# Teaching Understanding in the Context of Structural Engineering

An honors thesis for the Department of Civil and Environmental Engineering

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by

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## Abstract

The goal of this research project is to analyze different teaching methods that are effective in encouraging true understanding of fundamental concepts. The hypothesis is that teaching methods seriously influence a student's ability to gain true understanding, especially in the field of structural engineering. Two systems of key factors are identified as the basis for this theory. The first involves the balance of showing physical relationships, creating intimate learning environments, and presenting role models. The second system includes identifying student preconceptions, developing expertise, and using a metacognitive approach. If all of these components were incorporated into courses, students would develop or maintain the motivation to truly understand concepts they are learning. The validity of this hypothesis has been tested over the course of the academic year in two different courses. The first, *Structural Art*, was a first-year elective. During this course, a small laboratory section was taught with a focus on learning fundamental concepts of structural analysis through methods illustrated in Figure 3. The second was *Introduction to Civil Engineering*, taught to sophomores during the spring semester. In this course, the laboratory was based on the students own designs of structural systems that could be analyzed using theory learned in lecture. In both cases, a strong focus was placed on encouraging the students to relate the complex theories they were learning to examples that they understood on a physical level. The intended outcome of this research is to show that, in general, students develop a true understanding of material when the teaching methods outlined in Figures 1 and 3 are employed.

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# 1.0 INTRODUCTION

## 1.1 Purpose

Education shapes a person's life. A meaningful education can inspire a person to pursue her passions, while an unsatisfying educational experience can leave her without direction. To gain a meaningful education, one must develop a true understanding of the topic she is investigating. Understanding is achieved when one can apply a known concept or theory to an unfamiliar situation and reach a legitimate result (NRC, 2000, p. 8)[1]. For example, it is important for engineering students to be able to transfer their knowledge to new situations because undefined engineering challenges are discovered all the time. In the context of structural engineering, it is important for students to understand physical behavior in order to use the appropriate equation for a given scenario.

As a senior civil engineering major, I believe that the way in which a topic is presented in the classroom is crucial to a student's ability to gain understanding. Though it is not solely up to the instructor to create a desire to achieve true understanding, she is extremely influential in the process. There needs to be a motivation to achieve understanding, and the question of how to inspire this motivation is an interesting one. The goal of this research project is to investigate what methods of teaching best inspire motivation to achieve true understanding during a student's educational career, specifically in the context of structural engineering. Being motivated to truly understand all aspects of one's studies is necessary for an enriching and satisfying academic experience in which a student can begin to develop mastery of her subject.

[1] This citation refers to Bransford, J. D., Brown, A. L., and Cocking, R. R. (2000). "How People Learn: Brain, Mind, Experience, and School.", and will be used throughout this report.

### 1.2 Background

In general, there seems to be a lack of connection between textbook problems and real-world, physical examples. The National Research Council (2000, p. 5) describes the tendency for typical curricula in the current education system to focus on memory and neglect to assess understanding. From my own experiences, it seems that the focus in classrooms today is on the introduction to many different equations, and it is too easy for students to apply these equations to situations without a true understanding of what they mean. This leads to successful completion of courses, but does not foster a real sense of understanding of the material.

David Billington (2003) discusses the modern state of structural engineering education versus historical practices in Switzerland. He says that "education in structural engineering – indeed, in all engineering – has deprived students and the general public of the humanistic values inherent in engineering and so central to architecture and literature" (p. 14). He is highlighting the fact that historical analyses are so essential to an education associated with architecture or literature, but curricula have lost sight of that in today's engineering education. One defining characteristic of the field of structural engineering is that many of the top engineers in the field can be traced back to just two teachers. William Ritter and Pierre Lardy were responsible for the educations of Robert Maillart, Othmar Ammann, Heinz Isler, and Christian Menn. These six men are credited with the design and creation of many of the most elegant structures in the world.

It is no accident that these engineers were all educated by the same means. The teachers' focus on visual analysis can be traced back to Carl Culmann, the original author of *Graphic Statics*. Culmann was the founding father of civil engineering education at the Federal Institute of Technology in Zurich, and in fact taught both Ritter and Lardy (Billington, 2003, p. 20). In reference to his groundbreaking book, Culmann was quoted as saying, “drawing is the language of the Engineers, because the geometric way of thinking is a view of the thing itself and is therefore the most natural way; while with an analytic method, as elegant as that may also be, the subject hides itself behind unfamiliar symbols” (as cited in Billington, 2003, p. 20). A common sentiment among undergraduate students today is that Culmann’s view seems to have been lost in their courses (Appendix C, see p. 148). The top structural engineers were educated with a focus on visual aids and physical models in relation to the mathematics they were learning, but current curricula tend to separate the two until late into a student’s undergraduate career. A desire exists among structural engineering students to return to the Culmann culture of education in order to develop truer understanding of the material they are exploring.

### 1.3 Hypothesis

Teaching methods seriously influence a student’s ability to gain true understanding. Additionally, a student’s motivation is directly related to her gaining true understanding. Teaching methods critically affect students’ motivation. The key components that must be present in the classroom to develop and maintain motivation in structural engineering students are shown in Figure 1. An effective combination of the components is necessary to create a learning environment with a focus on motivating students to gain true understanding.

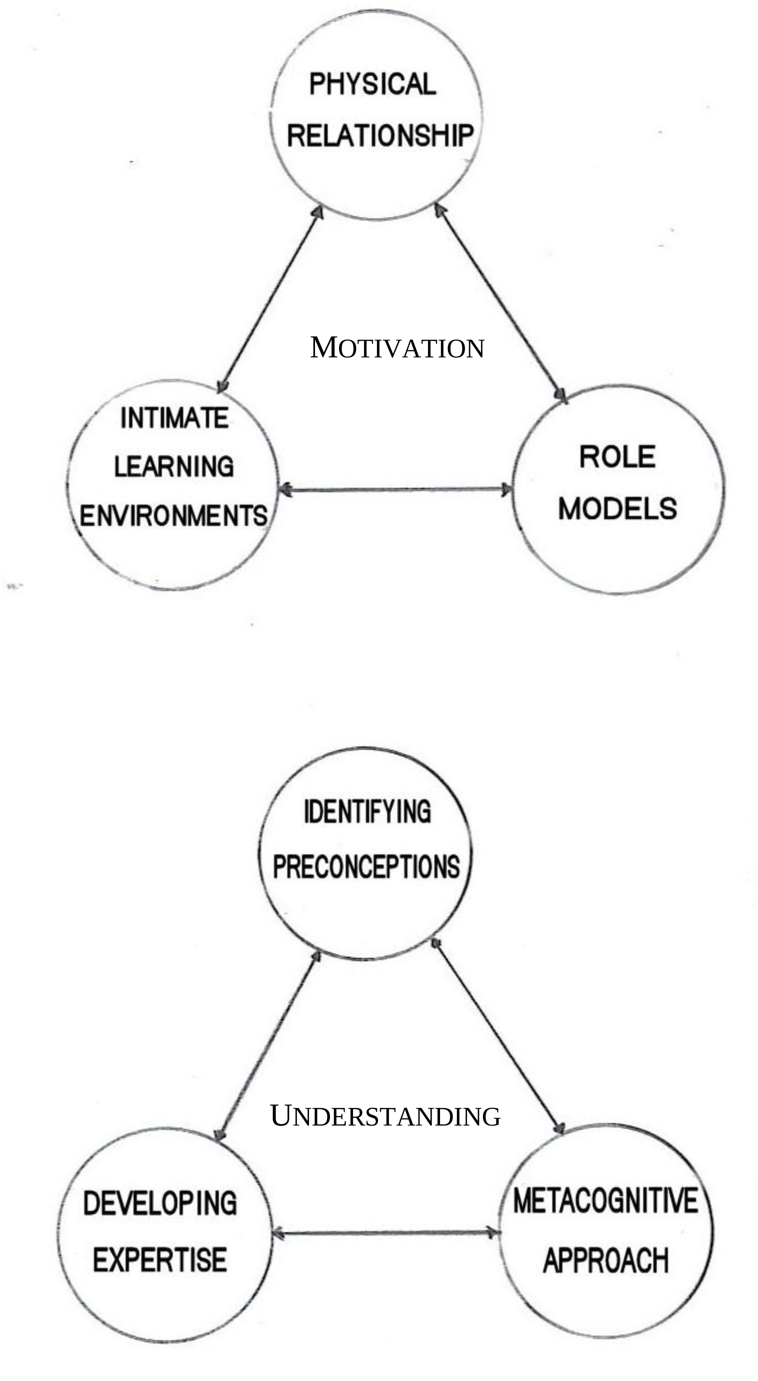



**Figure 1: Key Factors to Enhance Understanding in Undergraduate Curricula**

The Motivation System shows components that directly relate to student motivation. It is assumed that students enter their undergraduate careers with inherent levels of motivation, but focus must be placed on maintaining and enhancing that motivation. Techniques of presenting material with a greater focus on application to physical models and visuals are necessary so that students realize *why* they are learning specific concepts (NRC, 2000, p. 18). Topics should be presented in a way such that students see the relevance of what they are learning. If students can draw parallels between what they are learning in the classroom to what is meaningful to them on a personal level, their educational experience will be much more fulfilling. Maintaining a focus on physical relationships also reveals the connections between physics and mathematics that engineering students tend to appreciate. Small laboratory sessions or recitations foster an intimate learning environment where students feel comfortable asking questions and taking risks in terms of trying new problems. In addition, the use of mentors close in age devoted to these laboratory sections gives the students an outlet to seek information from someone who is not far removed from learning the material herself and is not as intimidating as a professor may be. Creating an environment in which students feel comfortable asking questions and taking risks from the beginning of their undergraduate careers is crucial in order to allow students to pursue true understanding of engineering concepts. Last, students must have a role model in their field. Most often this falls to the professor, who should relate her expertise in a way that motivates students to attain the same level of knowledge. A professor is a role model for better or worse, and she should have the clear intention of engaging her students in her field while maintaining respectability. Role models may also be found in respected professionals or historical figures who have achieved success in their fields. A balance of each of these three components early on in one's academic career can lead to a more enriching learning experience.

The Understanding System relates more to measures that can be taken specifically by professors to encourage and sustain understanding. The three components are the key elements described in the book *How People Learn* that the National Research Council deemed as essential for teaching understanding. The definition for each was taken as the starting point for observing the effectiveness of the teaching methods employed throughout this academic year. Identifying preconceptions is knowing that “students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom” (NRC, 2000, p. 14). Many instances of this could be seen in working with the first-year students, most notably their preconception that a bending moment diagram should exactly reflect the physical shape of a loaded system, which is fundamentally incorrect. In conjunction with this is developing expertise, something attained by “(a) having a deep foundation of factual knowledge, (b) understanding facts and ideas of a conceptual framework, and (c) organizing knowledge in ways that facilitate retrieval and application” (NRC, 2000, p. 16). Current students in the senior civil engineering class acknowledge the need to master analysis techniques through repetition of textbook problems, but also find it necessary to be able to connect those problems to real-world phenomena in order to feel as though they have attained true understanding. Last, the idea of a metacognitive approach is to allow students to take serious ownership of their own knowledge by “defining learning goals and monitoring their progress in achieving them” (NRC, 2000, p. 18). The laboratory for second-year students was designed in such a way as to give the students minimal direction in terms of how to complete the assigned experiment and write-up their reports. This was done so that they would develop their own ideas of what was the most important information to gain and how to relate it to others.

In general, these two systems must work in tandem, and there should be a focus on at least one component from each system during every lesson and course that is taught. The systems are not combined because there is a clear distinction between motivation and understanding. The first system directly relates to measures that can be taken to ensure that students' levels of initial motivation do not diminish, but in fact increase. Once components of the Motivation System are established, the Understanding System can then employed more directly. Understanding cannot be achieved without motivation, but motivation cannot be enhanced without a focus on eventually gaining true understanding. For this reason, the systems must both be present within each course because one would not succeed without the other. If a student is motivated to develop true understanding of the material she is learning, she tends to have a more meaningful educational experience.

Another key aspect of the educational process should be to maintain a focus on relating all information to real world, physical examples. This enables the student to see how the information she is learning is relevant to what she already understands or is interested in discovering. Many seniors now say that they have a better understanding of fundamental concepts than they did when they were first introduced to them, but is this because of repetition or a shift in the way the material was presented later on in their academic career? There is a question of how much maturity plays into a student's ability to gain true understanding, but the hypothesis is that teaching methods are much more influential than maturity in gaining that understanding.

Observations and analyses of past experiences support the notion that there is a way to teach so that true understanding can be achieved earlier on in one's academic career. For example, one concept that is often hard for structural engineering students to grasp is that it is optimal to design structures so that they reflect the shape of the moment diagram associated with their applied loadings. One such structure is the Eiffel Tower. Eiffel designed the Tower with the clear intent that it reflect the moment diagram produced from applied wind loadings, the governing loads on the structure.  The development of his application of this theory can be seen below (Figure 2).

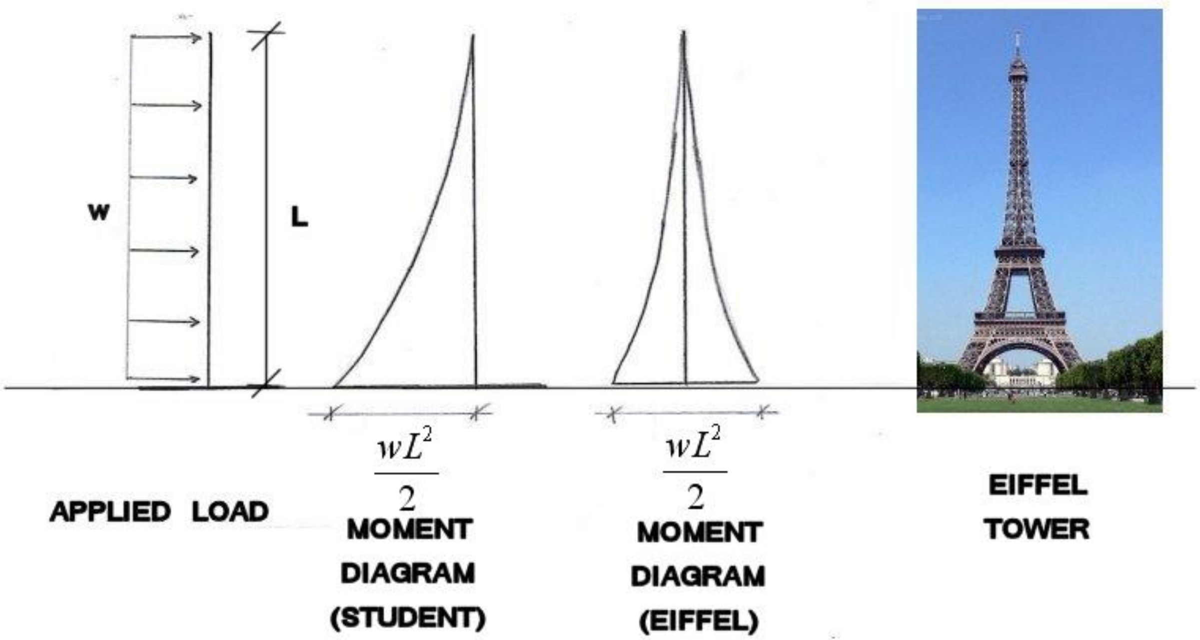



**Figure 2: Application of Mathematics to Physical Structure**

Eiffel exhibits his expertise by utilizing the mathematics to create an efficient, yet not predictable, structure.  A student newly introduced to structural analysis would simply see the first moment diagram and fail to realize that the second diagram is a representation of the exact same scenario.  Eiffel, however, was able to choose the shape based on the understanding that providing the most support and stability at the point of greatest moment would make his structure maximally efficient.  Though it is a small adjustment, Eiffel's decision to develop a form that maintained a maximum moment capacity of $\frac{wL^2}{2}$ is a consequence of his true understanding of physical behaviors in relation to structural analysis.  The application of a theoretical concept to a real structure is extremely transparent in this example and allows the concept to become accessible to students after it is introduced to them. This highlights the importance of real-world examples. A progression of how to best structure both undergraduate curricula as well as individual semesters is presented in Figure 3. The culture of the university needs to be redirected so that students are learning to attain understanding, not to just successfully complete courses.

