbook:

Structural Analysis: Using Classical and Matrix Methods (3rd Edition)
By: James K. Nelson, Jr. and Jack C. McCormac
John Wiley and Sons, © 2003

Course Outline:

1. Introduction to structural analysis
2. Estimation of design loads
3. Static equilibrium of beams, frames and trusses
4. Shearing force and bending moment diagrams
5. Analysis of statically determinate trusses using
6. Influence lines for statically determinate structures
7. Introduction to calculating deflections
8. Calculating deflections using energy methods
9. Analysis of statically indeterminate structures using energy methods
10. Application of the slope-deflection method to statically indeterminate beams and frames
11. Application of moment distribution to statically indeterminate beams and frames