A Framework for Teaching Project Based Structural Engineering Courses

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Paul is an educator, structural engineer, and mountaineer. He holds degrees in Mechanical and Civil engineering, and is a licensed engineer in numerous states. He worked through college as a steel detailer, and spent the last 20 years working on unusual (and ordinary) projects. His favorite work is on historic, industrial structures, on the verge of falling down (or well on their way). He is the lead editor of the Architects Guidebook to Structures. In his spare time, he loves being with his wife and kids; climbing, hiking, sewing packs, remodeling the house, and living life.

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Abstract

This paper outlines how the author teaches structural design courses, set in context of actual projects. The framework mimics what occurs in a consulting office, with a focus on helping students become proficient in what structural engineers use 80% of the time. Rooted in project-based learning, students utilize ASCE 7 to calculate loads, and the associated material codes to design beams, columns, frames, walls, footings, and connections. They utilize structural engineering software for in-depth analysis and CAD software to prepare framing plans, elevations, and details. Students who are experiencing this framework are preparing a work product on-par with new practicing engineers.

1 Background

I had been a practicing engineer for four years when I first started teaching as an adjunct at the University of Utah. The real struggle of applying what I learned in school to actual design problems, and how to navigate life in a structural design office was fresh on my mind. It was rough; not something I wanted to ever repeat. I was determined to prepare my students for these realities better than I had been, but how?

As I pondered this question, I kept coming back to project-based instruction. While I did not know it by this name back then, I figured if I do projects for my job, maybe that was a good way to teach students. Although imperfect, I began to see it working. My students left school knowing how to design structures; the way they get designed by practicing engineers. This paper documents my project-based teaching methods over the last 20 years.

A vast body of knowledge exists regarding project-based learning. Rather than do the injustice of trying to summarize it here, please refer to *The Power of Project-Based Learning* [1] an expert guide on this framework. Dr. Wurdinger tells his own story of struggling to learn in the traditional lecture-based format, then expands on how project-based learning changed his life trajectory.

2 Why Teach this Way

Given the rich history of project-based teaching, it is natural to teach upper-level design courses in the context of actual projects, rather than as hacked-up bits. This is how practicing engineers work, and by teaching this way, we prepare graduates to be more capable and successful earlier in their careers.

I have observed the following significant advantages to this framework. Students:

1) Solve problems in context of an actual building or bridge.
2) Determine the loads on their structure.
3) Perform the structural analysis of their system
4) Engage in understanding and interpreting building codes
5) Learn industry- standard structural engineering software

6) Expand their nascent drafting skills
7) Understand how their decisions impact the whole design process

3 How I am Teaching

Here is the framework for how I do this.

3.1 Project Based

A design project of the student's choice is the basis of class. I provide them with general parameters, such as minimum number of bays and stories, but they have great freedom to configure their project. Some choose something basic; some choose something impressive (see

Figure 1 for an example student project). This gives them buy-in to what they are doing and presents them with the realities of conflicting decisions. Whether complex or simple, their designs are in the context of a project, and that is what opens their minds.

3.2 Structural Layout

The first submittal I require is a CAD or clean hand drawing of their structure. This includes a plan layout of columns with dimensions, and an elevation showing story heights. I started including this submittal when one of my students asked why there were not beams small enough in the steel manual. When I saw they had columns at 6'-0 centers both ways, I realized I needed to review their layout before they went down this road very far. We both learned an important lesson that day.

3.3 Focus on the Basics

Most practicing engineers are not pushing the edges of the state of the art. They are applying basic principles, over and over. For most of them, that means following material design codes like ACI 318, AISC 360, TMS 402 And the NDS. I call this the 80% principle. I would like my students to be proficient in what structural engineers use 80% of the time. This may represent 20% of the knowledge in our field, but if they cannot size a steel beam for lateral torsional buckling, it will not be of much value to know how to do a nonlinear dynamic time-history analysis. If they want to get into the nooks and crannies of our profession, I encourage them to go to graduate school.