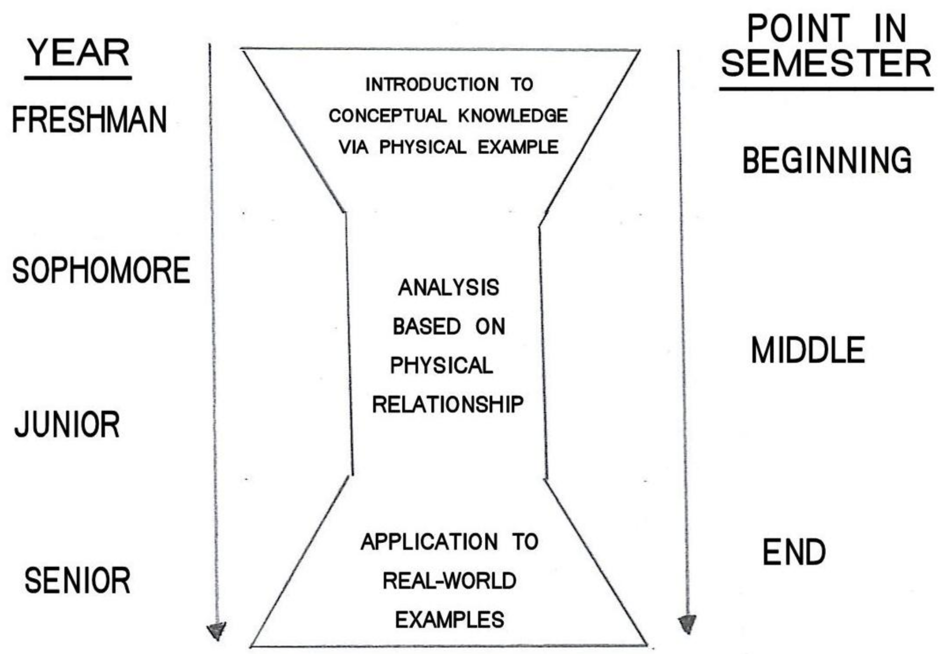



**Figure 3: Progression of Teaching Methods**

## 1.4 Motivation as a Driving Force

Where the motivation to gain true understanding comes from is a major question when assessing the development of true understanding in students. It is important to note that in this context, the desired understanding is not the surface understanding that most students demonstrate in order to graduate from top universities. It is quite possible for students to move through their entire education with only surface level understanding of the major concepts associated with their degree. Howard Gardner (2000) describes a "smoking gun" at such top universities as M.I.T. and Johns Hopkins. Physics students who performed well on assignments and exams were asked to describe everyday physical phenomena, for example the trajectory of a pellet after being propelled through a curved tube. Gardner (2000, p. 120) says that "not only do a significant proportion of students (often more than half) fail to give the appropriate explanation; even worse, they tend to give the same kind of answers as peers and younger children who have never studied mechanics." This again begs the question of why curricula tend to shy away from pursuing deep understanding early on if laypeople can reach similar levels. This project is interested in how students develop and maintain the motivation to achieve true understanding of the topics they are studying.

Professors are experts in their field, and they have a responsibility to foster a motivation in their students. Gardner (2000, p. 133) states the need for teachers to "feel expert, and to embody expertise in the eyes of their students." This relates to the "Role Model" component of the Motivation System and to the "Developing Expertise" component of the Understanding System. However, the onus is not entirely on the professor. Students must first possess some level of inherent motivation in order to be ready for a professor to motivate them to reach a higher level of understanding so that they are "partners in their own education" (Gardner, 2000, p. 135). If a professor educates in a way that motivates a student to develop expertise, that student is much more likely to retain and later apply information throughout her career.

Students commonly feel that the connection between fundamental concepts and real-world applications or examples is not made until much too late in their academic careers. There seems to be a trend that the fundamental concepts are taught and are later applied to actual structures. The steps rarely happen simultaneously. Similarly, on a theoretical level, the relationship between forces and deformations is paramount in structural engineering, yet the two are often separated until the third or fourth course in a series of four required courses concerned with structural analysis. This directly relates to the "Physical Relationship" component of the Motivation System. Indeed, "learners of all ages are more motivated when they can see the usefulness of what they are learning" (NRC, 2000, p. 61). Not knowing or understanding the reasons behind one's path can lead to frustration and difficulty in maintaining motivation. Hence, the need for the teaching progression described in Figure 3 and a metacognitive approach to learning so that students can have confidence in the knowledge they possess. In studies on Project Enhanced Learning, researchers have noted that they believe "the lack of connections aids the student who wants to believe that they will never need to know or use [the] material again after [a] class is over" (Barroso & Morgan, 2009). In order to develop true understanding, students need to have a physical picture in their minds of the concepts they are learning, as well as knowledge of why the concepts they are learning are important or will be in the future.

An accurate gauge of a student's willingness and motivation to learn is if she is "likely to work hard, to be persistent, to be stimulated rather than discouraged by obstacles, and to continue to learn even when not pressed to do so, for the sheer pleasure of quenching curiosity or stretching [her] faculties in unfamiliar directions" (Gardner, 2000, p. 76). A way to encourage this behavior is to give the student an intimate learning environment in which to make mistakes and where a more experienced peer is available to relate to and correct preconceptions. Experiences in the lab sessions with both the first- and second-year students validate this assertion, and encompass the remaining components of the two systems.

### 1.5 Methods

For this project, student motivation will be assessed through observations of lab sessions, interviews with students, and analyses of both student work and my own experiences. Many quantitative methods have been developed to assess students' levels of motivation including the Situational Motivation Scale (SIMS), which is used to assess levels of intrinsic motivation, extrinsic motivation, and amotivation in students in science and engineering fields (Guay *et al.*, 2000). However, for the purposes of this study the focus has been placed on observational methods of analysis. The humanist movement in psychology is one of the largest schools of thought in the field and is highly dependent on the use of observational methods to draw conclusions about an individual's psychological state (Beverage, 2002). First-hand accounts and observations of both real-time and recollected experiences are the best way to assess an individual's own motivation to pursue a subject. Observations on the effectiveness of teaching methods employed to encourage that motivation throughout the academic year are the main outlet for conclusions to be drawn. The goal for any student should be to have the most satisfying educational experience she can possibly have. If students feel engaged and motivated after a class, then the methods used can be classified as effective.

# 2.0 FIRST-YEAR EXPERIENCE

## 2.1 Introduction to Fall Semester

Overall, this project was designed to try to answer some of the questions associated with the way people learn. During the fall semester of 2009, five students were chosen from an elective engineering course, *Structural Art,* to take part in this project. Three freshmen, one sophomore, and one post-baccalaureate student agreed to participate in a lab section that would be run differently than those of their peers. This was the first semester that each of the students was introduced to structural engineering. The main goal of this lab section would be to use physical relationships and real-world examples to teach fundamental structural analysis concepts. By definition, this was all done in an intimate learning environment.

The lab section met twice a week in addition to course lectures and was divided into three topics: cantilevers, beams, and frames. The course culminated with a design project for all students that involved the design of a trolley-stop canopy given only the restriction that it must be contained to a certain area. The hypothesis was that the students in this lab section would gain a good understanding of the physical behaviors of cantilevers, beams, and frames, and then transfer that knowledge to produce a respectable design for their canopy at the end of the semester.

## 2.2 Discussion of Laboratory Sessions

### 2.2.1 Early Laboratory Sessions

During the first session, the students were introduced to the most basic concepts involved in structural analysis including shear, axial, and moment forces and diagrams. Almost none of them even knew what a force was. Their first assignment was to bring in an example of a cantilever. Some examples included humans, bookshelves, and skyscrapers. It was interesting to hear what they came up with because they had not been told what a cantilever should be (NRC, 2000, p. 14). This led to creative discoveries that someone who had been introduced to cantilevers through a schematic in a textbook might not have exposed. The students were asked to build their own cantilever for the next session and were given no direction other than to "build a cantilever" in order to see what they would produce simply based on intuitive knowledge. This would act as a good gauge to assess the preliminary level of understanding of the students, in other words what preconceptions they possessed.

The second session began with a short video showing the construction process of the Hemeroscopium House in Madrid, Spain. The house is made up of many different cantilevers and is almost more a piece of sculpture than a house. Overall, the house was a good way of showing a real-world application of cantilevers. It is important to introduce students to projects like this not only to stimulate interest in the field that they are dedicating their education to, but also to reinforce the need to learn basic concepts so that they can complete interesting projects in the future.

In general, questions that developed during the *Structural Art* lectures were discussed at the beginning of each session. The opportunity to revisit ideas in an intimate setting was a highlight of the laboratories for most students. They were able to ask the questions that they were not comfortable asking in lecture, most likely due to fear of embarrassing themselves in front of their peers or professor should they make a mistake. In addition, repetition is necessary in any educational setting. The chance to repeat problems that were done in class or discuss ideas that did not fully make sense initially was essential. During the second session, an example of a seesaw acting as a cantilever was used to discuss the process of summing moments about a support in a structure. The equation for a moment is quite simple, a force times a distance, but many students have trouble understanding exactly what that means physically or why it is important to know. It is difficult to strike a balance between only giving an equation to calculate moment summation and explaining why that equation works on a simple, conceptual level. The seesaw example helped to show how distances and reaction forces vary in relation to each other when analyzing moments.

The original goal of this research project was to teach the *Structural Art* students the concept of virtual work by the end of the fall semester. Virtual work is a process used to find deflections of members within structural systems.

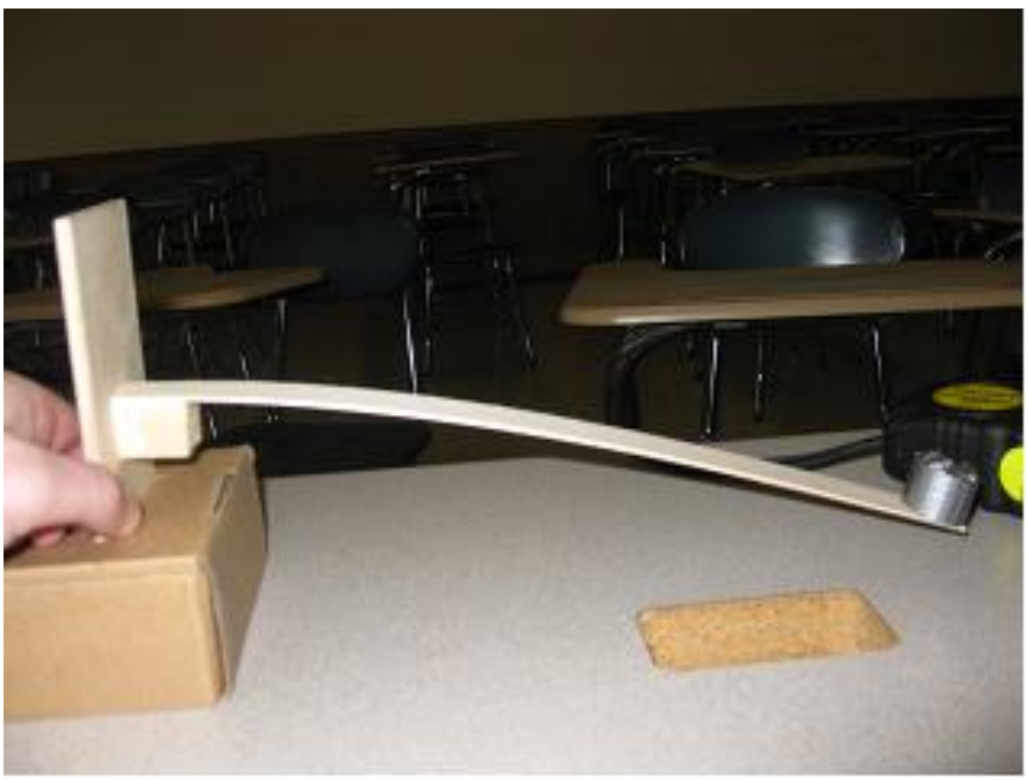


**Figure 4: Cantilever Experiment**

An experiment was conducted during the second session that compared the calculated deflection of a balsa wood cantilever to the actual measured deflection (Figure 4). First, the distance from the table to the tip of the cantilever was measured with no weight acting on the cantilever (Figure 5). Then, a $\frac{1}{16}$ lb weight was placed on the tip of the cantilever and the distance from the table to the tip of the cantilever was measured again (Figure 6). The difference between these two values was total deflection of the cantilever as a result of the applied weight. The experiment was repeated with different weights placed in different locations in order to show how various loading situations affect structural behavior. As a rule, the deflection at the tip of a cantilever can be calculated as $\Delta = \frac{PL^3}{3EI}$, where P is the load, L is the length of the cantilever, and E and I are strength properties of the member. Using the values of P, L, E, and I from the experimental set up it was shown that the calculated value was within 0.005 in of the measured value.

**Figure 5: Students Measuring Deflection**

A physical example is rarely used to prove that an equation actually works. Generally, students are asked to have faith that the equations are correct without seeing the physical proof for themselves. Undoubtedly, the equations taught in schools are valid, but there is something to be said for experiencing the physical manifestation of the derivation for oneself. Equations are often originally discovered through experiment, so why should students today not discover them through experiment as well? Even if the discovery happens in a much abbreviated version as compared to the original discoverer, there is much value in the experience in terms of developing true understanding. Rene Descartes described it plainly when he said, “We never understand a thing so well, and make it our own, as when we have discovered it for ourselves” (Goodman, 1997, p. 553).

**Figure 6: Student Performing Cantilever Experiment**

This experiment also led to good discussion of modulus of elasticity (E) and moment of inertia (I), and how each variable affects the behavior of a structure. These properties are generally not introduced until the sophomore year, and their conceptual relevance is rarely explained. It is important to introduce students to these concepts in a way to which they can relate early on in their education. Even if the concepts do not make complete sense at first, the earlier students are exposed to them the better they will be understood later on.

The most interesting part of the session was that each student brought in extremely different models of cantilevers (Figure 7).

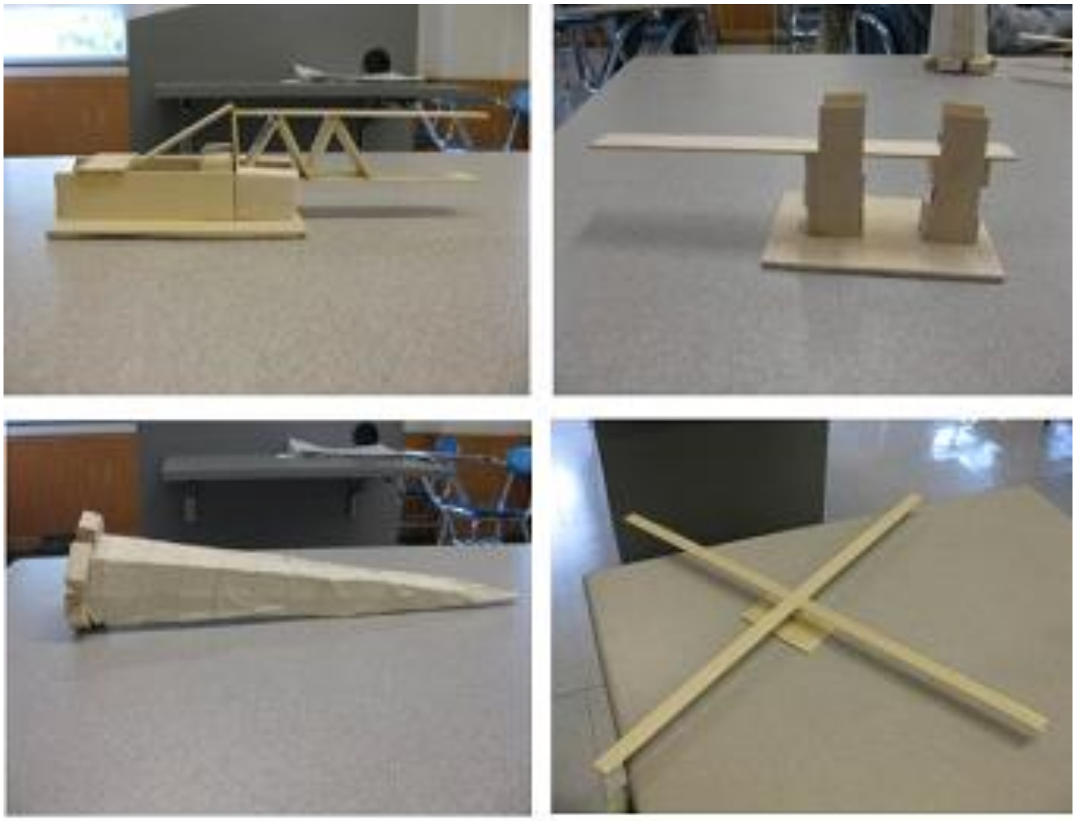


**Figure 7: Student Cantilevers**

The fact that each student came up with such a creative design given minimal direction simply shows how differently peoples' minds work. From this, it can be said that it is unreasonable for professors to expect students to learn basic concepts in the same way. Although the definition of basic implies a lack of complexity, anything new can be difficult to comprehend. Especially in terms of structural analysis, students tend not to have any established knowledge of fundamental concepts. It should not be expected that simply because an equation is not complex numerically it will make sense conceptually.

