Introducing Projects into Undergraduate Structural Analysis

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Abstract

The civil engineering department at Texas A&M University has modified the standard introductory undergraduate structural analysis course to incorporate team projects based on realistic structural systems. These projects are open ended problems with multiple possible solutions and are designed to emphasize interpretation of numerical results rather than pure numerical computations. As such, they serve to improve learning outcomes through critical thinking and evaluation. To accomplish this goal and emphasize good written communication skills, a detailed written report and discussion is part of the submission requirement and counts as a third of the project grade. As the problems posed are more realistic than standard homework assignments, the structures to be analyzed are more complex and computer software applications are used to solve the numerical component of the projects. The course content was modified to include how to convert a physical system (structure and corresponding loads) into the most adequate mathematical model in order to perform the analyses. Additionally, approximate methods were brought back into the course, and the students are required to use them to evaluate the results from the computer software package. This requirement is important in addressing a major deficiency that many new graduates have: the lack of ability to evaluate whether the computer results make sense or someone committed an error in the input. Course materials (including projects); student acceptance and performance; and course assessment and evaluation will be addressed in the paper.

Introduction

The many education conferences, workshops, and sessions on engineering education that have taken place over the last two or three decades seem to indicate some degree of dissatisfaction with the way we are educating civil engineers[1,2]. The advances in computation and information technologies have affected significantly the role that civil engineers will play in the future. As a result, the material they should be learning must also change.

One deficiency frequently identified in current civil engineering undergraduates is the lack of training on how to convert a physical system, such as a structure, into the most adequate mathematical model, in order to perform the analyses. Another problem, closely related to the previous one, is the students' lack of feeling for the order of magnitude of forces and deflections. Students are unable to check in a fast, simple, way whether the computer results make sense or someone committed an error in the input. More importantly they lack any feeling about how the structure behaves.

To address these issues, the standard structural analysis course was modified to incorporate team projects based on realistic structural systems in addition to standard homework assignments. Within these projects, students:

a) Get exposed from the first analysis course to actual structures instead of only their mathematical models, and learn why the structural type was selected, how the analysis model was constructed, how the loads were determined, how to estimate initial dimensions, etc.
b) Learn in a rigorous way the basic principles of structural analysis, then in detail simple approximate methods to estimate forces and deflections, conducting finally more accurate analyses with existing computer software to assess the validity of their estimates.
c) Use computer software to carry out a large number of analyses of actual or realistic structures to gain familiarity with the expected order of magnitude of dimensions, loads, forces and deflections and the structural behavior. This should provide experience equivalent to various years of practice in an engineering office. It requires a careful selection of the appropriate structures.

Traditional course content has been used for the most part. However, significant time has been spent on modeling, loads, and approximate methods. It would be difficult to incorporate the projects into a class that did not include these topics. To make room for these topics, our course includes less of the "classical" methods than did the course offered in previous decades. Most notably, virtual work and slope deflection are included; moment distribution is not. A list of course topics is given in Appendix A.

Problem Description

This course incorporates a project-based approach in order to relate basic concepts to real engineering problems[1]. Such an approach is expected to improve students' understanding, motivation and creativity. The projects in this course are all centered on different realistic civil engineering systems, with loading specified according to *ASCE 7 Minimum Design Loads for Buildings and Other Structures*[3]. These projects have several objectives: (1) to allow students to tackle larger and more realistic civil engineering analysis problems, (2) expose students to computer software packages available for structural analysis, (3) evaluate critical thinking and communication skills. The projects are designed to be solved by student teams, who are told they are acting as consultants on the project posed. The students are presented with a scenario (building location and function) and a possible structural system design. The students are asked to evaluate the proposed solution and develop at least one alternative design for the project.

They must make a recommendation in their final report, and the basis for their recommendation must be clearly linked to their analysis. Students are asked to consider both purely structural considerations as well as other factors, such as constructability and const. This approach forces the students to think about the significance of their results, rather than blindly crunching numbers.

A sample project from the Fall 2004 semester is included in the Appendix B. As the students are expected to use structural analysis software to calculate the response, the emphasis of the project is on the modeling of both structure and load, and the interpretation of the results. As loading descriptions are taken from the code, students are frequently uncertain about exactly what is meant by different problem definition statements. For example, in the project presented in the Appendix, a common question concerns how to interpret the fact that some loads are based on "horizontally project area" of the roof. Even in this simple problem, some modeling assumptions have to be made. Specifically, students must decide how to handle the self-weight of the structural members. For most students, this situation is the first time they are exposed to the fact that there is no single correct way to solve a problem.

The evaluation process is also open ended. While questions are posed to help students consider different issues, no hard criteria are provided. Frequent questions arise along the lines of "but which is more important: smaller deflections or forces? And if the system has a better structural response but is more expensive, is that ok?" These decisions are left to the students, and they must decide as a team how to weigh all the different factors.