3.4 Course Materials

For each topic, I provide my students with a PowerPoint of the key principles, clear design example, and video hitting the high points of what I want them to know. In my PowerPoint slides, I like to provide the following:

1) Failure example, to clarify how something behaves in reality
2) Code equations and definitions, tied to a clear sketch of the key variables
3) Code requirements beyond strength and deflection, such as minimum reinforcing steel in a beam
4) Drawing details showing how a given member is shown

In my examples, I like to start at the very beginning by finding the loads on the members, doing the required structural analysis, then sizing the member and ending with a clear sketch of the design.

3.5 Codes and books

I require the following codes and recommend the associated books.

Concrete Design

I require *ACI 318 Building Code Requirements for Structural Concrete* [2], and recommend *Reinforced Concrete, Mechanics, and Design* [3]. Additionally, ACI 318 Plus provides the code and two additional, fantastic resources, *Reinforced Concrete Design Handbook* [4] and *Case Study: 16 Story Hotel* [5].

Steel Design

The *Steel Construction Manual* [6] is required for my steel courses, and I recommend *Unified Design of Steel Structures* [7] to my students. Additionally, AISC provides several free resources, including *AISC 360* [8], and the *Companion to the AISC Steel Construction Manual* [9], which is replete with design examples.

Masonry Design

TMS 402 Building Code Requirements for Masonry Structures [10] is the basis of my masonry course, and I recommend [11] for additional help. These provide a sound technical basis for students.

Timber Design

For Timber, I require the *National Design Specification for Wood Construction* [12]and recommend *Design of Wood Structures* [13] for further guidance on wood design.

All the code organizations provide steep discount pricing on their products for students, making their products far more accessible.

I also recommend the *Architect's Guidebooks to Structures* [14] series published by Routledge. I edited these books, with contributions from over 20 practicing engineers and architects. They are based on the 80% principle and my course notes.

One final note on building code interpretation: I find it valuable for some submittals to not give students a well-developed PowerPoint; but rather have them read and interpret the code provisions for a specific structural element. I find this teaches them how to wrestle with the code and come up with their own interpretations.

3.6 Lessons on ASCE 7

ASCE 7 Minimum Design Loads and Associated Criteria for Buildings and Other Structures [15] is the starting point for most structural analysis in the United States. Why not make this a core part of structural engineering education?

I have two thorough lessons on this code, focused on gravity and lateral loads, respectively. These lessons are complete with examples and videos. They offer students the basics of *ASCE 7*, without spending an entire semester studying it. I require them to develop their gravity and lateral loads in a submittal, which I can then review and make sure their loads are reasonable. These same loads are used for the remainder of the course.

3.7 Submittals

The heavy work for the course comes in the form of design element submittals. Students design representative elements of their structure. These range from beams and columns to connections, and seismic systems. They follow the applicable code provisions, develop calculation submittals (see Figure 2), summarize their design results, and provide a hand sketch or CAD drawing of their final design. These submittals are required at regular intervals throughout the semester (see Figure 3). As a note, the included schedule is for an introductory structural engineering course where we spent one third of our time on analysis, concrete, and steel design. The students in this course analyzed a 3-span bridge (Figure 4), and designed key elements out of both concrete and steel.

3.8 Structural software

A few years ago, as I started preparing my lessons on indeterminate analysis, I got a dusty feeling in my mouth like I was preparing to teach my students the slide rule. The last time I did moment distribution was in 2000 during the first week of my first engineering job, because our computers had not arrived yet. Twenty-one years later, I had to ask myself why I was going to teach my students something used once in my career. I could not justify it. I changed course and taught them RAM Elements, an industry standard structural analysis and design software. They loved it. Given their generational, computer-savvy, they blew my mind with how fast they learned the software.

RAM Elements is now a crucial part of all my design classes. (They have free student licenses, as do many of the leading structural software developers.) Figure 5 shows student work completed to analyze and design a mat foundation, the way practicing engineers do it. I find it to be exceptionally valuable for students to have a full, working model of their structure early in the semester.