### 2.2.2 Observations and Analysis of Modern Curricula

Curricula tend to move quickly through the basic equations so that more time can be spent on the complex concepts. However, if more time were spent on the basic concepts, there would be no need to spend excessive time on the complex concepts (NRC, 2000, p. 20). Developing a stronger foundation of basics would establish the ability to comprehend difficult material in a more meaningful way. In the simple example of a cantilever, how can students be expected to analyze written problems when there seems to be so many ideas of what a cantilever actually is? Being able to visualize the problem is often the key to performing the correct analysis, and experienced professors may forget that students are not always able to develop an accurate picture in their mind early on in their academic careers.

The notion of constants is also interesting to consider. Many important variables are often taken to be constant throughout introductory structural analysis courses. More specifically, students are generally told that E and I are constant or they are values provided when solving a problem. While this may simplify the problem for someone just setting out to learn the concepts, it stimulates a belief that these are trivial parts of the equation. On the contrary, E and I are extremely important material attributes of the member being analyzed, and are in fact the driving force behind how the member will behave in any given loading situation. The fact that these values are given as constants allows the students to bypass understanding of where they come from. There is no deeper thought required about their meaning. It is true that these variables are fixed throughout a problem for every material and member, but it is easy for students to overlook just how influential they are because they are constant.

It became apparent just how extrinsic the importance of E and I is during the third lab session when the main question the students had was “what is stiffness?” If someone does not have any conception of the definition of a property, how can she be expected to understand the variables that affect that property? This example demonstrates how important it is for students to know where they are going in terms of their education. Even though the concept of something like stiffness may not make complete sense to a freshman, it is still important to introduce it on a fundamental level. It should be clear to students why something is included in almost every problem they complete, which will in turn encourage deeper understanding of the procedure as a whole.

A parallel can be drawn from the way stiffness is handled in the undergraduate curriculum to the way functions are introduced in math class in elementary school. Often, students are given tables with a set of numbers on one side and are asked to fill in the other side after performing a specific operation. It is important to note that the words “input,” “output,” “function,” or any other math jargon are not used in the description of this assignment. Although those are what each number and the process are technically called, the words are seldom used until much later in one’s academic career. For many, the connection that what is taught later on in middle school is actually the same thing that was done in elementary school is enlightening. There is no need to fully understand the power of functions in elementary school, yet it is important to build a foundation so that they can be fully explored later in the education process. However, if the potential use of functions was made more clear earlier on, students might develop a truer sense of why they should understand them on the most basic level. A quality of a good educator is never letting her students be in a state of wondering why they are learning what they are learning.

### 2.2.3 Rationale for Redirection of Fall Semester

The second session led to the realization that teaching the principle of virtual work should not be the primary goal of the fall semester. As I began to explain the concept of the principle, I found myself falling back on mathematics to convey the idea. My intent was to explain the concept so that it made sense physically without a focus on mathematics, and because I could not do so I chose to steer the class in a different direction from this point forward. I realized that if I was not comfortable enough with the concepts behind the development of the equation to explain them on a conceptual level, then the students should not be expected to jump to full understanding either. Though the students would probably be capable of applying the principle by the end of the semester, I decided that developing a true understanding of the fundamentals that are used to define the principle was far more important. The focus of the laboratory section was then adjusted to developing shear and moment diagrams and deflected shapes of different scenarios. Without correct representations of these diagrams for a given problem, the use of virtual work is meaningless. A direct parallel can be drawn to Culmann's notion that drawing is the language of the engineer. Here having the correct drawing allows the student to understand the principle necessary to complete the engineering.

Examples of the importance of visual connections can be seen in the kinds of questions that the students asked throughout the semester. During the third session, the students asked the question, "Why isn't the bending moment diagram curved?" in reference to Figure 8.

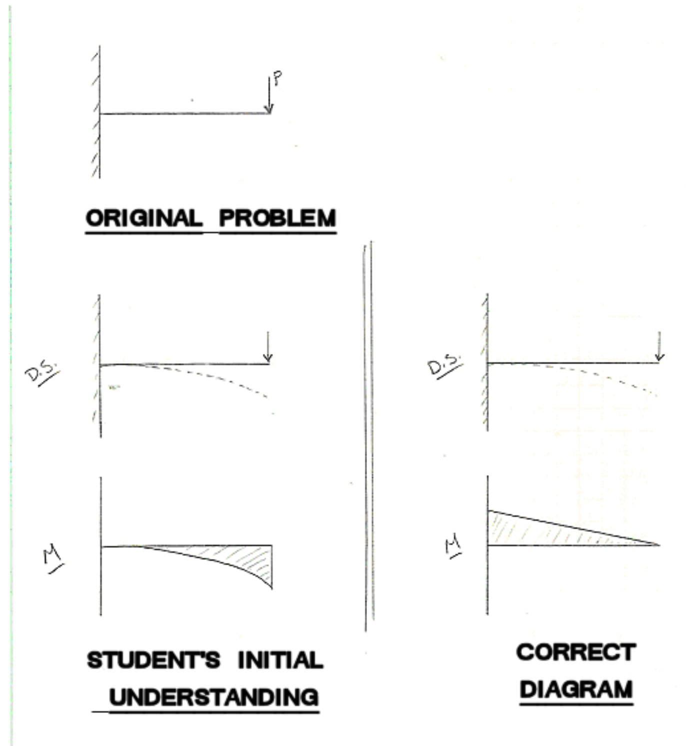



**Figure 8: Moment Diagram Example**

Intuitively, the students believed that the moment diagram should be a representation of how the system actually deformed. This situation also highlights the importance of an instructor understanding where her students are in terms of having preconceptions relating to the material they are learning. The students may not even know they have preconceptions unless they are asked for the solution first and are shown the correct solution thereafter. There must also be an open dialogue between student and professor about where something went wrong. The fact that the moment diagram ends at zero instead of beginning there for this particular problem is a difficult concept to grasp if the latter is the initial belief an individual. It is difficult to make a concept real to someone if it is never adequately explained to her why her initial reaction is incorrect. This relates back to a fundamental idea described in *How People Learn,* which is that "students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom" (NRC, 2000, p. 14). If students are able to discover their mistakes on their own and explore why they are incorrect, the correct solution becomes much more meaningful.

Maintaining a direct focus on having a sense of direction and transparency regarding the purpose of learning the concepts presented is essential, especially early on in a student's career. If students are led through their education with the notion that each step will build on the previous, eventually the harder concepts will come as a natural progression. This is a way to create and maintain motivation within students. Students will be more apt to appreciate what they are learning and care about developing true understanding if the underlying process of the curriculum depends on knowing not only where one is, but also where she has been and where she is going.

In education today, students are overloaded with examples of various problems, but rarely take the time to understand fully a basic few. They are then familiar with a substantial amount of information, but may not truly understand any of it. The way the education system is constructed allows students to be successful without achieving full understanding of the information they are being taught. Though it does not often sit well with students, making a mistake can often uncover the areas of misunderstanding that need more attention. With a need for institutions to produce successful students and the drive for students to achieve top grades, mechanisms like grade inflation actually leave room for inadequate understanding while still producing impressive results on paper. I have had many experiences in which I received a good grade but still did not feel like I had a good understanding of the material. While good grades can motivate some students to gain understanding, they may also deter some students from exploring a subject to the extent necessary to gain true understanding.

Harry Lewis (2006), former dean of Harvard College, succinctly notes, "education is not mere classroom teaching at all." In the context of engineering, classroom teaching can be taken to be a situation where a professor relays equations for the entire class period, assigns problem sets where students employ those equations, and then ends the semester with an exam that tests the employment of all the equations learned. This kind of education has become all too prevalent is today's universities. In these situations, it is too easy for students to achieve not only passing, but high grades and move on to more advanced courses without the level of understanding that an "A" should represent. Lewis (2006) says, "A curriculum with no expectations is meaningless," and that there is "no consensus on the purpose of grading." There is no consensus on the purpose of grading because grading itself has lost true meaning. More often than not, an "A" does not mean that a student has mastered the material. Grades can be used as a motivation tool, but they can also inadvertently deter students from striving to achieve deeper understanding. I have observed and experienced this phenomenon throughout my college career and do not believe that it is the best way to give students the best education possible. Derek Bok (2006), former president of Harvard University, discusses the same issues in *Our Underachieving Colleges*, saying the "education offered undergrads has become incoherent and incapable of addressing the larger questions of what we are and what we ought to be." The sentiment that grades have lost their purpose is prevalent in America's top universities, and it seems that traditional ways of creating motivation have become clouded.

Above all else, it is important to have ownership of one's knowledge (NRC, 2000, p. 18). The laboratory section was constructed so that the students would first attempt to figure something out on their own and then receive instruction based on the questions they developed. This process allowed me to distinguish between what was intuitive knowledge and what subjects deserved more time and explanation. An instructor must understand this distinction in order to tailor the way she presents the material to a specific set of students. Students need to ask what an equation is all too frequently, specifically what physical phenomenon it represents. In talking with current engineering students and professors, the aspect of engineering they seem to enjoy most is the connection between mathematics and physics (Appendix C, see p. 157). It then makes sense to maintain an emphasis on how any mathematics used in engineering classes is related to the physical phenomena it represents. There often is a disconnect between the equations presented to students on paper and their real-world counterparts. If students can understand the real-world application of their knowledge, they are more likely to be motivated to believe in it.

### 2.2.4 Discussion of Homework Assignments and Problem Analysis

Another interesting element of this project was that the students in this laboratory were assigned homework sets designed by myself while the rest of the students in *Structural Art* completed a set of more traditional homework assignments given by the professor (Appendix A, see pp. 87-89). This allowed for a real-time comparison between conventional teaching methods and the alternative techniques used for this project. Students in this section voiced multiple times that they felt they had a better understanding of the concepts presented in the lectures than their classmates (Appendix A, see p. 106). With all of the students being early on in their academic careers, most were simultaneously taking introductory physics and calculus courses. The students said that the information in lectures could be overwhelming, but “rather than just reading a packet” to try to understand moment diagrams there was a focus on understanding the basics first in the laboratory. The post-baccalaureate student, who graduated with a mathematics degree, said that the explanations given in the laboratory sessions avoided using mathematics and just showed pictures, and then “it all made sense.” She said that even though she is quite comfortable with mathematics, the concepts associated with structural analysis are still difficult to comprehend, and it is the pictures that make sense. One freshman student said that he watched his friends complete the regular homework assignments and they were just “trying to plug stuff in,” whereas in this section the students were encouraged “to think about what [was] actually going on.”

The first homework assignment was discussed in the fourth session (Appendix A, see p. 87). Instead of an instructor-led review of the assignment, a different student explained the solution for each problem. It seemed more beneficial to the students to have their peers present the solutions because the other students could offer an explanation that was much more relatable as they had newly discovered the information themselves. Explaining simple concepts becomes more difficult as one becomes more removed from the time of introduction. It is more helpful for a confused student to have a peer explain something because she is relatively on the same level in terms of understanding. The student explaining the concept is also rewarded because one must truly understand something in order to teach it to someone else successfully. Having an undergraduate mentor follows this same logic.

In addition, watching students complete problems on the blackboard gives great insight into their thought processes. The instructor is able to see what really makes sense to them, what does not, and the way that they think about the problem. Knowing how students are approaching a problem is almost more important than if they are getting the right answers. If the approach is flawed, corrections can be made so that the process will be correct in the future, which will inevitably lead to correct answers. The importance of understanding the approach was exemplified when one student presented the answer to the second part of problem one, which was simply a variation of the first part of the problem. He noticed that the deflected shape should have a smaller slope because the point load was now applied in the middle of the cantilever, so it would create a smaller moment. He originally drew a negative moment at the support, but while working at the board noticed the moment should in fact be positive. This is another benefit of having students work through problems in real-time, as they can work through their own mistakes to gain understanding. The well-established Thayer Method of Instruction at West Point is heavily based on students performing work at the black board during class as a metacognitive approach to teaching (Shell, 2002).

It was interesting to have a sophomore in the laboratory section who was taking *Introduction to Statics and Dynamics* concurrently. Much of the early material seemed straightforward to him because he was learning it in another class, but it also may be true that the sessions helped to reinforce the concepts for him. There is something to be said for learning the same material in two different ways at the same time. He always seemed to understand the problem at hand and was the one who would explain concepts in a way to which his classmates positively responded. He seemed to have a deeper understanding of the basic material, but still appreciated the visual approaches used in the laboratory section as opposed to the traditional teaching methods he encountered in his other classes. The fact that he had been introduced to some of the material already gave him an advantage in terms of attaining understanding, but from the kinds of questions he asked it was apparent that he had not yet gained true understanding before entering the course.

Problems in textbooks are often two-dimensional and do not encourage a deeper understanding of why an answer is correct. If a student can relate a complex concept to something they know on a physical level it is often much easier for them to grasp. A theme in this laboratory section was using familiar examples to explain concepts, for example describing that a cantilever with a point load on the end will behave the same way as a diving board with a person standing on the end. This tactic was used by other mentors in their sections, although it may have been subconscious on their part. In one section, when a mentor began to explain cantilevers he immediately held out his arm and described how it acted like a cantilever. As undergraduate students themselves, the mentors seemed to understand that using a physical example was the quickest and clearest way to explain a new concept. Another example of this kind of teaching was shown when this particular mentor was explaining how different supports worked. To describe a roller he used a keychain that only supported the weight of his finger in the vertical direction. To describe a pin he held a pen at its base to show that it supported the applied weight of his finger in both the vertical and horizontal directions, but was still able to rotate about the base. This simple demonstration allowed his students to see the subtle differences between the supports that would have been difficult to describe on paper. At the end of his session, the mentor was describing his senior project to his students, which involved the analysis of suction caisson foundations. To explain what they are he turned his coffee cup upside-down on the table and one of his students exclaimed, “See, something I can relate to!” This scene proves that there is a serious need for students to see and relate to physical examples throughout their education.

Other groups took the more stereotypical approach to their homework assignments and focused more on getting the answers to the questions than understanding how to get them. Students said things like “I did [the homework], but I didn’t really understand why I was doing what I was doing,” and “I could kind of see what I needed to do, but couldn’t really get there on my own.” These sentiments arise all too often in engineering education today. The students got the correct answers on the assignment they were describing, but they clearly did not have a true understanding of the material. Students can receive high scores, but when asked to transfer the knowledge that was tested to new situations they are stuck. This level of understanding should not be rewarded to the extent that it is in today's educational system.

For this reason, homework assignments were still an integral part of my laboratory section and the second assignment consisted of three analysis problems (Appendix A, see p. 88). The intent of this assignment was to move from cantilevers to beams and was set up in a way that would lead the students to see that beams are just variations on cantilevers. The problems also increased in complexity from the first assignment by adding more than one load to a system. Adding more loads to a cantilever confused the students even though the process is the same as if only one load was applied. As they worked through the problem on the blackboard, though, they began to see exactly how the two problems related to each other and noticed that adding more loads did not make the problem much more difficult.

It is important to ask students how they arrive at their answers even if they are correct because it exposes their true level of understanding. When one student was asked to draw a picture of what an equation he had just written represented he could not do it. He was on the brink of true understanding, but his inability to represent his answer visually showed he had not fully mastered his ideas. He then approached the problem a little differently so that he could represent it visually, and this seemed to help him develop a better understanding of what was happening overall. When students realize that they may not fully understand something, they tend to find other ways to make it make sense.

### 2.2.5 Mid-Semester Laboratory Sessions

The students were asked to construct a model of a beam for the sixth session and encouraged to use their model to help them complete the last problem of the second assignment. Although the model would not give them the numerical answers, it would give them insight into how the beam should behave and if the answer they produced made logical sense.

