2006-2582: PROJECTS IN DEPARTMENT-WIDE JUNIOR CIVIL ENGINEERING COURSES

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Projects in Department-Wide Junior Civil Engineering Courses

Introduction

The civil engineering department at Texas A&M University (TAMU) has modified two junior-level courses, dynamics and introductory structural analysis, to incorporate design-oriented team projects based on realistic civil-engineering systems. This change represents a move towards project-based learning, a pedagogical approach that closely models engineering practice. 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. In addition, the project teams serve to give the students experiences intended to improve ABET[1] and TAMU departmental outcomes, specifically:

TAMU 1. Ability to apply knowledge of basic mathematics, science, and engineering [ABET a]
TAMU 2. Ability to function on multi-disciplinary teams [ABET d]
TAMU 3. Ability to formulate and solve civil\ocean engineering problems [ABET e]
TAMU 4. Ability to communicate effectively (verbal & written) [ABET g]
TAMU 5. Ability to use computers to solve civil\ocean engineering problems [ABET k]

These projects have several objectives: (1) to allow students to tackle a larger and more realistic civil engineering dynamics problem, (2) expose students to computational tools used in solving problems, (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 (TAMU 2). 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 content in these courses 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 (TAMU 1 and 3). To 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 (TAMU 4). Additionally, the students are required to use approximate methods to evaluate the results from the computer software package (TAMU 5). 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.

This paper discusses the changes in the courses and the implementation of the projects. Assessment and evaluation of the impact of these projects include data from faculty and students. These include an evaluation on how the courses and projects address specific Department and ABET outcomes. Student perceptions are evaluated immediately at the conclusion of the course and substantially after the conclusion of the course, for example in a follow-on course. Performance in a senior design course is used to compare the impact of having exposure to these projects prior to the complete design experience at the senior level.

Course Modifications

Like problem- or project-based learning (PBL) students develop a deeper understanding of the subject area by focusing upon a realistic problem[2,3,4]. Like PBL our goals are to aid students in the acquisition of critical knowledge, problem solving proficiency, self-directed learning strategies, and team participation skills. Unlike PBL, where students work in small groups to explore and develop a solution to a "real-world" problem under the guidance of a facilitator/instructor, projects in these courses are used as a supplement to traditional instruction. By requiring students to expand on course material to tackle a bigger problem, we (like PBL) hope to encourage students to take charge of their own learning.

Something significant cannot be added without consideration of what should be deleted. The depth of understanding that can come from a project is well worth the sacrifice of ***some*** superficial learning on selected topics. Typically, several methods for computing deflections, frequencies, etc are included in junior level analysis courses. These topics are still covered in the courses, and it would be difficult to incorporate the projects into a class that did not include them. However, only one or two methods are now covered, to allow for time to discuss topics and discussions specifically on project topics. For example, in the structural analysis course significant time has been spent on modeling, loads, and approximate methods. Specific changes in the individual courses are contained in previous papers by the authors[5,6]. Choice of topics to be covered or omitted from a course cannot be made in a vacuum, and should be made in consultation with instructors of parallel and subsequent courses.

The insertion of projects into an existing class is not without peril. Students are used to homework and quizzes; they do not learn the same things from projects; and often do not feel that projects prepared them *"for the exam"*. The most frustrating comments come from those who *"LEARNED THE MOST FROM THE PROJECTS"*, while complaining that the projects took to much time, hurt their grades as they could not spend their time in other course activities. In short, our goals of student learning don't match well with their goal of maximizing grades.

Part of the student discomfort can be addressed by explicitly telling them that the projects are geared towards developing and assessing a different set of skills than homework and exams. The projects are graded based on their analytical content as well as the evaluation and presentation of the results, and this fact must be emphasized to the students. Appendix A contains a sample grading rubric for the report component of the projects, which is worth 30% of the final project grade. Additionally, the project grade must be a significant percent of the final course grade in order for the students to take the experience seriously and gain the benefits from the experience. In our experience, the projects must be a minimum of 10% of the final course grade to achieve this.

Projects

These projects have several objectives: (1) to allow students to tackle a larger and more realistic civil engineering dynamics problem, (2) expose students to computational tools used in solving civil engineering problems, (3) evaluate critical thinking and communication skills. The projects are designed to solved by student teams, who are told they are acting as consultants on the project posed. These projects are open ended problems with multiple possible solutions and are designed to emphasize interpretation of numerical results rather than pure numerical computations.