And lest you worry about my student's ability to solve indeterminate problems by hand, we spend several days learning approximate indeterminate solutions, which they use to validate their analysis results. Fast, effective, and realistic.

3.9 Computer Aided Drafting

Our students at UVU take one drafting class; usually in their first year. Then in Capstone we expect them to draw something. This just does not work out so well.

To help our students be more prepared for their Capstone experience, I have included full sets of example drawings, and snips of such in my PowerPoint slides. I require them to draw parts of their designs using good drafting practice. See Figure 6, for example student drafting work. I ask them to draw:

1) Framing plans and elevations calling out the members they have designed
2) Lap splice, beam, column, retaining wall, foundation, and lintel schedules
3) Details of connections, base plates, footings, and columns to name a few

3.10 Flipped Classes

Last year I decided to flip my design courses. I did this after having an impromptu discussion with a steel class on a particular connection I was designing in my professional practice. I loved how the discussion went and wanted a way to more frequently have conversations like this. I'm still adjusting this teaching method to improve its effectiveness, but here is what I do: I provide a PowerPoint, a thorough design example, and a video explaining the following:

1) I Require that my students study the material before class and take a quiz
2) In class, I spend 15-20 minutes reviewing new material.
3) I give students the remaining time to work on their design submittal. This gives them a chance to run into roadblocks during class and get help from their peers, and me. I circulate through the classroom, and often review questions on the board with the whole class.

4 Challenges

As you can imagine, teaching within this framework presents its own challenges. Here are some of the biggest hurdles I have encountered:

4.1 Desire for Well-Defined Problems

Those students who like to follow step-by-step directions, struggle the most with this teaching framework. Design freedom can be intimidating, especially when much of our engineering curriculum promotes single, correct answers. I find encouraging words and frequent office hour availability to be the most effective in helping these students settle into my courses. I also make sure the design submittal requirements are clearly spelled out, even if they don't give step-by-step guidance.

4.2 Time

The second biggest challenge is students not setting aside enough time to do their design submittals. I tell my students early on that their design submittals will take as much as homework and preparing for and taking exams combined in their other classes. Design iterations and code interpretation take time. Those who start early and ask questions in class rarely do not earn full points. Those who start the day the assignment is due, tend to struggle.

4.3 Comfort with the Material

Because each project is different, I do not have a solutions manual, and students tend to get into all kinds of interesting places in the code. This puts a burden on me to really know the material, which incidentally has made me a better practicing engineer. When I do not know something, I simply tell them so. I then come back the next class period with the answer or get reference material out in class and we figure it out together. This teaches them it is OK for a practicing engineer to not know everything, and that there are resources on which one can rely.

5 Evidence

Does it work? Absolutely! How do I know? My student's work product is on par with that of young, practicing engineers. Let me expand.

I managed engineers for 15 years, and just hit 23 years of professional practice (which continues today). My work and that of those I managed was and is routinely peer reviewed. The bulk of this work is now built or under construction and ranges from guardrail to large, complex industrial facilities. When the work my students prepare is on par with that of practicing engineers, I consider this the best metric possible. Yes, some do sub-par work, but that's life in school.

How else do I know? My students tell me in their reflections, and in written reviews. This feedback comes from the fall of 2022, which a student submitted to the UVU's Office of Teaching and Learning.

"Paul understands that lecturing the entire class is not effective. Students need to get involved in a discussion to actually learn something. Paul led a hybrid course where he discussed/lectured for 30-45 minutes and then let us work on our homework in class. This allowed us to actually start thinking for ourselves about how to attack homework problems and then when we hit bumps we were right next to our professor and could ask questions at any time."

Would it be valuable to complete carefully designed studies to formally assess the effectiveness of this framework? Definitely. Have I done it? Not yet. However, based on student feedback, teaching assessment scores, and project-based teaching evidence, I am comfortable recommending this method to you.