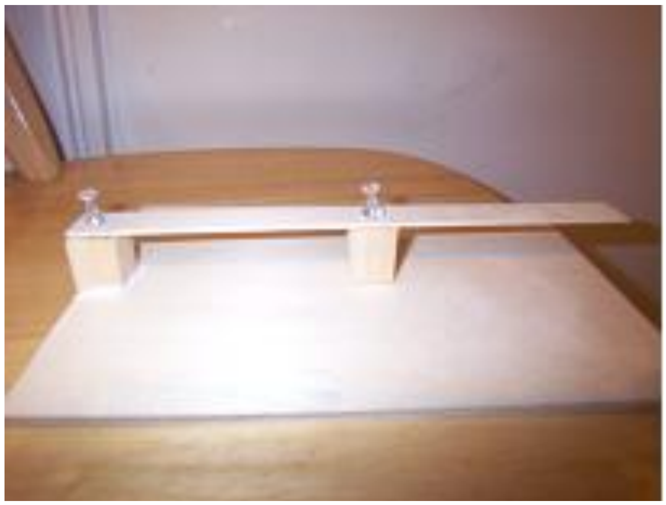


**Figure 9: Beam Model**

When discussing the third problem during the session, the students interacted with a model that resembled the given problem and assessed how the beam behaved when a load was applied (Figure 9). At first, they tried to apply mathematical ratios based on the spacing of the supports on the beam to find the reactions. This was a good intuitive approach, but when they looked at the model it was clear that this could not be correct.

The students expressed their content with focusing on the basics many times, and the effectiveness of this process was apparent when a student discovered the relationship between the problems in Figure 10. The fact that he made this connection on his own spoke well to the capacity to understand how structural analysis is simply a collection of basic principles.

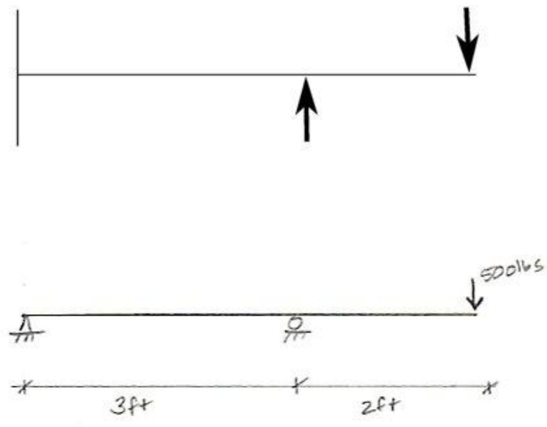



**Figure 10: Comparison between Cantilever and Beam**

The students said that they were glad they did the three different problems because they were able to see how each example built on the one before.

After the second assignment, the students asked for a set of extra practice problems, and when they presented their work it was clear that they were beginning to understand the fundamentals of structural analysis (Appendix A, see p. 89). Statements like, “I had an idea of what it should look like, but couldn’t quite get the numbers” in reference to the moment diagram for a problem with multiple loads suggested conceptual understanding even if the problem may not have made mathematical sense. In general, it seems as though the approach of introducing concepts on a large scale, narrowing them down to analyze the mathematics, and then relating them back to the large scale makes a good impression with the students (NRC, 2000, p. 24).

It is always important to relate structural analysis to real-world buildings so that students develop an appreciation for how the material they are studying is what makes the construction of great structures possible. Showing examples like the Pompidou Center in Paris and the George Washington Bridge in New York gave students inspiration by showing what is possible with the knowledge they were acquiring. A video of the Tacoma Narrows collapse was also shown to the students because although it is a defining moment in civil engineering history. I was never shown the video by a professor, and it seems that such an important event should be a key point of discussion in structural engineering courses. Aside from creating motivation, it is also important to show real structures so that problems become something more than just arrows pointing to a line.

### 2.2.6 Final Laboratory Sessions

The focus of the last part of the semester shifted to the canopy design project. First, the students were asked to bring in pictures of existing canopies. There is no way that they could design their own canopy if they did not have a good feel for what a canopy actually was. Many students brought in examples that looked like sculptures, which was interesting because the canopies they found most beautiful looked like pieces of art. In comparing the designs by the first-years to those that juniors produce in their *Steel Design* course, it seems that many students produced more aesthetically ambitious designs as first-years, but more realistic designs as juniors. This may be because the juniors understand their limits of analysis more clearly, but in general there should be an intentional effort to foster creativity while maintaining a sense of rationality.

In order to better understand canopies the students were introduced to portal frames and asked to bring in their own examples. Most examples included barns and other structures of the sort. A model frame was then used to demonstrate how these kinds of structures would behave under different loading situations (Figure 11).

**Figure 11: Model Frame**

All of the students had good intuition regarding how the frame would behave, predicting that only the legs would deform. Although their ideas were not entirely correct, they were fairly close to the actual behaviors that they witnessed when experimenting with the model frame. In this case, when the mathematical analysis behind the deformation was explained it actually helped the students to understand the behavior. Mathematics should not be discounted in any way, but should always be supplemented by visual aids and physical examples. Although the students may not have fully understood the behavior of portal frames, the fact that frames were introduced to them gave them insight into the range of possible structural behaviors and the factors they should consider when designing their own canopy.

An important part of any design process is the creation of conceptual sketches. Each student did well to create a set of conceptual designs and was able to discuss them eloquently. They seemed to understand the benefits and drawbacks to each, and were able to discuss why some designs would be successful while others may not if actually constructed. In order to gain further insight into their designs the students were then asked to build a scale model. After analyzing each of the five designs, the students picked the design that they felt would be the most successful if constructed.

The students were able to see the kinds of problems that developed once they built their models. One canopy was bowing a considerable amount and would most likely have exaggerated issues on a larger scale. The model showed that the design was not practical. Another student noticed from his model that his design would be extremely heavy on a larger scale and so adjusted the design to better suit his needs. When one student could not get her canopy roof to curve the way she wanted it to, she also adjusted her design to be able to build a sufficient model. She said that her design looked good on paper, but it was when she constructed the model that she noticed the flaws. Two of the students were mainly concerned with the users of the canopy and created designs that focused on the comfort of the people who would be waiting for the trolleys (Figure 12).

**Figure 12: Study Model**

It is interesting to note the considerations that different people focus on because they shed light on the many ways in which a problem can be solved. In the end, the students decided to focus on a design that had a wall similar in shape to a sine curve, but would have a split roof with two semi-circular slabs facing opposite directions (Figure 13).

**Figure 13: Design Concept for Wall**

All five students were concerned with the practical aspects of the canopy design, which shows that they understood their analysis capabilities and were striving to create a design that they actually understood on a fundamental level. During one of the final sessions, Professor Hines came in to give his introduction to calculating deflections of cantilevers. He took the approach of having every student go to the blackboard while he was explaining the derivation of the curvature diagram. The goal of the session was to derive the equation for deflection of a cantilever with a point load applied to its free end. He led the students through a series of exercises including demonstrating the different bending stresses that develop in various parts of a beam using a large eraser with vertical and horizontal lines drawn on the sides. While holding one end, he pushed on the free end to emulate the problem of a cantilever with an applied point load. The students were able to see that the top fibers split apart while the bottom fibers got closer together. He also used a strip of balsa wood to prove to the students that the amount of curvature varied along the beam.

Once the students could see how the beam would behave, Professor Hines asked them how they thought displacement should be calculated after knowing the curvature. The students correctly arrived at the idea that total deflection was simply a collection of all the curvatures along the beam multiplied by their respective lengths relative to the support. After a discussion of the definitions of stress and strain in a material, the students were able to determine that the equation for curvature was simply $\frac{M}{EI}$, where M is the internal moment. The fact that they could arrive at this simple, yet significant equation with limited guidance spoke highly of their ability to understand the concepts that are often thought to be too complex to teach to first-year students.

The highlight of the session was when the students found the expression for total tip deflection for a cantilever with a point load applied at the end. When they realized that it was the same equation that they had used to find the deflection of the model cantilever in the first week of the semester, $\Delta = \frac{PL^3}{3EI}$, they were all extremely excited. One of them exclaimed, “That is so cool!” The fact that the visual example was a precursor to the mathematics created a real trust in the equation. They had already seen what the mathematical result should be, and when the equation gave them the same result, they were all quite content and truly believed in the theory.

The way in which the concept was revisited also really seemed to solidify the students' understanding.

The students took this motivation into the final design sessions for their canopy (Figure 14).


**Figure 14: Students Collaborating on Canopy Design**

The group developed a seemingly simple design, but their process for arriving at that design was actually quite thoughtful. They moved from creating a solid wall, to one with eight columns, to one with just four after completing analyses of roof loadings to determine that only four columns were necessary (Figure 15).

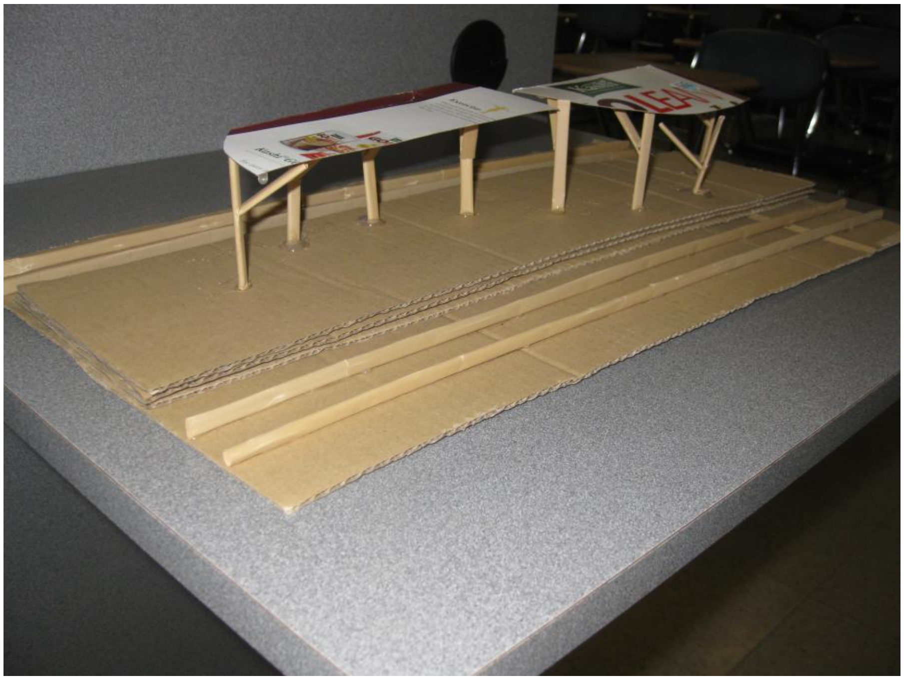


**Figure 15: Second Design Iteration**

They focused their design on simplicity and functionality (Figure 16). In comparison to the canopies created by other members of the class, this group's canopy may not have been the most creative in an aesthetic sense, but the amount of thought given to each and every design decision was impressive. The way they moved through the design process seemed to reflect the way they were taught throughout the semester, focusing on the basics and creating a simple but sensible design.

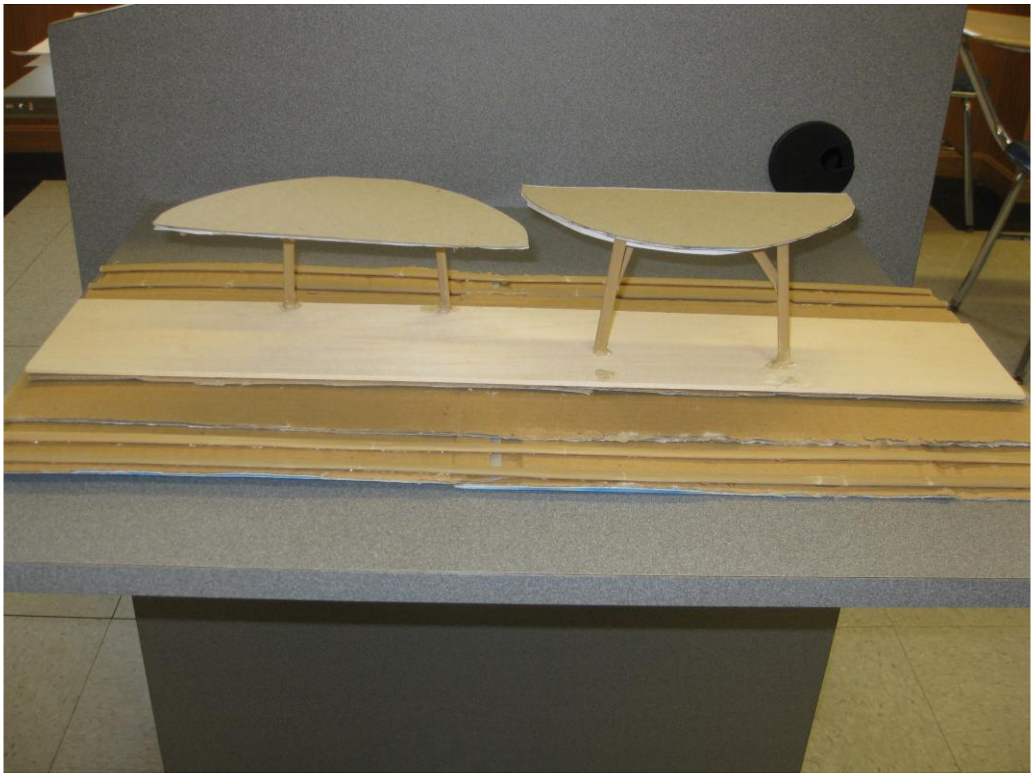


**Figure 16: Final Design Model**

Many of the other groups said they focused on simplicity as well, and many created impressive designs considering their recent introduction to structural analysis. Overall, though, this particular group was quite remarkable in their ability to create a design that was not only attractive, but also one they understood on a fundamental level.

## 2.3 Analysis of Fall Semester

In general, the fall semester segment of this project was successful in showing the effectiveness of teaching with visual aids and physical models. Though the students may not have fully mastered the concepts, most all of their feedback reflected positively on the teaching methods used (Appendix A, see p. 105-112). They said that they appreciated the greater focus on physical models as opposed to mathematics, which was a welcome change from their other engineering classes. There is a need for balance, though, and physical models as opposed to two-dimensional diagrams should simply supplement the mathematics. The students appreciated the small size of the group as it fostered an intimate learning environment. They mentioned that working with an undergraduate student as their mentor allowed them to better understand the material because the mentor was not far removed from learning the material herself. The combination of these three factors made for an extremely successful semester in that the students developed a basic understanding of the rudimentary principles of structural engineering.

As with any system, there is room for improvement in undergraduate engineering curricula. Some of the techniques used in this project may enhance the learning environment and reinforce the strong technical lessons that many universities focus on today. Change is good, and modifications to the current process may serve to encourage students to developing deeper understanding of the disciplines they are pursuing.

# 3.0 SECOND-YEAR EXPERIENCE

## 3.1 Introduction to Spring Semester

For the spring semester of 2009, the second-year introductory civil engineering course was run quite differently than in years past. The course was setup to cover many facets of civil engineering in the lectures, but the laboratory sessions would focus solely on the design and construction of simple structures. The focus would be to allow the students to create a process of getting a challenge, working through it, and relaying lessons they learned in a clear and transparent way. This process is something that they will then be able to apply to most all of their engineering courses. The laboratory assignments intentionally gave minimal direction, forcing the students to think through the best way to solve the challenge. This course would focus on all of the components of Systems 1 and 2, including “Identifying Preconceptions” and “Metacognitive Approach.” Intimate learning environments were created because an undergraduate student, a graduate student, and a recent graduate ran the laboratory sections. Creating physical relationships for the students was a clear intent of the laboratory, and the lectures sought to give the students role models in not only their professor, but also the many prominent civil engineering heroes they would learn about. Last, the course was designed to create an environment where students could begin to develop expertise in their field, mainly due to the focus on developing good processes to solve engineering problems and the emphasis on truly understanding fundamental concepts.

## 3.2 Discussion of Laboratory Sessions

### 3.2.1 Laboratory 1

For the first laboratory, the students were asked to measure deflections of a simply supported beam in order to develop a general equation for deflection of a beam of any span loaded at its center (Appendix B, see p. 113). The idea behind this was that the students would observe the physical phenomena and then develop the mathematics to represent it afterwards. This is in direct contrast to traditional teaching methods where the mathematics is presented and then followed by a physical representation, if there is ever a physical representation given at all.

The students may not have been exactly sure why they were doing what they were doing, but they were excited to do it. This shows how hands-on activities can serve to create engagement and motivation in students.