Both the scope and nature of the projects can be seen in the sample projects that are given in the appendices (Appendix B is a project from the structural analysis course, and Appendix C is a project from the dynamics and vibrations class). While the reader may view the instructions as *"handholding"*, it should be noted that the students typically view them as *"vague"*. It is essential that the instructor balance the student need (or desire) for explicit instructions with the learning which comes from struggling with:

- Choosing the best approach/theory to tackle the problem;
- Making appropriate assumptions; and
- Evaluating (often conflicting) results.

It also should be emphasized that the link between the theories and concepts presented in class and the real world projects ***is not obvious to the students!*** Some students fail to see any connection between the homework, exams & the projects even when links are made explicit in the class. Similarly, we have found it necessary to emphasize the links between the content of other courses (past, concurrent, and future) and what is happening in our classes and class projects.

Perceptions of Students in Course:

At the end of the semester, students are surveyed regarding the course; including questions related to how much the course met the specified ABET outcomes and how different course components enhanced their learning of the material. Table 1 shows the results of the questions regarding ABET outcomes from the Fall 2006 in both CVEN 345 Theory of Structures and MEEN 363 Dynamics and Vibrations. In general, students agree that both courses do add to their knowledge and skills in the specified ABET outcomes. In the dynamics course, students were somewhat neutral in the outcomes related to communications and computer skills.

Typical comments from students about the projects in the structural analysis course 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."

In the dynamics and vibrations course, although we still get a few "as a civil engineer I will never need or use this!" comments; more often we hear:

- "I finally am taking an engineering course where I feel like I can or will use this in the 'real-world'"

- "One of the best things was when you showed how this directly applies to a civil engineering problem" (referring to how to model civil systems using a masses and springs MDoF model)
- “The projects really helped to bring concepts to life”
- “The projects were the heart of my interest for the class. Without civil application I could care less about dynamics.”

Table 1: Student Perception on Course Adding to their Ability in Specific ABET Outcomes

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Ability to apply knowledge of basic mathematics, science, and engineering					
CVEN 345	17	29	3	1	0
MEEN 363	12	22	9	1	2
Ability to function on multi-disciplinary teams					
CVEN 345	21	26	2	0	0
MEEN 363	6	16	11	8	5
Ability to formulate and solve civil\ocean engineering problems					
CVEN 345	18	17	8	4	3
MEEN 363	10	26	6	3	1
Ability to communicate effectively (verbal & written)					
CVEN 345	10	20	16	2	2
MEEN 363	4	12	19	9	2
Ability to use computers to solve civil\ocean engineering problems					
CVEN 345	16	29	3	2	0
MEEN 363	2	14	16	10	5

Not all students were positive about the projects and the following comments illustrate two common themes:

- “The projects was a distraction from learning the material I needed to know for the final”
- “Most of the assignments and projects were confusing and ill-prepared. Students had trouble figuring out what it was we were supposed to be doing.”
- “The projects were frustrating because we didn’t always know exactly what we were supposed to be doing. I did however learn a lot by struggling through them.”

The first comment illustrates how some students are focused on exams and the grade, rather than on learning the material. The second comment is related to the discomfort most students feel when first presented with a realistic and open-ended problem.

Mid-term and final course evaluations for this class reflect that, though students find the course challenging, they indicate that these are courses where they see how the material relates to the practice of civil engineering, and that these connections enhance their learning of the material. Table 2 shows the student’s responses to questions regarding course overall.

Table 2: Results from Final Course Evaluation in Fall 2005

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Course emphasizes understanding vs. memorization					
CVEN 345	36	10	2	1	1
MEEN 363	22	19	3	2	0
Use of CE examples played a large role in learning the material					
CVEN 345	15	26	7	1	1
MEEN 363	6	18	15	6	1
Projects added to my understanding of course material					
CVEN 345	15	27	4	3	1
MEEN 363	3	12	16	13	2
I have learned a great deal in this course					
CVEN 345	25	21	4	0	0
MEEN 363	10	21	7	6	2

The one consistent complaint from the students is the time required to pull the projects together. Mid-term and final course evaluations for this class reflect that, though students find the course challenging, they indicate that these courses are one where they see how the material relates to the practice of civil engineering. The results from three questions related to the project are presented in Table 3. The results for MEEN 363 Dynamics and Vibrations are not as good as for CVEN 345 Theory of Structures. In part, these results can be attributed to the fact that some students still don't see the relevance of dynamic principles to their specific specialty area within civil engineering. Also, dynamics is traditionally a much harder course than static structural analysis for engineering students of all disciplines.