6 Conclusion

The belief that a newly graduated engineer is useless in the workplace for the first few years of their career is unfair to those relying on us to teach them. It is our responsibility as their guides to prepare them for the workplace they will enter tomorrow. While a few companies still have extensive and lengthy training programs; most do not. They expect their new hires to show up and take care of business.

Engineers design projects. They do this repeatedly. Teaching engineers in the context of actual projects is natural and highly effective.

This paper outlines how I have taught the structural design of timber, masonry, steel, concrete, and structural analysis for the past two decades. Does it work? Yes, absolutely. How do I know? Based on my experience of what is effective in professional practice and 19 years of student work product that closely matches that of a successful design office.

7 References

[1] S. D. Wurdinger, The Power of Project-Based Learning: HElping Students Develop Important Life Skills, Lanham: Rowman & LIttlefield Publishers, 2016.

[2] *Building Code Requirements for Structural Concrete,* ACI 318, 2019.

[3] J. K. Wight, Reinforced Concrete, Mechanics and Design, Hoboken: Pearson, 2022.

[4] *Reinforced Concrete Design Handbook,* ACI MNL-17, 2021.

[5] ACI, "Case Study: 16 Story Hotel," [Online]. Available: https://www.concrete.org/enhanceddm.aspx?EDocumentKey=CSHotel. [Accessed 2023].

[6] *Manual of Steel Construction,* AISC, Fourteenth Edition, 2017.

[7] L. F. Geschwindner, J. Liu and C. J. Carter, Unified Design of Steel Structures, CreateSpace Independent Publising Platform, 2017.

[8] *Specification for Structural Steel Buildings,* AISC 360, 2022.

[9] *Companion to the AISC Steel Construction Manual,* AISC, Version 15.1, 2019.

[10] *Building Code Requirements for Masonry Structures,* TMS 402, 2022.

[11] TMS, Reinforced Masonry Engineering Handbook, Longmont: The Masonry Society, 2015.

[12] *National Design Specification for Wood Construction with Commentary,* NDS, 2018.

[13] D. Breyer, K. Cobeen, K. Fridley and D. Pollock, Design of Wood Structures-ASD/LRFD 7th Edition, New York: McGraw-Hill Education, 2014.

[14] "Architect's Guidebooks to Structures," Taylor & Francis, [Online]. Available: https://www.taylorfrancis.com/series/architect-guidebooks-structures/AGTS?context=ubx. [Accessed 2023].

[15] *Minimum Design Loads for Buildings & Other Structures,* ASCE 7, 2022.