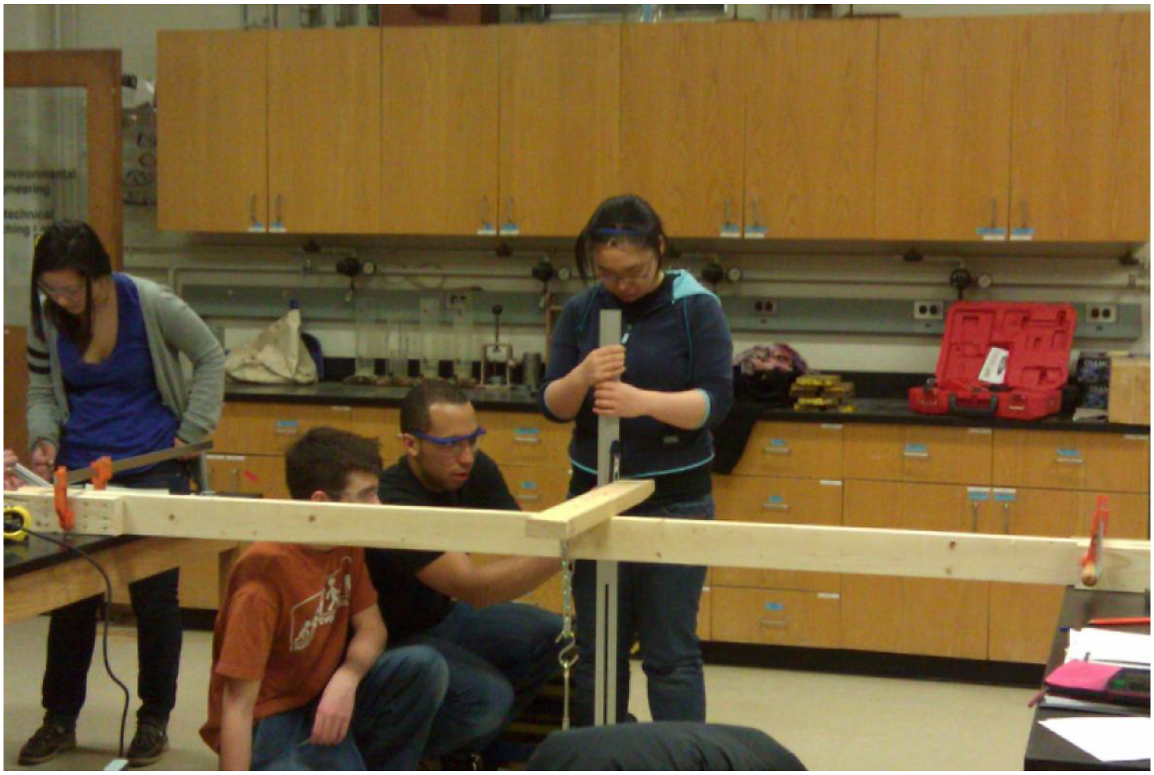


**Figure 17: Measuring Deflections of a Simply-Supported Beam**

Upon receiving their first laboratory assignment, the students needed some guidance in knowing how to best set up the test in order to take meaningful measurements. Though the task seemed scary to some at first, the students eventually began to appreciate the fact that they had such control over the amount of insight they were gaining from the laboratory sessions. The groups began to develop a good sense of priority in the tests they were conducting. They learned quickly that having a longer span would result in greater, more noticeable deflections so it made the most sense to begin tests there.

Throughout the laboratory session, I thought it was important to talk through what the ultimate goal was so that the experiments they chose to conduct made sense. I wanted to instill in them a sense that they should always be conscious of the end goal so that everything they did in terms of solving the problem made sense. I wanted to avoid anything seeming like it was just going through the motions. Every experiment should have a clear and understandable purpose for the students so that they do not lose a sense of ownership of the knowledge they are gaining.

Throughout the course it was shown that sophomores can have sophisticated levels of understanding that have traditionally been reserved for the junior and senior classes. When the students say things like "I like engineering when we're actually doing stuff!" and "I think we need a survey course to introduce us to all the branches with more hands-on stuff," it shows me that students are not getting all they want out of their engineering education. This demonstrates a need for teaching methods that can be used in ways to create more excitement and motivation in students.

#### 3.2.2 Laboratory 2

The goal of the second laboratory was to develop a general equation for deflection of a cantilever with varying back spans. Though the setup was similar to the first laboratory, it turned out that the analysis was much more difficult because the equation is more complicated than that for a simply supported beam. More variables to account for meant that the students had to test more relationships. The students were free to take any measurements they saw fit, and most realized from the week before that in order to develop an equation they needed to make sure to vary only one parameter at a time. One student said, “This is the most rewarding laboratory experience we’ve ever had. I feel like I’ve learned so much already!” That statement was gratifying for me to hear because it solidified that it is worthwhile to put time into developing laboratories that test students’ true understanding of concepts. A major component of these laboratories was getting the students to think about how the system would behave before they started to load it. This got them to be aware of their preconceptions before seeing the physical manifestation itself. Most students had an intuitive sense that the beam would break in the middle, but were not completely convinced until they witnessed the actual failure.

**Figure 18: Loading of Cantilever during Laboratory 2**

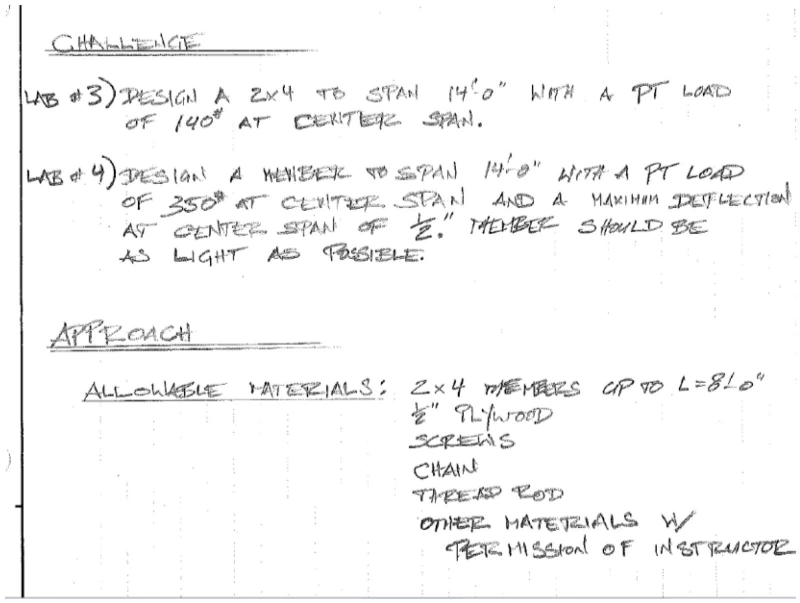
The students moved through the second laboratory much more smoothly than the first and had a good sense of how to best set up their tests in order to gather all of the data they needed to complete the assignment. At one point, a group loaded its beam and heard a cracking noise. One student said, “It’s yielding isn’t it?” Yielding is not precisely the correct word to use in this situation as yielding means deforming inelastically, where in this case the fibers in the wood were basically sliding relative to each other. However, the concepts are similar and the analogy was impressive because I did not fully understand the concept of yielding until the second half of my junior year. I knew which part of a graph meant something was in the yielding zone, but I really could not picture a physical example of something yielding until this laboratory. This comes back to a question asked during lecture about yielding, and shows that the students are connecting lecture to practice. The fact that the sophomores already have a sense of concepts like yielding suggests that they will have a much easier time understanding structural engineering concepts in the future. They will not have to spend as much time in their upper-level courses developing fundamental understanding of basic concepts, so will be able to pursue concepts more deeply.

It was also impressive when one group stopped halfway through their testing and said, "Are these numbers making sense?" Thinking back on my own laboratory experiences, I rarely understood what the numbers I was writing down meant until I went to analyze them later. There was a disconnect between the action of performing the laboratory and the process of understanding the concepts that it was testing. This laboratory pushed the students only to do something if they knew why they were doing it, and to relate their actions to fundamental concepts throughout the experiment. If they realized that they did not gather enough information one week, they had the opportunity to do a better experiment the next week because the laboratories built on one another. My classmates and I would have appreciated a laboratory like this during our undergraduate career because it teaches students the process of gathering meaningful information and analyzing it in a meaningful way. A process can be transferred to many different situations, whereas the specific knowledge developed from traditional laboratories is much less transferable. Overall, this was the most engaged and excited I had ever seen students during a three-hour laboratory session. More often than not sessions are a race to finish quickly, but I did not witness that sense of urgency in this laboratory. If someone does not want to devote time to an experiment, it generally means she is not engaged in the material, so by definition the sophomores cared about developing understanding.

Another point to highlight is that this laboratory is setup to "close the loop." The students explore a concept in a laboratory session, learn the theoretical concept in lecture, and then get another chance to explore the topic in their next session. I believe this is the best way to construct a class and follows my theory that people must explore these kinds of concepts physically in order for them to be fully understood. During the spring semester, the Curriculum Task Force hosted an engineering ethics panel, and there I noticed a clear disconnect between how professors and students view motivation. It sounded like everyone wants to achieve the same thing in terms of an enlightening educational experience, but each party thinks that the other is not working hard enough to get there. This is quite unfortunate, because if there were simply more open lines of communication many issues that both students and professors are complaining about could be avoided. Professors are role models and students have a responsibility to speak up if they feel as though their motivation is diminishing as a result of professors' actions. The professors also have a responsibility to communicate to their students if they are not working to the level that the professor expects. Success in the classroom is a mutual effort between student and professor and both sides are responsible for making the relationship work.

### 3.2.3 Laboratories 3 and 4

The third and fourth laboratories challenged the students to build a simple system out of 2x4s that could span 14 ft, but only 8 ft long 2x4s were available to them (Figure 19).


CHALLENGE

LAB #3) DESIGN A 2x4 TO SPAN 14'0" WITH A PT LOAD OF 140# AT CENTER SPAN.

LAB #4) DESIGN A MEMBER TO SPAN 14'0" WITH A PT LOAD OF 350# AT CENTER SPAN AND A MAXIMUM DEFLECTION AT CENTER SPAN OF 1/2." MEMBER SHOULD BE AS LIGHT AS POSSIBLE.

APPROACH

ALLOWABLE MATERIALS: 2x4 MEMBERS UP TO L=8'0"
1/2" PLYWOOD
SCREWS
CHAIN
THREAD ROD
OTHER MATERIALS W/ PERMISSION OF INSTRUCTOR

**Figure 19: Laboratories 3 and 4 Assignment**

This meant they had to connect, or splice, the boards in a way that would maintain enough strength to sustain loading. It was interesting to see that when they saw the physical product of what they had drawn on paper they were not always satisfied. Both groups were not thrilled with their original designs. One group decided to stick with their original plan while the other made some significant changes (Figure 20 and 21).

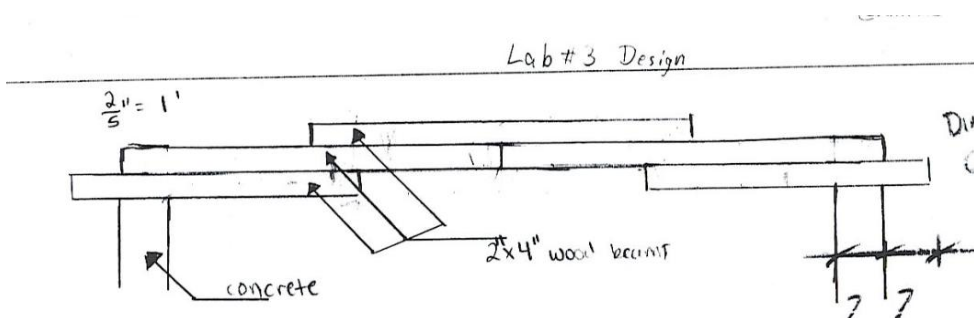



**Figure 20: Original Laboratory 3 Design**

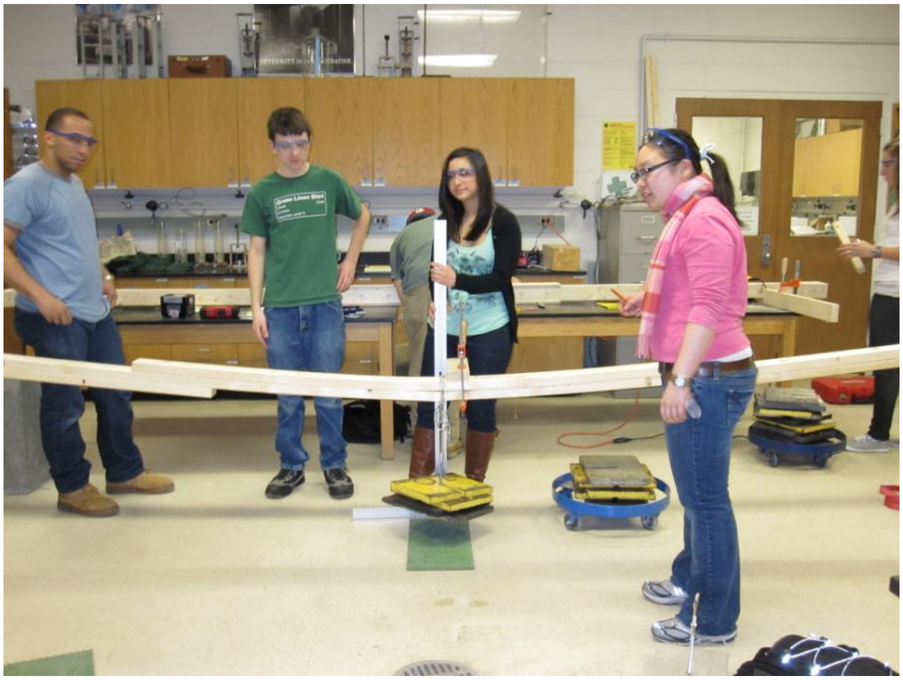


**Figure 21: Testing of Splice Design**

The group who made changes was originally going to use thread rod to hold the center of their splice together but realized drilling holes in the way they wanted to would most likely split the wood. They decided to simply make a box of plywood around their splice, which turned out to be quite successful (Figure 23). Both groups' designs help upwards of 140lbs, but both deflected to a point where the weights were resting on the ground. The one group did have time to experiment with the threaded rods, though, and discovered how close to the edge of a board they could drill without compromising the wood. They decided to incorporate the rods in their Laboratory 4 design. The other group realized that they should not construct anything on its weak axis because it would result in huge deflections. It took this group an extra week than most to realize this, but the fact that they witnessed it for themselves means that they will are unlikely to make that mistake again. This group also did not have any reinforcement on the tension side of their member, and through this experiment realized that was the most important place to have reinforcement. This laboratory gave them important insight as to the factors that strongly influence stiffness of a structure. They could not see these things on paper, but it became quite clear to them once they started constructing and loading their design.

**Figure 22: Redesign and Construction of Splice**

In general, each group made fairly good predictions about how their designs would behave. They really saw what they needed to work on by watching their systems deform.

**Figure 23: Testing of Second Splice Design**

One student noted, “It’s like in [*Mechanics of Materials*] when we look at stress over an area.” This showed that this class is reinforcing theoretical concepts in the laboratory. The fact that the students can make these kinds of connections suggests that they are way ahead of where I was at that age in terms of understanding. My classmates and I agree that we did not remember making those kinds of physical connections until much later in our academic careers and feel like we would have been much better off now had we made them sooner. The fourth laboratory was quite similar to the third, and further reinforced for the students important aspects of design to consider. The main difference between the two laboratories was that Laboratory 3 tested strength while Laboratory 4 tested stiffness, which helped to further reinforce the differences between the two properties.

**Figure 24: Testing System during Laboratory 4**

### 3.2.4 Laboratory 5

For the fifth laboratory, the students were asked to design a crane. This was the first laboratory in which the students were constructing something in the vertical direction, so issues of stability would play a major role. Up to then, the students had designed and built systems that remained in the horizontal plane, such as the simply supported beams. Stability is not an intuitive concept, mostly because it only arises in three dimensions. Traditionally, students are only presented with two-dimensional problems throughout their undergraduate curriculum, so they have a difficult time grasping the concept of stability. The concept is not easy to relate to because the physical connection does not exist.

A design that works on paper has the potential to fail at significantly less than the design loads if it is not properly stabilized during construction. This is a case where it is important to understand why it is optimal to design a structure to mimic its moment diagram, like Eiffel with his Tower. The students were given the instructions that the crane must stand five feet high and its arm be four feet long, and sustain 210lbs applied at the end of the arm (Figure 25).