Table 3: Student Perception on How Projects Enhanced the following

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Critical Interpretation Skills					
CVEN 345	36	10	2	1	1
MEEN 363	4	12	20	8	2
Connection Between Concepts					
CVEN 345	15	26	7	1	1
MEEN 363	2	10	20	12	2
Motivation for Course Concepts					
CVEN 345	15	27	4	3	1
MEEN 363	2	9	13	19	3

Faculty Perceptions

As students see the connection of the course material with actual application in civil engineering practice, they are more engaged in learning the material. During the course of the semesters several seminars are presented that relate to dynamics applications in different civil engineering specialties. While these seminars are geared to graduate students, undergraduates in this course are encouraged to attend and offered a small amount of extra credit for writing a summary of the key topics. These summaries indicate that the students do follow the key ideas presented in most cases, and the better students frequently come and discuss the ideas with the instructor after class.

This exposure to cutting edge design and research opens the students to the possibilities for research. The projects also increase student confidence that they can successfully tackle larger problems that deal with advanced topics. Two undergraduate students who took the course in the Fall of 2002 were recruited to participate in research on structural health monitoring. Very few undergraduates participate in undergraduate research within our department, and none were previously involved in dynamics research in any meaningful way. These students each worked on a research project for about a year. At the end of their experience, they also wrote a short conference paper and gave a presentation at a seminar for undergraduate research. Both are currently in the graduate program at Texas A&M. Another student is currently working on his Honors thesis in relating to dynamics. Three other students were involved in undergraduate research projects in the Spring and Fall of 2005 after taking the dynamics course, and two will be starting graduate school in structural engineering in the Fall of 2006. Both of these students have expressed interest in continuing research in a dynamics related field and explicitly stated that MEEN 363 was their motivation for advanced studies.

Former Student Perceptions:

The addition of these projects is providing an important tie between the introductory structural analysis course and the follow-up design courses as well as work done in engineering internships. A student from CVEN 345 in a previous semester sent one of the authors the following email:

“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!”

Students in the senior level reinforced concrete design were surveyed to determine student perception substantially after the conclusion of the structural analysis course. Students in the concrete course had taken the structural analysis course at various different semesters (ranging from Fall 2003 to Summer 2005) and under at least four different instructors. They were first surveyed as to how the structural analysis course they took met the specified ABET outcomes, and the results are shown in Table 4.

In the final course evaluation, students were also asked how the project in CVEN 345 aided in their understanding and ability to complete the reinforced concrete course project. The survey asked how strongly they agreed with a series of statements regarding the structural analysis course project. The results are shown in Table 5.

Table 4: Reflecting back on CVEN 345 and its ABET Outcomes

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Ability to apply knowledge of basic mathematics, science, and engineering	17	29	3	1	0
Ability to function on multi-disciplinary teams	21	26	2	0	0
Ability to formulate and solve civil\ocean engineering problems	18	17	8	4	3
Ability to communicate effectively (verbal & written)	10	20	16	2	2
Ability to use computers to solve civil\ocean engineering problems	16	29	3	2	0

Table 5: Impact on Structural Analysis Project in their Ability to Complete Senior Reinforce Concrete Design Project.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Previous exposure to determining load patterns and demand envelopes helped you in completing the first part of the design project	13	15	5	2	0
Projects in CVEN 345 helped you in this course?	8	16	7	2	1
The project in CVEN 345 added to your skills in writing technical reports	9	10	12	4	0
Working in teams was an important skill in successfully completing the project	20	19	2	3	0
The required evaluation of the system response in the projects help your critical interpretation skills	10	16	13	3	0
Previous use of an analysis software package (such as Visual Analysis) help you in learning ETABS	9	18	7	6	1

Typical positive comments collected include the following:

- I enjoyed the CVEN 345 project because of its application to "real world" problems. Although each step of the project was challenging, this project taught me successfully taught me how to completely analyze a structure. By talking to my peers in other sections, I realized that completing the project was much easier when the student had the professor that actually wrote up the project.
- I learned a great deal about determining applicable loads, load patterning, and tributary area. The project allowed me to fully understand the endless design possibilities. The project was wonderful in that it tested our grasp of all of the CVEN 345 course material.
- The project is very similar to the concrete as far as the thought process required, but the CVEN 444 project takes it a step further and requires the actual design of the members in the structure.
- The project that has helped me the most on this current project is the one from CVEN 345. I not only learned how to correctly analyze a structure, I also learned how to write an effective report.