Student Reception

Typical comments from students about the projects include:

- "I seriously enjoyed doing the project. I felt as though I could show my understanding of the class in these projects."
- "The projects helped tie the material together."
- "I could see how a structural engineer would actually do this in practice."
- "Being able to explore different truss configurations was very interesting. It really gave me a feel for these systems and how loads get transferred."

The one consistent complaint from the students is the time required to pull the project together. Recently, in part because of the time commitment, the number of projects has been reduced from three to two. In addition, intermediate deadlines have been added to each project. Although we do not need intermediate products, these deadlines have been useful in helping the students avoid procrastination, **and** perhaps have further reduced the perceived workload. Of course, reducing the amount of required homework also would reduce the *perceived* workload, while possibly increasing the amount of time the students have to spend on the projects "figuring out" what they would have learned from the homework. Additionally, the projects comprise a large percentage of the final course grade: more than the individual homework average and the same percentage as a mid-term exam. Reminding the students of the weight these projects have on their final grade helps mitigate work-load complaints.

Mid-term and final course evaluations for this class reflect that, though students find the course challenging, they indicate that this course is one where they see how the material relates to the practice of civil engineering. The results from three questions in the final course evaluations from the Fall 2004 are presented in Table 1.

Table 1. Results from Final Course Evaluation in Fall 2004

Rank	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Projects provide insight into application of material to real problems	12	22	7	2	
Projects enhanced my learning	8	24	7	3	1
Projects challenged me to utilize my knowledge fully	10	25	5	2	1

In spite of the complaints about the work required to complete the projects, the vast majority of the students "agree" or "strongly agree" with the stated value of the projects.

Conclusions

The addition of these projects is providing an important tie between the introductory structural analysis course and the follow-up design courses. A student from a previous semester sent one of the authors the following email after returning to the university in the fall:

"I just wanted to let you know that, though we complained about the work involved, the project you assigned in 345 was exactly what I ended up doing this summer at my internship. It really helped that I had already done something of this nature!"

We also believe that the incorporation of open-ended, real-world, design-like projects has tremendous pedagogical value. At the very least, it demonstrates to students what they do and do not know. At the best, it provides the context to make the theory learned in the classroom meaningful.

References

1. Mahendran, M., 1995, "Project-Based Civil Engineering Courses", *ASEE Journal of Engineering Education*, Vol 84 (1), pg. 1-5.

2. Roesset, Jose M.; Yao, James T. P., 2001, "Suggested topics for a civil engineering curriculum", *2001 ASEE Annual Conference and Exposition: Peppers, Papers, Pueblos and Professors,* p 9195-9204
3. American Society of Civil Engineers, 2002, ASCE 7 Minimum Design Loads for Buildings and Other Structures, SEI/ASCE 7-02.

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Appendix A – Course Topics

1. Introduction to course
2. Loads: types of loads, modeling, code provisions
3. Review of equilibrium principles
4. Determinacy and stability
5. Introduction to a structural analysis software package
6. Determinate Trusses: Method of Joints, Method of Sections, Zero Force Members, and Stability
7. Determinate Beams - Shear and Bending Moment Diagrams; Deflected Shapes
8. Determinate Frames
9. Virtual Work: Application to analysis of trusses; Application to analysis of beams and frames under bending; Members with both bending and axial effects
10. Flexibility Method - External Releases, Internal Releases, Temperature Change, Fabrication Errors, Multi-Degrees of Indeterminacy, Support Settlements, Elastic Supports
11. Influence lines for determinate structures
12. Analysis under moving loads
13. Influence Lines for indeterminate structures
14. Pattern loads & Moment Envelopes
15. Slope Deflection Method
16. Approximate Methods of Analysis
17. General Introduction to Stiffness Method
18. Direct Stiffness Method - Beams/Braced Frames

Appendix B – Roof Truss Project

You are the consulting engineer on a project and are being asked to evaluate the roof designs for a small warehouse. The primary design being considered is composed of Pratt roof trusses that are uniformly spaced at every 15 feet. A drawing for a similar truss is given in Figure 1. However, your truss has 6 equal width panels as opposed to 4. Additionally, it must span a horizontal distance of 42 feet, and the overall height at the peak is 18 feet from the bottom chord. All elements in this preliminary design have uniform cross-sections of $4in^2$. The second design being considered, a Howe truss, is utilized to support the same roof. In addition to evaluating these two proposed designs, your design firm will also propose a third alternative solution.