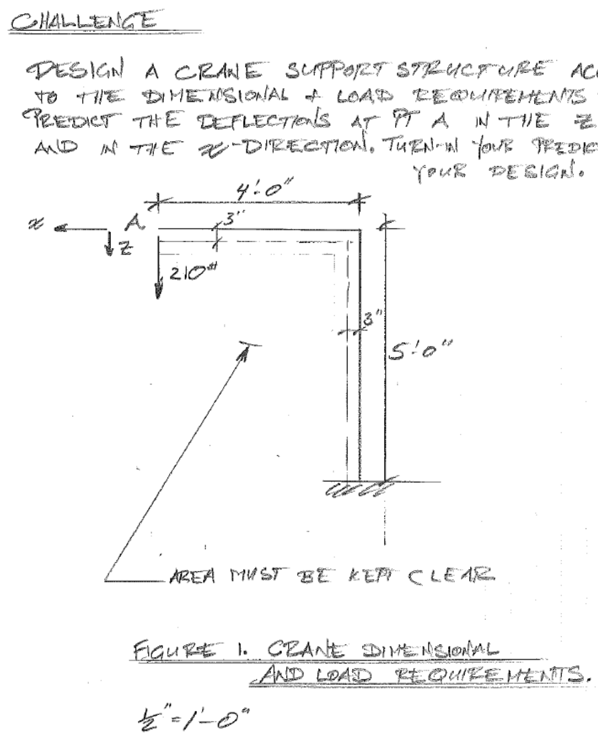



**Figure 25: Laboratory 5 Assignment**

The figure given is how to correctly represent the problem on paper, but would not be the best way to construct the system given knowledge of structural analysis. Fundamentally, where there is more moment in a member, more material is needed to resist that moment. The moment diagram for this system suggests that steps must be taken to resist large moments at the joint and base of the structure (Figure 26).

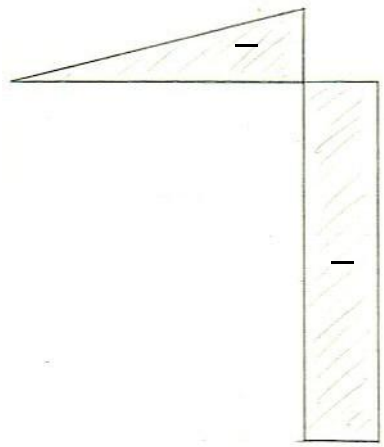


**Figure 26: Moment Diagram for Loading Case as Assigned in Laboratory 5**

The challenge of this laboratory would be not only to provide the required support to resist vertical loads and overturning moment in the counter-clockwise direction, but also to provide support so that the system would not fail laterally.

Based on student designs for this laboratory, most seemed to understand that they must resist the vertical loads and overturning moment, but did not consider lateral stability. Many added stabilizing pieces at the base of their structure, probably based on real-world experience with trying to make any tall, thin object stand up. One group's design is particularly interesting to examine (Appendix B, see pp. 138-145).

**Figure 27: Unloaded Crane**

The main body of this design directly reflects the figure on the given assignment (Figure 27). The group did add a length of nylon rope stretching over the arm and from an added back span on the top chord down to the base of the system. They believed that the rope would sufficiently transfer loads to the base and stiffen the structure enough to minimize deformations.

The idea of relating forces and deformations was extremely important in this laboratory. This group drew the moment diagram for their system showing zero moment at the base of the structure (Figure 28).

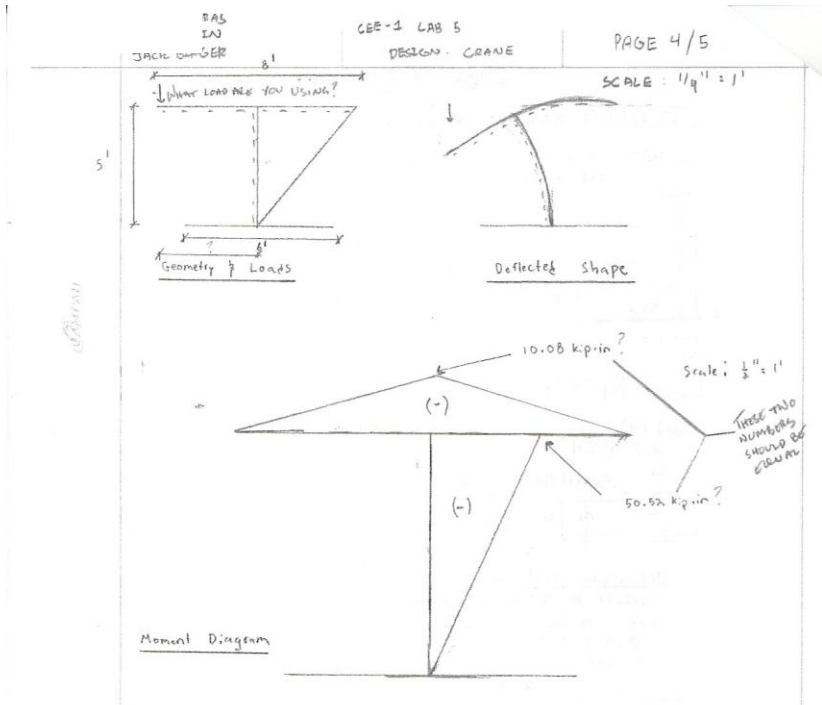



**Figure 28: Student Determination of Moment Diagram for Crane Design**

This is mathematically incorrect and could account for the fact that they did not think to add more support at the base. This group did in fact design their structure based on their moment diagram, exactly what they should have done. However, their moment diagram was incorrect.

This laboratory was an excellent way to allow students to test their own preconceptions. Before they tested it, I believed that the students' crane would not work simply based on theoretical analysis. It lacked adequate support at the base and joint of the system to resist the large moments that would be developed there, and there was minimal to no lateral support. They also had no way to pretension the rope used to a level necessary to transfer the loads in the way they were hoping to. However, they were so confident in their design that in trying to help them see their main flaws, they still adamantly defended their decisions. The fact that students invest so much in their preconceptions is an interesting phenomenon of education, and one that is often overlooked. If professors do not acknowledge that they must convincingly prove to a student why her preconceptions are incorrect, a piece of that preconception will always linger and cause some level of strife with the concept. It is clear that the best way for the students in this laboratory to see where they have gone wrong is to let them test their design as they have constructed it and see where and when failure occurs. The metacognitive approach taken here is essential in the students' learning process. I tried to tell them about aspects of their design to reevaluate, but they believed it would work and so continued. Nothing I could say would convince them. In witnessing failure, though, they would surely be convinced.

The crane did fail in approximately the ways I thought it would. The group actually ended up testing the system twice, but the first failure happened when the plywood split right at the base of their structure (Figure 29). The way that the structure was set up with the rope connecting back to the base of the structure meant that an extremely large moment was developing there. After the failure occurred, I discussed the moments in the structure with the students. I asked where they were seeing points of failure and they noted the joint and the base. The group began to see that they did not adequately design their structure to account for the moments in these locations.

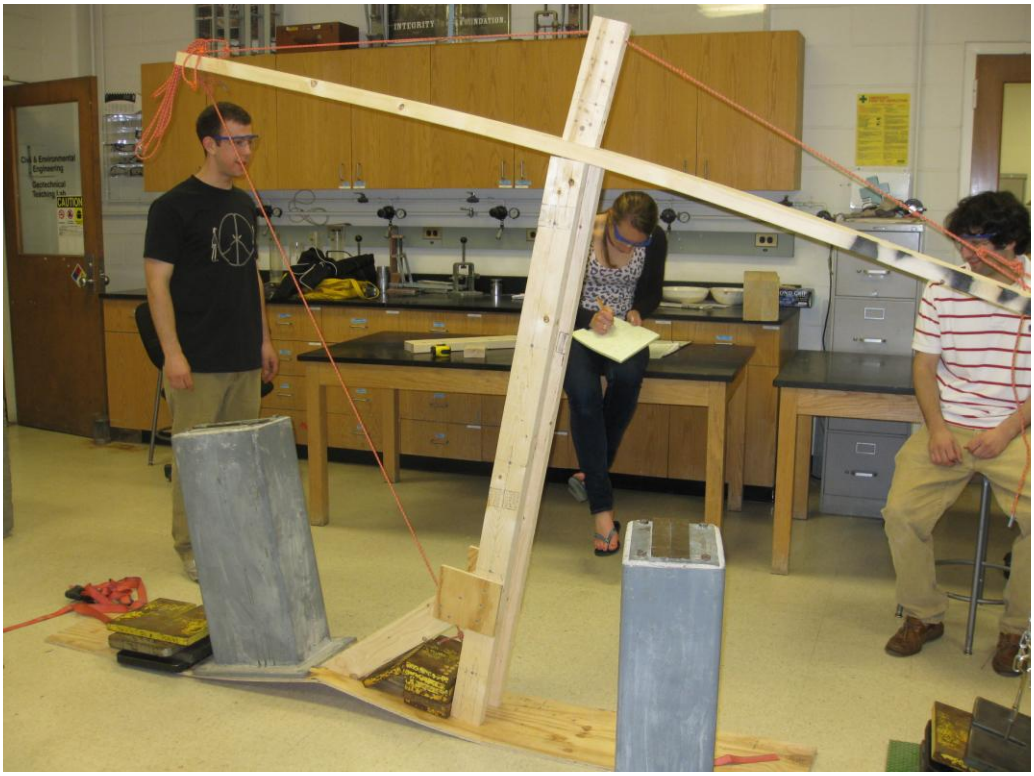


**Figure 29: First Crane Failure**

We also discussed how the moment diagram that they drew in their laboratory design was actually incorrect.  One student noted, "Our design reflects our moment diagram, but it's not the correct diagram."  The students understood that it was important to account for moments, but they pursued a design based on an incorrect diagram.  This demonstrates again the importance of having the correct picture in order to be successful in the engineering.  Another student added, "We added the rope in this way to counter-act the counter-clockwise motion.  We should have brought the rope straight down."  This was entirely correct, and the students then properly redrew the moment diagram to see why it was so.

The group noticed a few other major issues while testing their structure.  They quickly realized that they did not have nearly enough counterweight on the backend, but were confused at first why uplift was occurring.  They did not realize that they were creating such a big moment and that they had no part of their structure directly tied down to the counterweights to offset the weight on the other end. At one point one student said to another, “We’re really good in 2-D, but when it comes to 3-D we don’t really know.” This was a recurring theme throughout the laboratory sessions, and students really started to understand that they needed to think about what they were drawing on paper as having body. The group decided that they would test their structure with the back-rope connecting straight down to the counterweight because the structure was still mostly in tact (Figure 30).

**Figure 30: Adjusted Crane Design**

The crane held more weight during this experiment and deflected much less than the first time. They did notice more lateral movement of their top beam, but in general the students were able to see that changing the structure to fit the moment diagram did make it much more successful. The students were getting frustrated with the fact that they did not realize the counterweights were so important.  In discussing their issues, they said they tend to think locally and do not think about what is going on outside of their structure.  Standing alone the design was perfectly reasonable, but issues of lateral stability and overturning moment are major concerns that the students did not even realize they had to take into account.  One student became so frustrated with the realization that she exclaimed, “How the hell are we supposed to know what’s going to happen?”  It was great to see so much passion, and I explained that actually that was precisely the point.  There is no way to see lateral stability or overturning moment on paper.  It is extremely difficult to understand that a structure will move laterally when loaded vertically unless one can see it happening physically.

Failure occurred at the joint during the second test (Figure 31).

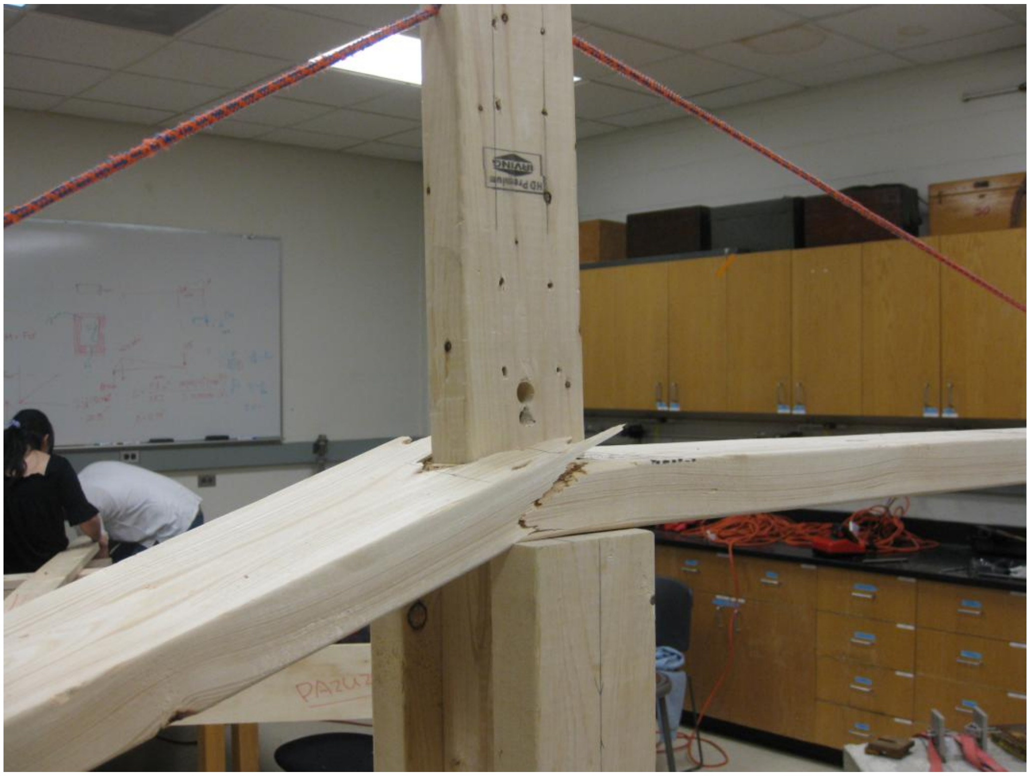


**Figure 31: Second Crane Failure**

This group had a difficult time understanding that the rope they were using was not actually performing the way they thought it would.  It is impossible to get the amount of pretension they needed in the rope to make it work like a truss.  If the rope were working correctly, they would not have seen any bending in their top beam and the failure would have occurred in the rope itself.  Instead, their structure was performing the exact same way as the cantilever in Laboratory 2, just elevated higher off the ground.  This laboratory allowed the students to see the flaws in their drawings and calculations in real time, and the discussion that occurred during the session suggested that they were really taking to heart the lessons they were learning.  Their design for this laboratory was quite similar to what they will be doing for parts of their final bridge design, and all of the students said that these tests were valuable for them to be able to understand the kinds of problems they will run into with their bridge.

Both groups had no lateral support on their structure, and the second group actually saw extreme lateral failure (Figure 32).  The concept of lateral stability was perplexing for the students, because their structures were standing.  To them, if the structure was not toppling over then it must be stable.  It was good for the students to see lateral failure of the second group's structure because it became quite clear that these structures were not stable.  A simple test to assess stability was developed during the laboratories, which said that the structure was considered stable if the students were able to push on their structures with significant force without seeing drastic movement.  The students saw considerable movement when they pushed on their structures during this laboratory, and as difficult as the concept is to grasp, the students seemed to begin to understand the magnitude of the consequences should they neglect to consider stability.  It was visibly hard for the students to come to terms with the fact that their structures failed in a way that they had not foreseen.  The frustration showed that they really cared about understanding why the failures were occurring and how they could take measures to prevent them in the future.  This laboratory proved repeatedly the importance of understanding students' preconceptions and allowing them to explore concepts repeatedly to develop metacognitive understanding.

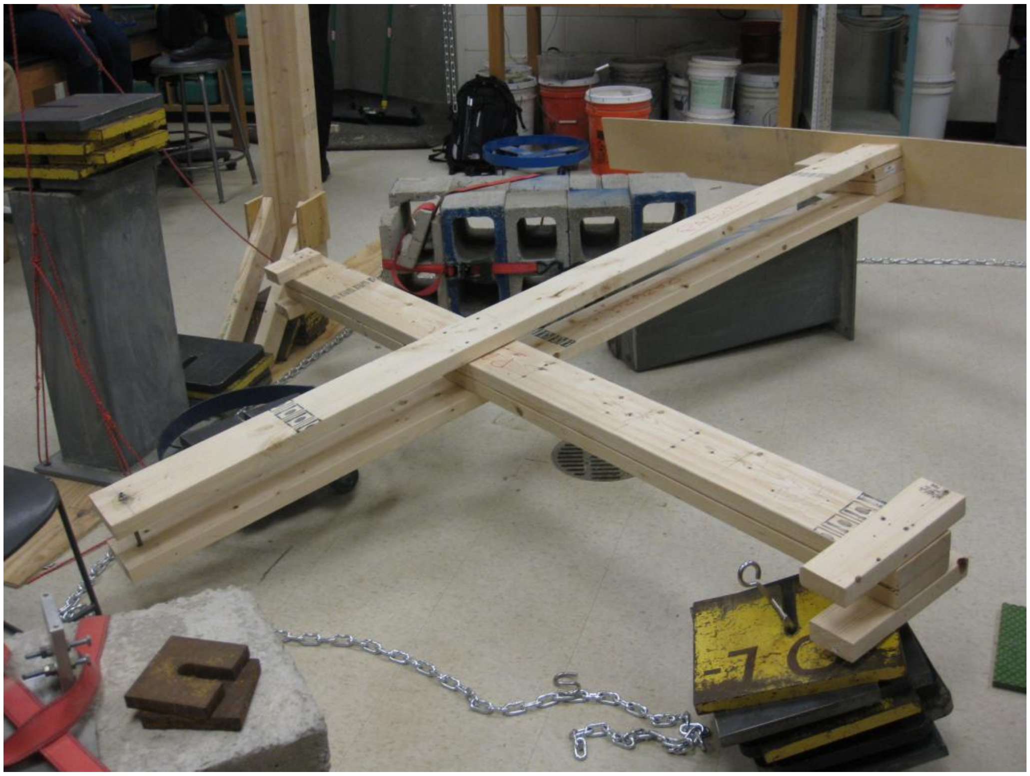


**Figure 32: Lateral Failure of Group 2's Crane**

### 3.3  Laboratory Reports

Grading the laboratory reports has also shown students' true processes of developing understanding.  Grading of reports was based on four categories: Data, Drawings, Conclusion, and Process.  These categories were thought to assess the range of skills that the students were encouraged to display through their reports.  Equal weight was placed on each of the categories, which followed the philosophy of the course that the process was just as important as the final answer.  The students' designs were assessed in the same fashion, with equal weight placed on Concept, Drawings, Details, and Calculations.  In addition, the three teaching assistants and professor graded the laboratory reports for the entire class collectively.  This allowed for clear development of the standard to which the students should be held, and this was communicated openly to the students throughout the semester.  Holding the students to a high standard from the beginning of the semester proved to encourage them to produce high quality work that demonstrated significant effort and thought.