The first comment above also points to a source for some of the negative comments. The instructors actively involved in developing the course projects typically are more explicit about linking the project tasks to the different course topics. As such, students in those sections see the links and motivation behind the required activities. However, other instructors were not as explicit about demonstrating those connections. So while the same material was covered and the same project was completed in different sections, students had very different experiences and perceptions of the projects. Some typical negative comments are:

- It was very tedious and confusing. Mostly busy work.
- The project was never well explained and we didn't get much help so I don't believe I learned much because we just did what we thought was right
- The project was not easy to comprehend what we were doing until we were on one of the last parts...this led to not understanding the project fully in the end.

Student Performance in Later Courses

1. Performance in undergraduate concrete design course

The first part of the course project in the senior concrete design class is the computation of the force and moment demands on a frame structure. Students are required to determine the appropriate loads, establish load patterns for the live loads, and develop the envelopes to capture the worst-case scenario over all patterns and factored load combinations. As such, this part of the project is very similar to the final project in the structural analysis course, CVEN 345. The CVEN 345 project also asks students to consider how they could improve structural performance by changing the structural system. As they are using finite element analysis software, they accomplish this through trial and error, and in the process become exposed to thinking from a design perspective.

The course project for reinforced concrete design involves the member design of a multi-story office building, starting from the calculation of member demands. In previous years, the class average on the analysis component of the project has been traditionally low. For example, in the Fall of 2000, that project component had a class average of 79, with the highest grade being a 90. In the Fall 2005 semester, under the same instructor as in the Fall of 2000, the average on the same project component had risen to a 90, with the highest grade being a 100. Table 6 provides the results of how different student groups performed in the concrete design course in Fall 2005. The groups are: (1) the entire class, (2) students who completed the structural analysis course with the project, and (3) students who did not have the project in their section of CVEN 345.

Table 6: Breakdown of Student Performance in Undergraduate Concrete Design.

	Entire Class	Project Experience in CVEN 345	
		Yes	No
Number of Students	57	35	22
Average on Exams			
Mid-Term Exams	76.7	80.18	74.11
Final Exam	76.2	84.18	69.87
Average Project Grade			
Analysis Project Component	89.38	92.7	86.94
Entire Course Project	92.52	95.19	90.44
Course Grade			
100 point scale	83.77	88.98	79.70
4 point scale	2.98	3.40	2.66

As expected, prior exposure to performing a demand analysis on a frame improved the students performance on that component of the project. While that group still had a better overall performance on the project, the gap between the groups became smaller. The group previous project experience also did better in the class overall, including a better performance on the exams, which also tested their ability to tackle open-ended design problems. The final exam for this course was an open book take-home exam that had individualized problem parameters.

2. Performance in graduate structural dynamics course:

One of the motivating factors for switching to the new format rather than traditional dynamics was the performance of students in the graduate dynamics course. Students struggle with the concepts and complain that it has been too long since they have seen and used the necessary mathematical concepts required, such as differential equations. We are now seeing students who had taken the undergraduate course in dynamics and vibrations entering graduate school and enrolling in the graduate dynamics course. The table below shows the average grade point averages for three different groups: (1) the entire class, (2) all students who had taken any vibrations based dynamics course, and (3) students whose only prior exposure to dynamics was the MEEN 363 course when they were an undergraduate. As expected, prior exposure to the topic improved their performance. The second group includes Ph.D. students who had taken a graduate dynamics course and, as expected, have the best performance in the course. However, the students whose only exposure was MEEN 363 also performed extremely well. The students who had no prior exposure to the material floundered, with 5 of them earning C's.

Table 7: Breakdown of Student Performance in Graduate Structural Dynamics.

	Entire Class	Taken a Vibrations Course Before	
		Any Previous Course	MEEN 363
Number of Students	30	7	4
Grade Point Average	3.30	3.86	3.75

Conclusions

To be successful, incorporating realistic project into a course requires that instructor makes explicit ties between course topics and the project tasks and outcomes. The authors strongly recommend emphasizing to the students that projects are not meant to serve as tools to master basic concepts, rather they serve to tie different concepts together and see how they are used to solve realistic concepts." The weight given to course projects in computing final course grades can aid in this if the percent is comparable to that of a midterm exam or course final.

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. The bottom line is summarized by the following CVEN 345 student quote:

"Overall this class introduced me to a more realistic approach to real world problems. It made me realize the importance of clearly understanding physical models and their behavior to certain applications."