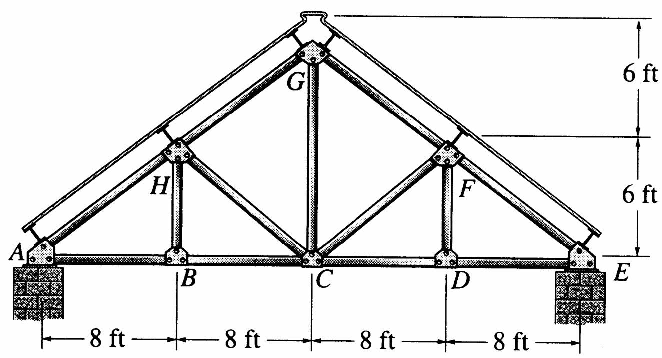

Figure 1 – Illustration of Pratt Truss

Loading Information:

- The deck, roofing material, and the purlins have an average weight of 5.6 lb/ft^2.
- The truss members are made of aluminum, with a weight of 165 lb/ft^3.
- The building is located in New York State where the anticipated snow load is 25 lb/ft^2 and the anticipated ice load is 12 lb/ft^2. These loadings occur over the *horizontal projected area* of the roof and act vertically downward as governed by gravity.
- The anticipated roof live load for Flat or Pitched roofs is given by (from ASCE 7-02):

$$L_r = 20R_1R_2 \text{ with limiting values given by } 12 \le L_r \le 20$$

where L_r = roof live load in lbs/ft^2 applied on the *horizontal projection* of the roof; and R_1 and R_2 are reduction factors given by:

$$R_1 = \begin{cases} 1 & \text{for } A_t \le 200 \text{ ft}^2 \\ 1.2 - 0.001A_t & \text{for } 200 \text{ ft}^2 < A_t \le 600 \text{ ft}^2 \\ 0.6 & \text{for } 600 \text{ ft}^2 < A_t \end{cases}$$

$$R_2 = \begin{cases} 1 & \text{for } F \le 4 \\ 1.2 - 0.05F & \text{for } 4 < F \le 12 \\ 0.6 & \text{for } 12 < F \end{cases}$$

where A_t = tributary area in ft^2 supported by any structural member and F = slope of the roof found by number of inches rise (vertical change) per horizontal foot (horizontal change).

- For the moment, wind and earthquake loads will be neglected.

Support and Member Connectivity Information:

The truss has bolted connections to the supporting load bearing walls. However, the connection on the right side is designed to allow horizontal translation to occur at that joint. The purlins are angled along the top members of the truss and are connected such that both horizontal and vertical force components can be transferred to the truss.

Tasks:

a. Determine the concentrated forces applied by the purlins on the truss due to the dead load, snow loads, ice loads, and roof live load individually. Identify the distinct factored load combinations applicable to this system (given the applied loads some factored combinations may end up looking identical when non-applicable loads are removed). Look carefully at the handouts from ASCE 7-02.

b. Use Visual Analysis or other structural analysis software program (such as RISA) to analyze *both* truss types. Enter individual unfactored loads as individual Service Cases in Visual Analysis. Then create a Factored Case for each applicable factored load combination identified in part (a). In this manner, you allow the software to scale and combine the different load types. Perform a First Order Static Analysis on all the factored combinations.

c. Document your results for both trusses using the clearest way to convey the information (the method is up to you). You must present information on reactions, member forces, and joint displacements. Include in the Appendices: a printout of the truss drawing from Visual Analysis showing both node and member numbering, a printout of the deflected shapes, and a text report from Visual Analysis using the Basic Static Results option from the Report menu. Be sure and do some handwritten checks of your analysis (you don't have to solve for all member forces, but you should check at least 3 members). Remember that one of the criteria your report must address is do the results make sense and match expected results.

d. Evaluate the numerical results. Some questions to consider: What are the peak tensile and compressive member forces? What is the maximum vertical deflection over all the joints in the truss? At what joint does the maximum deflection occur? (You must answer these questions for both truss types). Do these values seem reasonable?

e. In your role as a consultant, you wish to offer a third truss design for the roof system that will, hopefully, outperform the two designs currently being considered. You must keep the overall span of the truss the same, though the height may be different (you may want a flatter or steeper roof). You may change the number of panels in your new truss system. To support the roofing, place a purlin at each joint connection along the top of the truss. You may then need to recompute the loading condition. You may want to <u>initially</u> keep the same material and cross-sectional properties and try several different truss configurations – this process will help identify how external forces travel through this system to the supports, which will help you in selecting (and explaining your selection in your final report). However, you are free to change all design parameters except the material (keep it aluminum). You will probably try several different design changes before selecting your final alternative. Document and discuss your results for this truss: What are the resulting member forces? What is the maximum vertical deflection over all the joints in the truss? At what joint does this deflection occur? Again, document your work and place in the Appendix.

f. Compare the behavior of the three truss systems you have analyzed. What are the consequences of the change in truss type? Be sure to compare and discuss the differences member forces (both magnitude and tension/compression analysis – what possible failure mode happens in compression that may cause problems? So is it better to have members in tension or compression?) and in the maximum deflections for the two truss types. You may and should consider other considerations such as constructibility and cost. Which structural system would you recommend and why? How do you expect consideration of the lateral loads (wind and earthquake) to change your results? Assume cost for the truss is proportional to member volume (length * cross-sectional area) and number of connections. You may also wish to consider peak clearance under the roof as a performance criteria.