There was a clear distribution in the work produced between groups, but it was interesting to see the different ways students solved the given problem.  The students were given little to no direction on how to complete the reports, and the fact that most all were successful in describing their process and developing a reasonable conclusion was wonderful to see.  While most groups did not necessarily organize their information in the best way for the first couple of reports, their methods were generally easy to follow and showed exactly how they thought through the problem.  Having developed the equation for deflection of a beam in their own way after exploring it physically should make the equation truly meaningful to them.  They should now have an image in their mind of a deflected 2x4 whenever they see a deflection equation.

There was a marked difference in the organization of their second laboratory reports, as time went on the students developed excellent skills in conducting experiments and analyzing their data.  They were given an example write-up for the first laboratory report, which gave them just enough direction so that they felt like they knew what was expected of them.  It was interesting to see that they took advice from the sample laboratory report, but they also took their own approach to all future reports.  An example was necessary to give them something to strive for, much like a role model, but they still were able to relate the information they wanted to as opposed to information they were told to present. An example of a first and fourth report can be seen in Appendix B (see pp. 116-136). The difference in quality is immediately apparent and extremely impressive. The amount of effort the students put into completing their reports shows that they truly care about the work they produce. It is also clear from the depth of the reports that the students took time to understand everything they did during the session and why. The skills that they will take from writing these reports will benefit them in all future engineering classes, because communicating ideas in a transparent way is just as important as having the ideas themselves.

### 3.4 Analysis of Spring Semester

There are a few clear examples of students gaining fundamental understanding of system behavior from the spring semester. The students grappled with the idea of the elastic and inelastic range of flexural deflections early on in the course. This was something I cannot remember being acquainted with until the second half of my junior year. One student raised a question about the inelastic range of material deformation during one lecture, relating it to the deformation of the beam she saw during her laboratory session. The idea of elastic versus inelastic deformations became physical at that moment, and the basis for her developing understanding was apparent. The fact that the students saw deformations and experienced the inelastic range physically before knowing what it was theoretically actually seemed to have greatly enhanced their understanding of the concept. The fact that they asked these kinds of questions is proof in itself. The kinds of questions students ask are give the professor insight as to where her students are in terms of understanding, so the more students are encouraged to ask all of their questions, the better.

The topic of virtual work was also covered in lecture. The main difference between teaching virtual work to the second-years versus the first-years was that the second-years were taking *Strength of Materials* concurrently and most had already taken *Statics and Dynamics*. However, the students still had a difficult time grasping the concept. It is a complex concept that students often do not begin to understand until late in their junior year. These students, however, can now relate the principle to the physical manifestations they see in the laboratory, and seem to understand the true power of the equations they can develop. They used the theoretical derivations of virtual work in their reports to try to relate the actual phenomena they were seeing during experimentation. For structural analysis, it is so important to understand what an equation actually means on a physical level, and these students have had an opportunity to see first hand the application of virtual work.

During the virtual work lectures, one student had an extremely hard time grasping the concept. This is no fault of his own; it is highly likely that none of his classmates fully understood it either. However, he continued to ask the broad question, "What is virtual work?" Professor Hines and I noticed that it was impossible to try to explain it to him when we really did not know at what point he was getting lost. We could not meet him where he was. If one does not know where her student is starting in terms of understanding, it is nearly impossible to give an effective explanation. It is difficult to find a balance between getting a student to ask specific questions and not discouraging them from asking any questions at all. As a student, this is difficult to admit because it is often thought that the professor is there for the sole purpose of helping with these kinds of confusions. That is what they are there for, but if they do not know where their students are getting lost they cannot effectively help them develop understanding.

# 4.0 ANALYSIS

## 4.1 Perspectives on Motivation

In investigating the question of where to derive motivation, I thought it would be helpful to interview my own classmates and professors about how they develop motivation (Appendix C, see p. 146-158). After speaking with Senior 1, I concluded that the main role of a professor in the university should be to serve as a role model to his or her students. The student said that in pursuing a problem, the end result is the ultimate motivation, but going through the process is also important. To me, the end result he was talking about is the grade, but he did make a point to say that it is unsatisfying to not understand every piece of the problem upon reaching the final answer. He mentioned that often times while working through problems or projects he does things that he knows he is supposed to do but does not know why. This is a noticeable problem in education, but one that can be solved by taking the alternative approaches to teaching described throughout.

When discussing the professor's influence on a student's motivation, everyone interviewed said that the professor has enormous influence. They all acknowledged that some motivation must exist in the student, but professors should be held accountable for not letting a student's inherent motivation diminish. The professor is in a position to know what is important and what can be approximated. More often than not, real life does not mirror textbook problems, and a professor should be able to show connections between those textbook problems and real-life situations. Some said that if a professor glosses over a topic it leads to frustration in the students and a sense of distrust that the professor does not actually know the material he is teaching as well as he should.

Student 1 used this year's senior capstone project as an example because this year, for the first time, the seniors were not allowed to pick from a selection of projects. "What if we got to choose it?" he said, "we would then have some feeling that we want to do this. Attitudes are important and professors affect them." This led to the main conclusion that I drew from the interview, which was that professors should be role models. Every interviewee could give clear examples of which professors led their classroom by good example and which did not. They also described how their success in terms of understanding in each of these situations directly reflected the type of professor they had in the class. Students are in danger of missing opportunities to gain true understanding of material as soon as their professors seem to forget that they have such an effect on their students' educational development. Professors are role models, for better or worse.

In general, I noticed many common themes brought up by the students, and faculty as well. Student 1 said he does not like personal attacks on his work or motivation, while a few others said they hate being put on the spot in a class. However, Student 4 said that as much as she hates being put on the spot, she feels as though she learned the most in the classes where that happened. The sense of embarrassment she felt if she got the answer wrong in front of the class was actually a way to motivate her to really understand the material. It is an unsettling feeling at first, but the more students become acquainted with it, the more they will be willing to make mistakes and learn as much as they can in the process. The student also noted that putting students on the spot "forces an accountability for the knowledge." Professor 1 told a story of having a professor in graduate school who always put him on the spot during lectures. He said he became more comfortable in taking risks and exploring the material to gain true understanding once he realized he was not the only one who did not know the answers.

Another common theme was that everyone appreciated seeing how the mathematics they learn relates to the real world. Student 3 mentioned that once she learned how to approach problems from the physical side she was able to transfer that approach to other classes containing complex material. She gave the example of being able to see the physicality of the complex matrices presented in *Advanced Structural Analysis* during the first semester of her senior year. Many said that teaching a subject to others forced them to truly understand it. The students that described this were able to give vivid stories about recent times they encountered this, and most were from their mentoring experience in *Structural Art*.

A clear sentiment of the importance of a mutual relationship between student and professor came up in all of the interviews. Student 2 described it as a "one-ups-manship," but everyone hinted at it. Each of the seniors said that many fundamental principles did not fully make sense until their junior spring. It seems from this common reaction that there must have been a shift in teaching methods. Students also said they appreciate professors-of-practice who can more directly relate material to real world problems, again reinforcing the physicality of the problem. Student 4 was a bit different from the others because she said the relation to the real world scared her. Her first major is mathematics, though, so her liking more abstract ideas tends to make sense. Professor 1 said he always appreciated relating theory to practice so attempts to do that in the classes he teaches now. If he and the students agree, it is still perplexing as to why there was such a clear line drawn between students and faculty at the Ethics Panel.

### 4.2 Relating Theory to Practice

The themes that I noticed throughout the academic year are not unique or novel. In fact, the ways that I have outlined to better encourage motivation in students has been documented for centuries. For example, the following quote from John Locke the need to sustain motivation in children, but this can be extrapolated to students as a population:

> On the other side, if the *mind* be curbed and *humbled* too much in children, if their *spirits* be abased and *broken* much by too strict a hand over them, they lose all their vigor and industry, and are in a worse state than the former. For extravagant young fellows that have liveliness and spirit come sometimes to be set right, and so make able and great men; but *dejected minds*, timorous and tame, and *low spirits* are hardly ever to be raised and very seldom attain to anything. To avoid the danger that is on either hand is the great art; and he that has found a way how to keep up a child's spirit easy, active, and free and yet at the same time to restrain him from many things he has a mind to and to draw him to things that are uneasy to him, he, I say, that knows how to reconcile these seeming contradictions has in my opinion got the true secret of education. (Grant & Narcov, 1996, p. 33)

Sophomore year is a good time to develop sound work processes in students because they are less jaded than juniors or seniors. They still possess an enthusiasm for their studies that sometimes fades as students move through their academic careers. If an ethic can be developed during the sophomore year, students will be able to utilize it throughout the majority of their academic careers. This should be done by setting high expectations, but not making the goals of the class so unattainable that they lead to discouragement. This idea is clearly stated in *How People Learn* when the NRC (2000, p. 61) notes that "challenges, however, must be at the proper level of difficulty in order to be and to remain motivating: tasks that are too easy become boring; tasks that are too difficult cause frustration." I believe this was achieved in the introductory civil engineering course. In addition, if sophomores can develop effective problem solving techniques, they have two more full years to hone their skills. Having two years to master problem-solving skills in the safe environment that is the university is priceless. If the techniques are not developed until the junior or senior year, the student does not have much time to fine-tune them before entering the real world. Locke also comments on this issue when he says, “It will perhaps be wondered that I mention *reasoning* with children: and yet I cannot but think that the true way of dealing with them” (Grant & Narcov, 1996, p. 58). He is alluding to the notion that if one should treat a student as if they can handle complex information, then they will believe that they are able to attain high levels of understanding. If the sophomores are treated as if they are at a senior level, they will respond at a senior level. If they achieve success on their own, it is much more satisfying. This also builds a confidence in them that they can take into the junior and senior year. Specifically in design courses that are more apt to test students’ confidence, getting practice early on is essential.

A prominent figure who developed theories regarding children’s learning processes in the mid-twentieth century was Jean Piaget. He showed that age is immensely important in how people approach and solve problems. “Stated most simply, Piaget’s theory describes how intelligence is shaped by experience” (Kolb, 1984, p. 12). Though Piaget’s theory focuses on the learning stages that people go through at the beginning stages of life, it can be extrapolated to fit older students as well. The best way to develop understanding is by example and through experience. In general, “learning is the process whereby knowledge is created through the transformation of experience” (Kolb, 1984, p. 38). The teaching methods used in both courses during this study were designed to let students have personal experience with each of the topics presented in order to develop true understanding.

Locke's ideals overlap with those described in *How People Learn* when he says, "There is no virtue they should be excited to nor fault they should be kept from which I do not think they may be convinced of, but it must be by such *reasons* as their age and understanding are capable of and those proposed always in very *few and plain words*" (Grant & Narcov, 1996, p.58). This is the idea of identifying preconceptions and meeting students where they are in terms of their level of understanding. It is important to keep explanations in the students' terms, which helps to relate to what they know and concepts become much clearer. Like the first-years, relating a suction caisson to an upside-down cup gives them a gateway to understanding. To further pursue the point, Locke describes the importance of physical relationships noting that "they cannot conceive the force of long deductions: the *reasons* that move them must be *obvious* and level to their thoughts, and such as may (if I may so say) be felt and touched." (Grant & Narcov, 1996, p. 58)

Last, Locke highlights the importance of good role models, identifying that "of all the ways whereby children are to be instructed and their manners formed, the plainest, easiest, and most efficacious is to set before their eyes the *examples* of those things you would have them do or avoid. Which, when they are pointed out to them in the practice of persons within their knowledge with some reflections on their beauty or unbecomingness, are of more force to draw or deter their imitation than any discourses which can be made to them" (Grant & Narcov, 1996, p. 58). Coming back to the issue raised during the ethics discussion and during interviews, teachers are role models. It is human nature to follow the example of figures of authority. If professors demonstrate good work ethic, students will follow because they are looking for guidance. If this mindset is engaged from the start of freshman year, students will know nothing else and it will be engrained in the culture.

The idea of transfer is a large theme in *How People Learn*. Transfer means that a skill can be used to solve many different problems in many different contexts. Teaching methods are extremely influential on a student's ability to transfer her learning, and motivation also plays a major role. Understanding where one might use her knowledge in the future leads to great motivation to develop true understanding of the concepts she is learning at present. It is true that "learners of all ages are more motivated when they can see the usefulness of what they are learning and when they can use their information to do something that has an impact on others" (NRC, 2000, p. 61). Even though the focus of the laboratory sections for the spring course was on structures, the aim was for students to learn a problem solving process that they could transfer to any aspect of their academics. In both the fall and spring courses, the instructor's intent was to give the students a clear picture of the work they could produce with the knowledge base they were developing.

In general, realizing that each student is at a different level of understanding and acknowledging that varied techniques need to be employed to sustain motivation are fundamental priorities of teachers. Each student must make the classroom her own, and "the extent to which any student adopts a mastery or performance goal orientation depends on how each student constructs the social reality of the classroom for himself or herself" (Ames & Archer, 1988). In studying the kinds of strategies used in student educational processes, Ames and Archer (1988) showed that "it was the degree to which the classroom climate emphasized mastery, rather than performance, that was predictive of how students chose to approach tasks and engage in learning. This suggests that the presence of performance cues may not inhibit some aspects of achievement behavior when mastery cues are salient." If the clear expectation of a course is to develop expertise, students will rightly follow. Lastly, the study showed that a focus on mastery encourages long-term learning by emphasizing the correlation between success and student effort. In other words, creating an environment where students are encouraged to develop expertise leads to true understanding.

One experiment that was quite similar to the ones conducted during the fall and spring semesters was done in 1998 at the Polytechnic School of the University of São Paulo in Brazil. There "a series of transparencies was prepared to be presented to the students during the classes, aiming at showing them the importance and the beauty of structures and of structural engineering, the fundamental role they play in our lives and how the mathematical models are linked to the real structures" (Lindenberg & Arevalo, 1998). The instructors used structures that the students lived near so knew well in order to encourage an appeal for them and the notion of their importance. The study notes that it was first important to define what a structure is, giving examples ranging from a spider's web to a skyscraper. They then introduced famous structures a chronological context, showing students the major feats accomplished by historical figures. Overall, the presentations aimed to show "a) the sheer magnificence and beauty of the structures built by man from prehistoric to modern times, b) that the evolution of structural engineering depends very heavily on the use of new materials and new structural systems, and c) that based only on intuition and qualitative models man was able to produce extraordinary structures like Cheops Pyramid, the Pantheon in Rome, the Cathedral of Amiens, the dome of the Cathedral of Florence, etc" (Lindenberg & Arevalo, 1998). The last point can be related to the introductory civil engineering course because it is showing students that they do in fact possess the intuitive knowledge to make their structures work, and that they can then learn the theory behind it in order to enhance their understanding. In line with what students said during the interviews, many students involved in the Brazil study noted that the most significant lectures were the ones that related the mathematical models to the real structures. They said that "…for having shown that the theory presented in the classroom is really used in the design of real structures and for having explained how these mathematical models are linked to the real structures" were the most engaging parts of the course. It is interesting to note that both the first- and second-year students said virtually the same sentences throughout the semesters. This goes to show that being aware of physical relationships is vital for structural engineering students.