References

1. ABET (2006). Criteria for Accrediting Engineering Programs. Engineering Accreditation Commission.
2. Polman J. (2000). Designing project-based science: Connecting learners through guided inquiry. Teachers College Press.
3. Barron, B. J. S. (1998). Doing with Understanding: Lessons from Research on Problem- and Project-based Learning. The Journal of the Learning Sciences, 7(3&4), 271-311
4. Capon, N., & Kuhn, D. (2004). What's so good about problem-based learning? Cognition and Instruction, 22(1), 61-79.
5. L.R. Barroso and J. Morgan (2005). "Introducing Projects into Undergraduate Structural Analysis," Proceedings of the 2004 ASEE Gulf-Southwest Annual Conference, Texas A&M University-Corpus Christi, Corpus-Christi, TX. March 23-25, 2005.
6. J. Morgan, L.R. Barroso and D. Childs (2004). "Integrating Rigid Body Dynamics & Vibrations: An Introductory Course for Undergraduate Civil Engineers," Proceedings of the 2004 International Conference on Engineering Education, University of Florida, Gainsville, Florida, USA. October 16-12, 2004.
7. ASCE (2002), ASCE 7 Minimum Design Loads for Buildings and Other Structures, SEI/ASCE 7-02, American Society of Civil Engineers.

Appendix A – Grading Rubric for Project Reports

	Fail 0	**Poor** 3	**Fair** 6	**Good** 8	**Excellent** 10
Organization					
Title Page Complete					
Table of Contents w/ page numbers					
All pages appropriately numbered					
Sections presented in right order					
Figures, tables, Eqns. numbered					
Figure/tables have captions					
Figures, tables referred to in text					
Calculations in appendix					
Comments:				Sub-Total:	
				$\frac{\text{Sub-Tot}}{80} \times 10\%$	

	Fail 0	**Poor** 3	**Fair** 6	**Good** 8	**Excellent** 10
Writing					
Grammar & Mechanics (ex: spelling, sentence fragments, verb-subject agreement, run-on sentence…)					
Style (ex: consistent use verb tenses, main ideas emphasized, well structured presentation of ideas, logical connections between sections…)					
Comments:				Sub-Total:	
				$\frac{\text{Sub-Tot}}{20} \times 20\%$	

	Fail 0	Poor 3	Fair 6	Good 8	Excellent 10
Content					
Executive summary				points =	
Self-contained?					
Brief overall description of problem and solution approach?					
Includes main conclusions?					
Introduction				points =	
Presents overview of problem					
Discusses main issues to be addressed					
Effectively outlines in text form what will be presented					
Problem Description				points =	
Problem accurately described					
Assumptions given and evaluated					
Drawing of system clearly labeled					
Solution procedure described					
Relevant theory presented					
Results				points =	
Clearly presented					
Effective format used (tables, graphs…)					
Explained in text					
Explanation logical and consistent					
Refer to supporting calculations					
Compared with expected results					
Emphasize main implications					
Conclusions and Recommendations				points =	
Brief summary of results & issues					
Clear recommendations					
Appendices				points =	
Separated based on content					
Calculations easily followed					
Comments:				Sub-Total:	
				$\frac{\text{Sub-Tot}}{220} \times 70\%$	

TOTAL PERCENT FOR REPORT:	

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 $4 in^2$. 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.

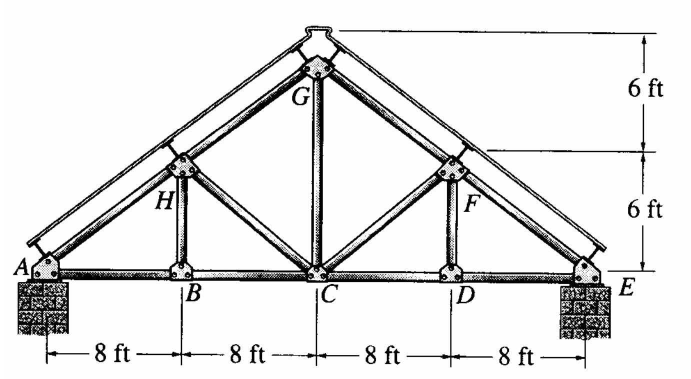

Figure 1 – Illustration of Pratt Truss

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 initially 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.

Appendix C – Modal & Frequency Analyses of MDOF System

Problem Definition:

Your engineering consulting firm is evaluating a 4-story office building in the Los Angeles area. The current proposed structural system is a perimeter moment-resisting frame, where rigid connections between beams and columns occur only on the exterior frames. You will consider two alternative solutions to improve the performance of the system: addition of braces and introduction of an isolation system. Your firm will then recommend the preferred design alternative.