FIGURES

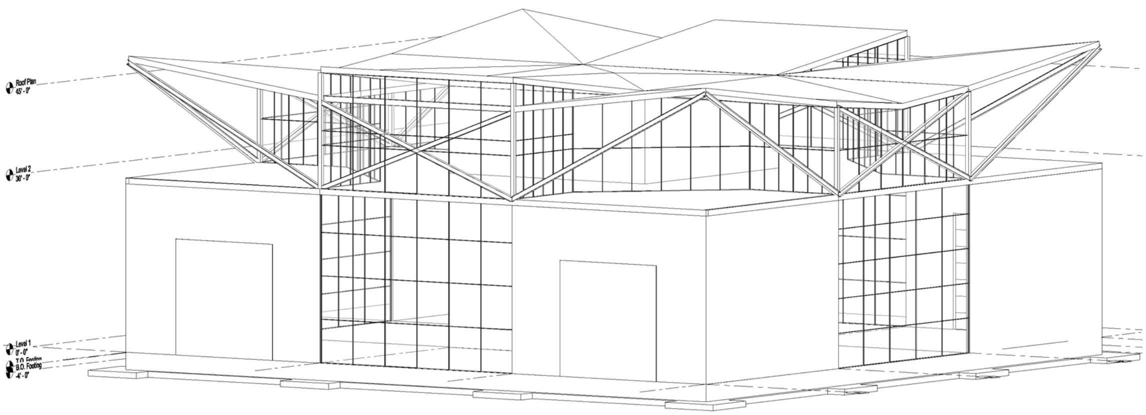

Figure 1 Example student project. © Brayden Allen

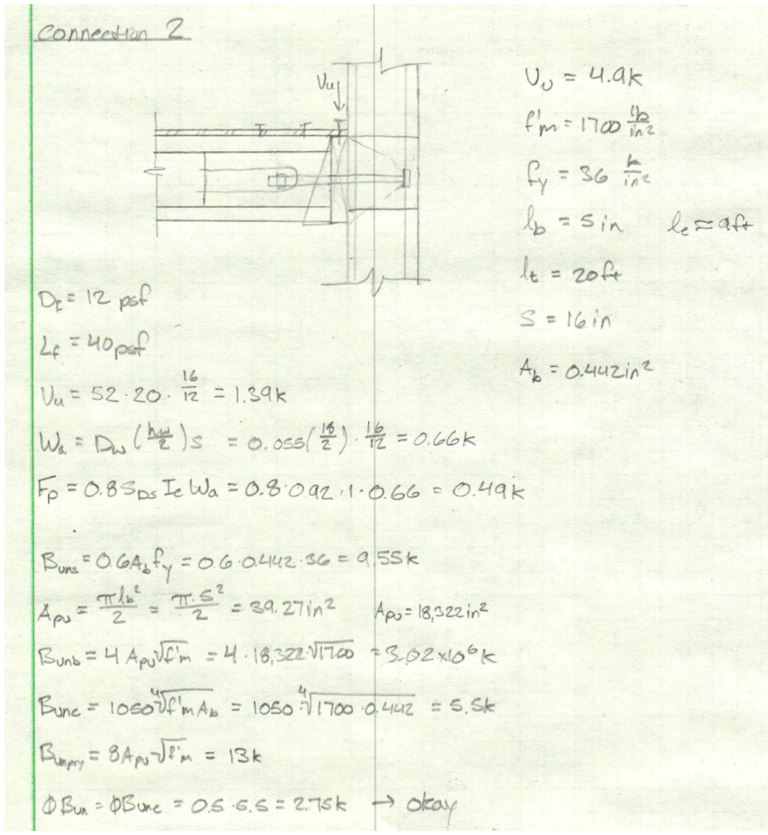

Figure 2 Example student calculations. © Michael Gustafson

DATE	MOD	SUBJECT	BEFORE CLASS	DUE	
23-Aug		Brief Course Intro	Creativity PPT		
	A1	Creativity	A1-1 Structural SYSTEMS.pptx		
		Structural Systems, How & Why Select			
25-Aug	A2	Gravity Loads	A2-1 Structural Loads GRAVITY.pptx	Memo 1	Creativity
30-Aug	A2	Lateral Loads	A2-2 Structural Loads LATERAL.pptx EXAMPLES	Memo 2	Structural Systems
1-Sep	A3	Truss Method Joints	A3a-1 Trusses- Mthd JOINTS.pptx	Sub 1	Loads
6-Sep		Labor Day			
8-Sep	A3	Truss Method Sections	A3b-1 Trusses- Mthd SECTIONS.pptx	Sub 2	Truss Method Joints
13-Sep	A4	Shear, Moment & Deflection Functions	A4a-1 Shear & Moment FUNCTIONS.pptx	Sub 3	Truss Method Sections
15-Sep	A4	Shear & Moment Diagrams Remember Site Visit	A4b-1 Shear & Moment DIAGRAMS.pptx EXAMPLE VIDEOS	Sub 4	Shear, Moment & Deflection Functions
20-Sep	A5	Approximate Indeterminate Solutions	A5-1 Approx Solutions.pptx	Sub 5	Shear & Moment Diagrams Remember Site Visit
22-Sep	A6	Finite Element Analysis (FEA)	A6-1 FEA Introduction.pptx	Sub 6	Approximate Solutions
27-Sep	A6	FEA Simple Models & Hand Checking		Memo 3	Natural Structures Report
29-Sep		Natural Structures Presenations		Sub 7	Finite Elements
4-Oct	C1	Concrete Fundamentals	ACI 318 Ch 1-4 C1-1 Conc FUNDAMENTALS.pptx C1-2 Develop Length EX.pdf	Memo 4	Site Visit Report