Project Goal and Objectives:

1. Determine dynamic properties of existing system
2. Evaluate the frequency response of this structure by looking at response under harmonic loads
3. Determine the modal properties of the structure.
4. Determine response of structure under seismic loads
5. Evaluate the response of the structure. Parameters to be considered:
    - Peak displacement response
    - Peak interstory drift response
    - Peak base shear
6. Recommend design solution. Possible alternatives:
    - Introduction of braces at each story
    - Introduction of base isolation system

System and Loading Definition:

A typical elevation and floor plan are shown in Figures 1 and 2 respectively. You are only interested in the performance of the structure in the North-South direction.

Member Sizes

Columns: North/South			
	Story	Section	I (in^4)
	1^{st}	W14x159	1900
	2^{nd}	W14x132	1530
	3^{rd}	W14x132	1530
	4^{th}	W14x132	1530

Connectivity

1. Columns are physically one member running from ground to roof. Fully rigid connection with the ground (fixed support) for all columns.
2. Rigid connections between girders and columns. Floor beams are not shown, but they have simple pinned connections to the girders and are not expected to contribute significantly to the lateral stiffness of the system.

Loading

Typical gravity loads that this system was designed for are:

1. Dead loads – applied on floor/roof areas:
   - Steel framing –includes main girders and floor beams....................................15.0 psf
   - Floor/Roof slab (including steel deck and 6" concrete slab)...........................53.0 psf
   - Combined Ceiling & Flooring – use ½ value for roof......................................3.0 psf
   - Mechanical/Electrical ....7.0 psf
   - Roofing ....7.0 psf

2. Dead Load – Exterior Wall (exterior cladding on full structure)
   - Distributed load based on wall area ....25.0 psf

3. Live loads:
   - Typical Floor (does not include partition load) ....50.0 psf
   - Partitions on a Typical Floor..20.0 psf

- 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 one structural member (so it varies member by member), and F = number of inches rise per foot.

4. In addition, as Los Angeles is in an area of high earthquake risk, so you will have to evaluate the impact of seismic hazards using dynamic analyses. Not all loads described above contribute to the mass of the system when considering dynamic analyses. For example, live loads include occupants, which may not all be present at the time; those occupants who are present are not rigidly connected to the structure, so cannot be assumed to fully participate in the response. As such, when determining the mass of the system for dynamic analysis of *this* building take all of the system dead-load and 20% or the partition live load. If you had a different type building, you might want to consider a different percentage of the live load to be dynamically active.

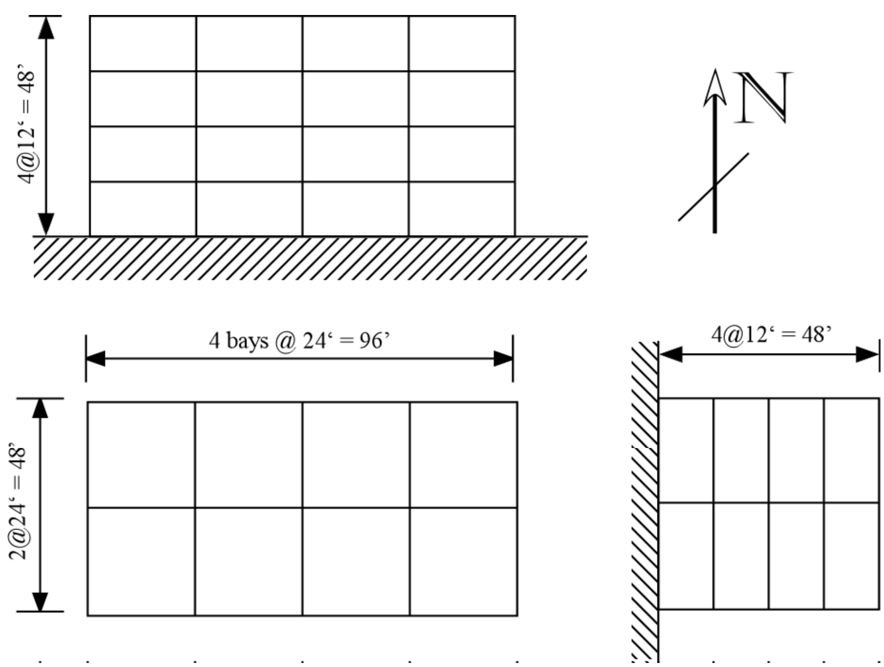

Figure 2: Floor Plan and Elevations

Earthquake Loads for Dynamic Analysis

You will investigate the forced response of this building to two different earthquakes that you believe characterize the seismicity of the area. Two files, named `eq1` and `eq2`, containing the acceleration records of these earthquakes are posted on the class website, with accelerations given as a fraction of the acceleration due to gravity. The accelerations given were measured at every 0.01 seconds. Note that all three records have been scaled to have a peak ground acceleration (PGA) of 0.8, in other words: $\max|\ddot{x}_g| = 0.8g$ (80% of gravity). You will need to multiply the values in the file by gravity to get actual accelerations values.

The response spectra for both ground motions are shown in Figure 2. Notice that these two ground motions have very different characteristics. To utilize this plot to interpret how severe the ground motions will be to your building, look at the S_a value at the fundamental, or first, period of your structure. As that mode is expected to govern the response, it will give you an indication of the expected forces your structure will experience.

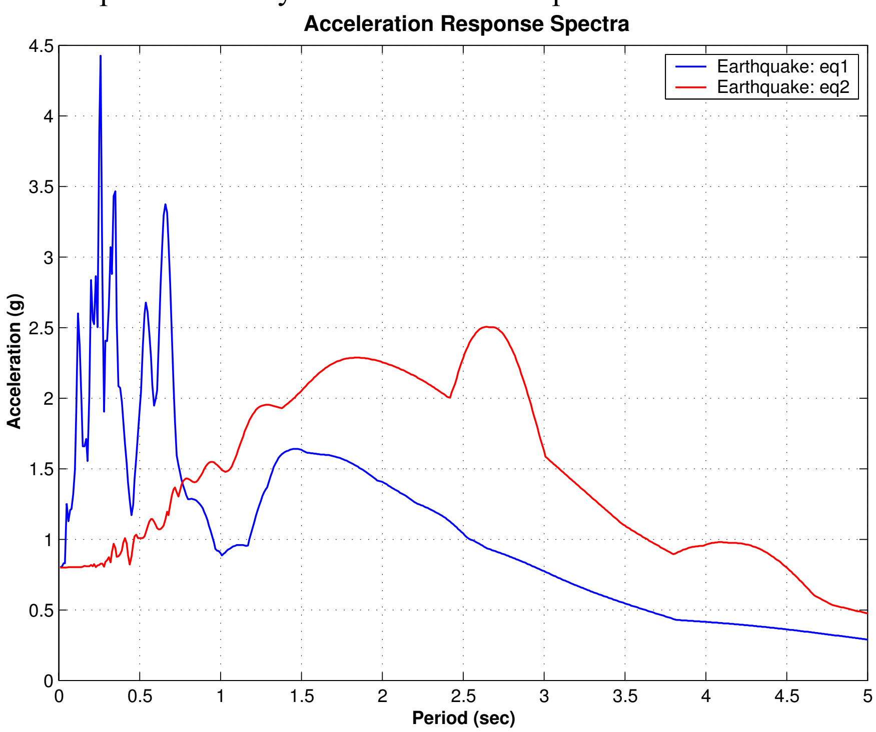

Figure 3: Acceleration Response Spectra for Earthquakes `eq1` and `eq2`

Detailed Tasks

Develop Model: Two-Dimensional Shear-Building Model of in North/South Direction

1. (Individual and Team) Determine the mass and stiffness properties for a shear building model of this building. Since all frames are fully moment resisting, they all contribute to the lateral stiffness of this structure. However, a simpler approach is to consider only one of the interior frames as representative of the full building. The mass that an interior frame carries is determined by the tributary area of that frame. In order to determine how much dynamic weight is carried by that frame, multiply the loads (given in lbs/ft^2) by the tributary area for

the frame to determine. The tributary area is found by taking ½ the distance to neighboring frame on each side and multiplying by the length of the frame. So for a typical interior frame in the North/South direction, the tributary area is = 24ft x 48ft = 1152ft^2.

2. (Individual and Team) Derive the undamped dynamic equation of motion for this system. Use displacements relative to the ground (as measured about static equilibrium) as your degrees-of-freedom. Apply a general dynamic force, $F_i(t)$, at each degree of freedom. Your equation of motion should be in the form of:

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{K}\mathbf{x} = \mathbf{F}(t)$$

Modal Analysis

1. (Individual and Team) Determine the modal properties (frequencies, $\omega_{n,i}$, and mode shapes, $\{\phi_i\}$) of your model. Normalize/Scale your modes so that the absolute value of the roof displacement is 1.

2. (Individual and Team) Assemble your modal mass, $\mathbf{M}^m$, and modal stiffness, $\mathbf{K}^m$, matrices.

3. (Individual and Team) Assemble your modal damping matrix, $\mathbf{C}^m$, using 1% damping in the first two modes and 2% damping in the third and fourth modes.