6-Oct	C2	Concrete Bending	ACI 318 Ch 9, 22.3 4-1 Conc FLEXURE.ppt 4-2 Conc FLEXURE EX.pdf	Memo 5	Concrete Fundamentals
11-Oct	C2	Concrete Bending		Sub 8	Lap Splice Schedule
13-Oct		Fall Break			
18-Oct	C3	Concrete Shear	ACI 318 Ch 22.5, 6 5-1 Conc SHEAR.ppt 5-2 Conc SHEAR EX.pdf	Sub 9	Concrete Bending
20-Oct	C4	Concrete Compression	ACI 318 Ch 10, 22.4 6-1 Conc COMPRESSION.ppt 6-2 Conc COL EX.pdf	Sub 10	Concrete Shear
25-Oct	C4	Concrete Compression			
27-Oct	C5	Concrete Footings	ACI 318 13 8-1 Conc FOUNDATIONS.ppt 8-2 Conc FOOTING EX.pdf	Sub 11	Concrete Compression
1-Nov	S1	Steel Fundamentals	S1-1 Steel Fundamentals.pptx	Sub 12	Concrete Footings
3-Nov	S2	Steel Tension	S2-1 Axial Tension.pptx S2-2 TENSION EX.pdf	Memo 6	Steel Fundamentals
8-Nov	S3	Steel Bending	S3-1 Steel Flexure.pptx S3-2 BEAM EX.pdf	Sub 13	Steel Tension
10-Nov	S3	Steel Bending			
15-Nov	S4	Steel Shear & Torsion	S4-1 Shear & Torsion.ppt S4-2 SHEAR EX.pdf	Sub 14	Steel Bending
17-Nov	S5	Steel Compression	S5-1 Steel Compression.pptx S5-2 COMPRESSION EX.pdf	Sub 15	Steel Shear
22-Nov		Thanksgiving Holiday Week			
24-Nov		Thanksgiving Holiday Week			
29-Nov	S5	Steel Compression			
1-Dec	G1	Lateral Design Introduction	G1-1 Lateral Design Intro.pptx	Sub 16	Steel Compression
6-Dec	G2	Structural Integrity	G2-1 Structural Integrity.pptx	Memo 7	Lateral Design Introduction

Figure 3 Example course schedule.