Frequency Analysis: Forced response to various sinusoidal loads of different frequencies

1. (Team) Now you need to find the response of your system to a proportional harmonic load. For this problem, assume that the forcing amplitudes on all 4 floors if constant at unity (1 kip). Let the forcing frequency, ω, vary from 0 to 120 radians/sec in increments of 1 radians/sec. You need to find the amplitude, x_{jo}, and phase, α_j, of the response of each original degree-of-freedom, and plot them with respect to the excitation frequency, ω.

2. (Team) Interpret your results: What can you infer from these plots? What is the connection between these results and the results of your modal analysis?

Total Response Analysis: Using Modal Superposition with ALL Modes

1. (Team) Create a MATLAB script that performs an analysis of the response of each mode of the structure. Your script must take general system input (mass, stiffness, damping ratios, and load information) and create the system equations in the original coordinate system. The script must then find modal properties and transform to modal coordinates. Then the response in modal coordinates is found by calling a Runge-Kutta based numerical integration routine. The results must then be transformed back to your original coordinate system.

2. (Team) Run analysis for both eq1 and eq2. Include plots on displacement response for all four floors.

Your code must also compute the drift response for all four stories. The story drift for the i^{th} story, δ_i, is defined as the relative displacement between the top and bottom of that story. By definition, the first story drift is the relative displacement of the first floor. For all other stories:

$$\delta_i = x_{r,i} - x_{r,i-1}$$

Include the plots of the drift response for all four stories in your write-up.

3. (Team) List in a table the peak absolute value of: displacement response for each degree of freedom, drift response, drift ratio, story shear. The drift ratio is a common way to normalize drift information by dividing the drift by the story height. The result is a non-dimensional fractional value. For linear analyses, drift ratios of 0.01 are considered high, but expected for severe ground motions.

   The springs in our model correspond to the columns in our building. The spring forces are, therefore, related to the total shear in the columns each story. As spring forces are proportional to the relative deformation of its ends, the story drift provides a good indication of the total story shear. To find the peak story shear, multiply the peak interstory drift by the equivalent stiffness of the story.

4. (Team) What can you infer from your results? Be sure to address the following questions, but you are not limited to only these issues.

   a. Compare the results of eq1 and eq2. Do they agree with what you would expect by looking at the Response Spectra and using information from the first mode?

   b. What is the connection between these results and the results of your frequency analysis?

   c. What can you infer about time history of story shears from your plot? Will you expect your elements to have yielded?

Estimated Response Analysis: Using Only First Mode

1. (Team) Modify MATLAB code such that only the first mode will be utilized to find the system response. You will need to modify:
   - The section where Modal Properties are determined. Suggestion – define a new variable that is composed of only the first column of $\mathbf{\Phi}$: `phi_r = phi(:,1);` Then use this variable to find your $\mathbf{M}^m$, $\mathbf{K}^m$, $\mathbf{C}^m$, and $\mathbf{F}^m$.

   - The `for` loop within the response analysis. Instead of looping through all 4 modes, you now only want it to use 1 mode.

   - The transformation back to original coordinates. Again, you will just have to use your newly defined `phi_r` for the transformation matrix. So in this situation, your transformation matrix is **not** square.

2. (Team) Run analysis for both eq1 and eq2. Include plots on displacement response for all four floors, as well as the plots of the drift response for all four stories in your write-up.

3. (Team) List in a table the peak absolute value of: displacement response, drift response, and drift ratio.

4. Evaluate how well your analysis using only 1 mode did by comparing it to the results when using all modes.

Determine an Alternate Design Solution

Your consulting group is being asked to improve the performance of this building. Two possibilities under consideration are: (a) adding bracing elements spanning every 2 stories, and (b) adding an isolation system to this structure. In the first option, your model will still have 3 degrees of freedom, but a spring connecting (1) the ground and the second floor, and (2) the second floor and the roof. In the second option, you will be adding one more degree of freedom, resulting in a 5 degree of freedom model. Evaluate both designs under consideration. You don't need physical parameters for the bracing elements or isolation bearing, equivalent stiffness values will suffice for this project. Your new system should reduce all interstory drifts by at least 25% from the original design.

1. (Individual and Team) What is the effect on the natural frequency and period of these changes? Based on the Response Spectra, do you want a stiffer or more flexible system? To what range do you want to shift your period/frequency?

2. (Team) What would be your recommendation for meeting the response criteria? Why did you choose the system you did? Give specific values for your stiffness of the bracing system or the stiffness of the isolation bearing and corresponding isolation period.