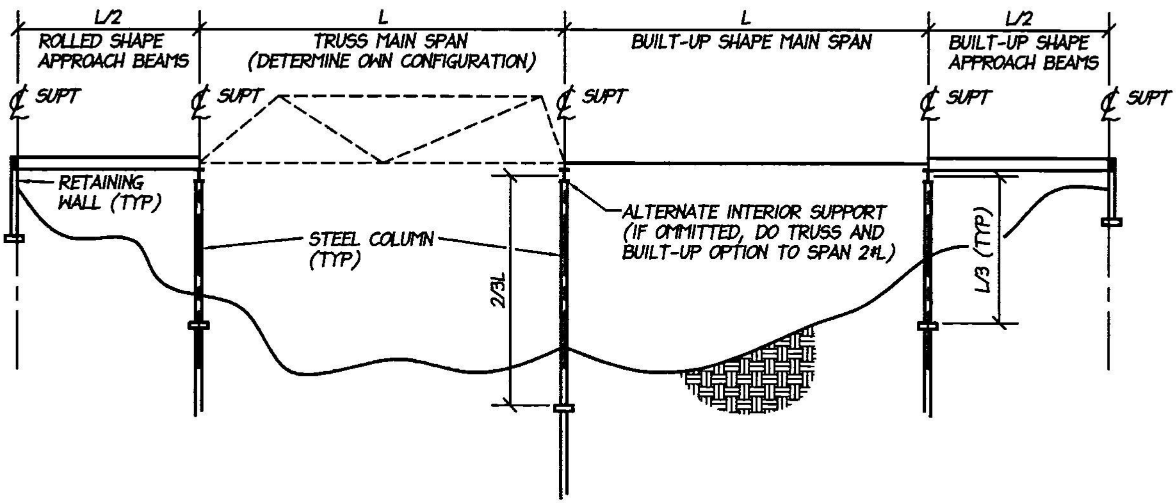

Figure 4 Bridge design project.

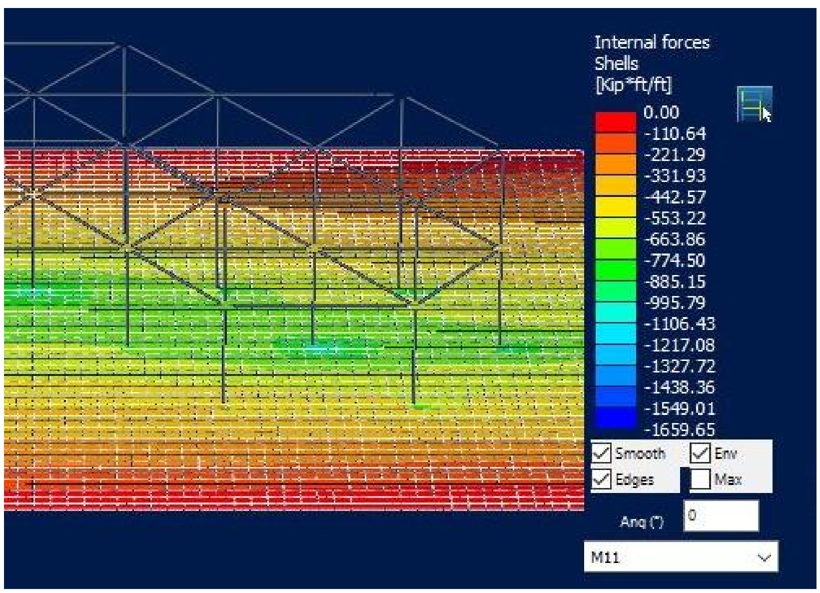

Figure 5 Mat foundation analysis example. © McKenna Kirby

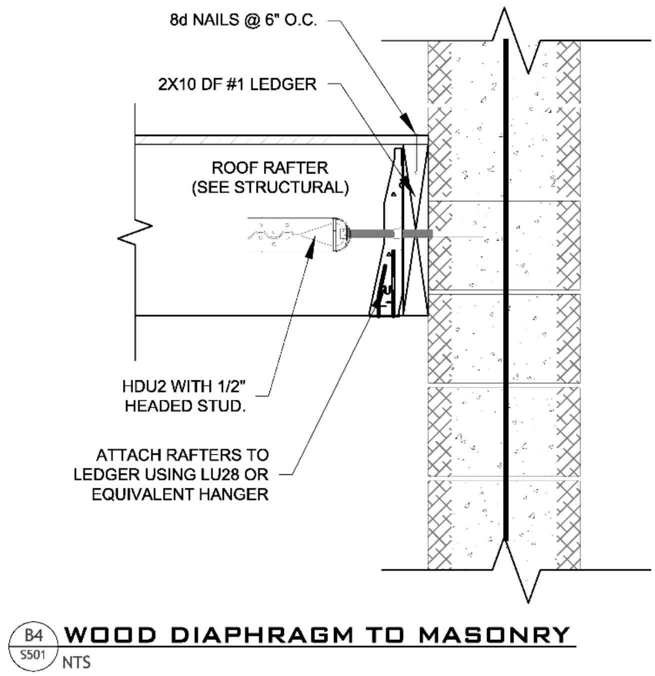

Figure 6 Example student CAD detail. © Jordan Barney