### 4.3 Personal Connections

Looking back at my own academic career, I have realized that the people I respect the most are also the most genuine. This is not only restricted to my teachers and professors, but also includes older peers who helped me progress as a student. When observing the first years and sophomores, I tend to compare their experience to my own experiences. I tried to teach them the way I wish I had been taught and tried to give them the information I wished I had when I was in their position. For example, I wish I had known that sometimes people fail. Personally, making mistakes was never something I was comfortable with. I am not comfortable when I perform badly on an exam or problem set. In my opinion, this mentality leads to the blind application of equations in order to achieve top grades. I have had many experiences throughout my undergraduate career where if I was able to plug in numbers to the right equation I performed well on an assessment. I did not always understand why I was using the equation, but I knew that if I could make the numbers work out then I would receive the grade I strived for. Perhaps I should have focused more on understanding the concepts before moving on, but the way my semesters have been set up I felt like I did not have the time or the opportunity to take that extra time without sacrificing my grade or falling behind in the class.

There must be more opportunity for undergraduates to take risks within their curricula. It is important for students to develop the confidence to take risks while still in the university setting so that they are willing to take risks once entering the real world. One way to incorporate more risk taking opportunities earlier in one's undergraduate career is through small laboratory sessions. In speaking with many students and faculty, barely anyone likes being put on the spot. Many described having a feeling of terror when a professor asked them to complete a problem on the board in the middle of class or asked them a question they had not previously thought about. I believe that the feeling of terror exists because it is not often that students are put on the spot in this fashion. If it were to occur more often, beginning earlier in one's education, a culture could exist where students know that everyone is in the same position. The fear often comes from a feeling of embarrassment if a student answers a question wrong in front of his peers and professor. There is such a negative stigma attached to making errors and mistakes that students are actually hindered from taking chances. Many I spoke with also said that they learn the most from the mistakes they make, so why are students so often punished for making them? This is where some disconnect between students and faculty may come into play, because faculty may not see assigning poor grades as punishment. Grades are meant to be a form of communication between student and professor, but they are more often seen by students as the end-all, be-all of students' educational careers. This idea is a defining factor of the culture of an institution, and it is hard to shift students' opinions of grades because they have grown up with the notion that they are the most important aspect of their education.

Aside from grades, the small laboratory session is an excellent way to introduce students to taking risks early on in their undergraduate career because it removes some element of pressure that exists when the professor is present. This is why it is important for these laboratory sessions to be run by undergraduate or graduate mentors. The most important point is that the mentor is somewhat close in age to the students. This gives the students a sense of comfort and ease, where they are probably much more intimidated by a professor than someone just two or three years older than themselves.

In my experience, some of the greatest life lessons I have learned have come from peer mentors. The first example I think of is my high school sports teams. As much as I respected my coaches and learned a great deal about the game from them, it was my older teammates who directed my ambition in striving to be the best player possible. Watching the upperclassmen play their hardest and achieve goals they had set for themselves showed me that I could do the same. A satisfaction comes from impressing a teammate that is different from impressing a coach. Learning from the example of a peer and then performing to a level that contributes to their success as well is invaluable.

Another personal example is when I became involved in a group called Nerd Girls during my freshman year. Nerd Girls is a group of female engineers who are responsible for the design and construction of a solar-powered car. As a freshman there were only three senior girls working on the mechanical design of the car. I would sit in on their meetings and have no understanding of the concepts they were discussing, but each time they reassured me that they felt the same way as freshmen and by the time I was a senior I would be doing exactly what they were doing. It was not easy to believe them at the time, but as a senior on the team now, I am the one telling the freshmen members the exact same thing. The professor who advised the group told me the same thing as the girls did, but I tended to believe them more whole-heartedly because they had been in my position not three years before. They were close enough to the experience to remember the exact feelings that I was having and relate to them in a way that the professor, many years removed, could not. It is not that the professor did not have the same experience; it is just that he has had much more experience since then and a different relationship existed.

Overall, the attribute I respected most about my older peers was that they were genuine. They could tell me explicitly what to take most seriously about what a coach or professor said, how they had reacted to situations that I was now experiencing myself, and what they wished they had known when they were in my position. Working with students now, it is my goal to do these same things. The most important help an undergraduate mentor can give to students is the retrospective view of someone who was in the same situation so recently. I remember going through the same classes that they are now because they were just a few semesters ago. I remember exactly where I had trouble, what the most important ideas to focus on were, and how to adapt to different classes and different professors' teaching styles. A peer's advice is invaluable, and I have heard that from freshmen to seniors coming from being both the mentor and mentee.

From the other perspective, being an undergraduate mentor helps develop a confidence in not being sure of one's own knowledge. Being a mentor is another opportunity to be "put on the spot" in a different way. As much as it is embarrassing to not know an answer in a class that one is currently enrolled in, it is even more embarrassing to not know the answer to a question from a class one has already completed. Having an underclassman ask a question that contends an upperclassman's knowledge is a scary thing for that upperclassman. However, it has been said countless times that one learns best through teaching. Many students and faculty who were interviewed echoed the same sentiment, and noted that one way they knew they truly understood a concept was when they could teach it to someone else. Assuming the responsibility of being a mentor creates accountability for one's knowledge.

In terms of actual assignments, one of the biggest complaints my classmates and I have had about the laboratories we have had throughout our undergraduate careers is that they do not build on each other. If a mistake was made during one laboratory, there was never an opportunity to correct it. This created a sense of indifference about the laboratories because there was no visible benefit in trying harder. In a laboratory where the next weeks' results depend on what one has learned from the previous week, there is much incentive to get as much as possible out of the first laboratory. This was the design of the *Introduction to Civil Engineering* laboratory, and it seems to have been productive. The students' reactions to the laboratory are extremely positive, and upperclassmen who saw it have voiced their jealousy in not having the same experience. The amount of effort put into this laboratory is evident in the students' laboratory reports. The difference between the first laboratory submitted and the fourth is monumental. I do not remember ever putting in the time or energy into a laboratory report that the sophomores are putting into their designs and reports, and it is a wonderful phenomenon to witness. The students do become frustrated by not having the clear cut guidelines they are used to for writing the reports, but by the third and fourth they developed enough confidence to take the risks necessary to produce excellent pieces of work. The reports are not always stellar, but there has been a noticeable shift in the students from being overly concerned over a poor grade to wanting to understand the concepts and where they can improve above all else.

# 5.0 CONCLUSIONS

There are a number of factors that must come together to create a meaningful learning experience. Relating real-world examples to theoretical concepts learned in the classroom is extremely important. Students need to know *why* they are learning what they are learning. Material should first be presented in relation to physical examples, then time should be spent honing in on fundamental concepts that are the foundations of those examples, and then all of that should be related back to a real-world example in order to allow students to see the relevance of what they are learning (Figure 3). By using this method students always have an idea of where they have been, where they are, and where they are going in terms of the material they are studying.

Overall, the use of the Motivation and Understanding systems is essential in creating a meaningful learning environment (Figure 1). The Motivation System involves showing students the relevance of material they are learning through application to physical models and visual aids, the creation of intimate learning environments, and the presence of role models. The Understanding System consists of identifying students' preconceptions, developing expertise, and taking a metacognitive approach in teaching and learning. The most significant aspect of these systems is conducting small laboratory sessions in conjunction with classes where students are learning important theory is necessary to reinforce concepts in a meaningful way. Recitations sections are often used to accomplish this intimate environment, where students feel comfortable asking questions and taking risks in terms of trying new problems. Integrating undergraduate mentors in some capacity for these types of small laboratory sessions is essential. It is often said that teaching something is the best way to learn it, and it is especially true when the material is fresh in someone's mind. The fact that upperclassmen have recently learned the material themselves means that they most likely still remember the troubles they had in learning it and are equipped to help underclassmen learn the material in a productive way. It is easier for students to relate to someone on a similar level, and giving students an outlet to ask questions to someone not far removed from the learning process themselves is extremely beneficial.

I believe that this is the ideal. However, there is much debate surrounding the word ideal and the possibility of ever achieving it. Should we achieve it? It is necessary to establish an ideal so that there is something to strive for. Ideals may be adjusted and modified, but they should always exist. Just as students need to see where they are going with their education in order to make it meaningful, those creating curricula or lesson plans must have an idea of an optimal way to have their students achieve the best understanding of the material presented. There are different approaches to take, but using the Motivation and Understanding Systems at the undergraduate level is an effective way to allow students to develop true understanding of concepts.

It should be noted that nowhere in this scheme am I directly calling on professors to provide understanding to students. I believe the goal is the creation of an environment, a culture, in which the undisputed ultimate objective is to achieve true understanding. Professors can construct this environment by example and using the other methods described throughout. It is also more effective if the entire school maintains this mentality as opposed to sporadic, individual professors. This inherently means that there is no immediate way to fix the problem should it exist at a university. The problem being that students feel they are not achieving true understanding of the material they are learning. In our society today the notion that problems need to be solved immediately often leads to rash decisions that may not address the problem at all. Whether our current situation is a product of society or not, there are steps that can be taken to improve it as long as professors and students alike are willing to invest the time and energy to do so.

Students are not only misled in achieving understanding by their own preconceptions or errors while analyzing structures, but textbooks can contribute to misunderstanding immensely. Figure 33 shows a deformed shape diagram from a textbook used for the course that comes third in the series of structural analysis courses.

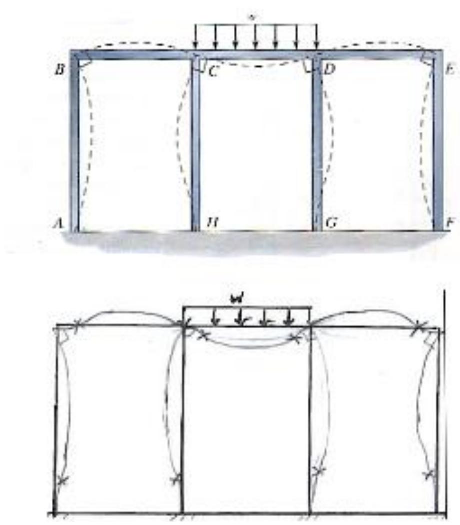
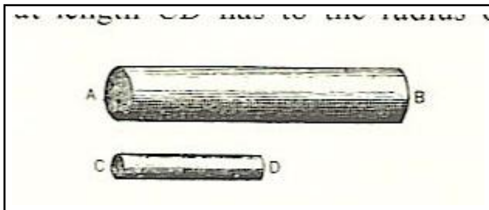


**Figure 33: Correction of Textbook Deflected Shape**

Below it is a representation of the correctly drawn deformed shape. The figure from the textbook fails to show inflection points at critical locations and has members deforming as if they were pin-connected as opposed to fixed, which is how they are drawn. It is impossible to expect a student to correctly represent physical behaviors if the textbooks used to teach them are not even showing the correct diagrams. This is why it is important to allow students to test theories on a physical level. If the frame system shown were recreated in a laboratory and loaded as shown, the students would be able to see exactly how the system should behave. It is quite difficult to deny a fact when it is physically apparent, whereas it is much easier to misrepresent a physical system in two dimensions. This is just another example of ways in which students can lose faith in what they are learning and be deterred from gaining true understanding.

These ideas are not new. Galileo wrote about discovering two new sciences, Statics and Dynamics, over 350 years ago in 1638. It is hard to imagine these pillars of scientific analysis as new sciences, but the way he chose to relate his discoveries was through a dialogue between three characters. A clear connection can be drawn between people today and the characters in the book. The three characters represent Galileo at different stages of his life (Galilei, 1638/1974, p. xiii). The oldest and wisest is Salviati, who can be compared to a professor. Salgredo represents a middle-aged Galileo, comparatively an undergraduate or graduate mentor. Last, Simplicio embodies the naïve but curious Galileo at a young age, or in present terms a first- or second-year student. Many of the conversations between these men remind me of conversations I had with my students throughout the academic year. One conversation in particular is reminiscent of many had during this academic year. Salviati, or the professor, begins by introducing the proposition that there is a relationship between geometrically similar solids and the compound moments they create about their own bases when acting as a lever (Figure 34).




**Proposition:** The compound moments of [two geometrically] similar cylinders or prisms, resulting from their own weights and [from their own] lengths serving as levers, have to one another the ratio that is the three-halves power of the ratio of the resistances of their bases. (Galilei, 1638/1974, p. 121)

**Figure 34: Galileo's Representation of the outlined Proposition**

This excerpt begins with Simplicio realizing that his initial understanding of the concept was actually incorrect, and is struggling to understand the concept in the correct way. Sagredo then admits that he had great difficulty in grasping the concept when it was first introduced to him, able to relate to the confusion that is expressed by Simplicio.

> *Simplicio:* This proposition strikes me as not only new but surprising, and at first glance very remote from the judgment I had conjecturally formed. For since the shapes are similar in all other respects, I should have thought it certain that their moments against their own resistances would also be in the same ratio.
>
> *Sagredo:* This demonstrates the proposition which, as I said at the beginning of our discussions, seemed then to reveal itself to me through shadows.
>
> *Salviati:* What is now happening to Simplicio happened also to me for some time. I believed the resistances of [geometrically] similar solids to be similar, until a certain observation, itself not very definite or correct, suggested to me that among similar solids there is not to be found an equal tenor of robustness, and that the larger are less fitted to suffer violent shocks. Thus large men are injured more by falling than are small boys; and as we said at the beginning, a great beam or a column is seen to go to pieces where a stick or a small marble cylinder falling from the same height does not.
>
> *Simplicio:* Now I recall something or other that was proposed by Aristotle in his *Mechanical questions*, where he tries to give a reason for the fact that the longer pieces of wood are, the weaker they are and the more they bend, even though the shorter [pieces] are quite thin, and the long ones very thick. If I recall correctly, he reduces this to the simple lever. (Galilei, 1638/1974, p. 122)

Elements of the Motivation and Understanding Systems described in the original hypothesis can be seen throughout *Two New Sciences*. This particular passage highlights the importance of having role models, developing expertise, and creating intimate learning environments. Salviati serves as a role model, demonstrating to both Sagredo and Simplicio the depth of his knowledge in the subject area. Simplicio demonstrates that he is developing expertise because he is transferring previous knowledge to this new situation. Though he is confused initially, he is ultimately able to think about the concept in a way that makes sense to him. He is developing true understanding. Last, Sagredo is relating to the fact that he did not understand the concept initially either, and can comfort Simplicio in this way. In the end, Simplicio is able to gain true understanding as a result of his experience. The similarities between situations described by Galileo regarding his own experiences and those described by students today are striking. Teaching in a way to motivate understanding is not an easy task, but the fact that the discussion has been ongoing for this amount of time is disconcerting. In both past and present, it has been shown that teaching methods do seriously influence a student's ability to gain true understanding. Serious attention must be paid to implementing necessary changes throughout undergraduate curricula in order to create the most effective and enriching learning environments possible.

Observational methods were the basis for conclusions to be drawn throughout this project. These methods were believed to be the best way to initially test the success of the teaching methods outlined. My ultimate hope is that all students feel as though they had a meaningful undergraduate educational experience, and an effective way to assess if this is the case is to ask students directly, analyze the work they produce, and observe them as they are learning. Qualitative analysis was the optimal method in determining the validity of the hypothesis for this project because it allowed for a direct view into how the students were responding to the new teaching methods in real-time. In addition, feedback they provided had much more depth than a numerical study could have shown. By using this method of analysis we now have personal accounts of what students felt worked and what did not, as well as a progression of the work they produced in order to truly see their progress.

What I learned most from this project is how difficult it is to construct a classroom environment that is optimal in providing the best methods of instruction for all students. However, I believe that utilizing different components of the Motivation and Understanding Systems, as well as maintaining a focus on relevance for students is a way to engage them at all levels. It is not an easy task to provide each individual with an exceptionally meaningful undergraduate experience, but that does not mean it should not be attempted. This project showed me that it is possible to create vibrant, engaging learning environments, and I hope to continue to explore the effectiveness of the outlined teaching methods in the future.

I believe this project should only be the beginning of a study that deserves serious attention. In analyzing results from this academic year, the teaching methods outlined are deemed to be successful in developing student motivation and true understanding. The next step is to test these methods over the long-term. Another possible study could be to follow a group of students from freshman to senior year who are exposed to these teaching methods and compare their experiences to those students who are taught by more traditional methods. The biggest limitation of this project came from the inability to conduct long-term observations, but overall this study showed the effectiveness of taking an alternative approach to teaching fundamental concepts. My recommendation is to continue to maintain substantial focus on motivation and understanding throughout the undergraduate curriculum in order to promote a meaningful educational experience for all students.

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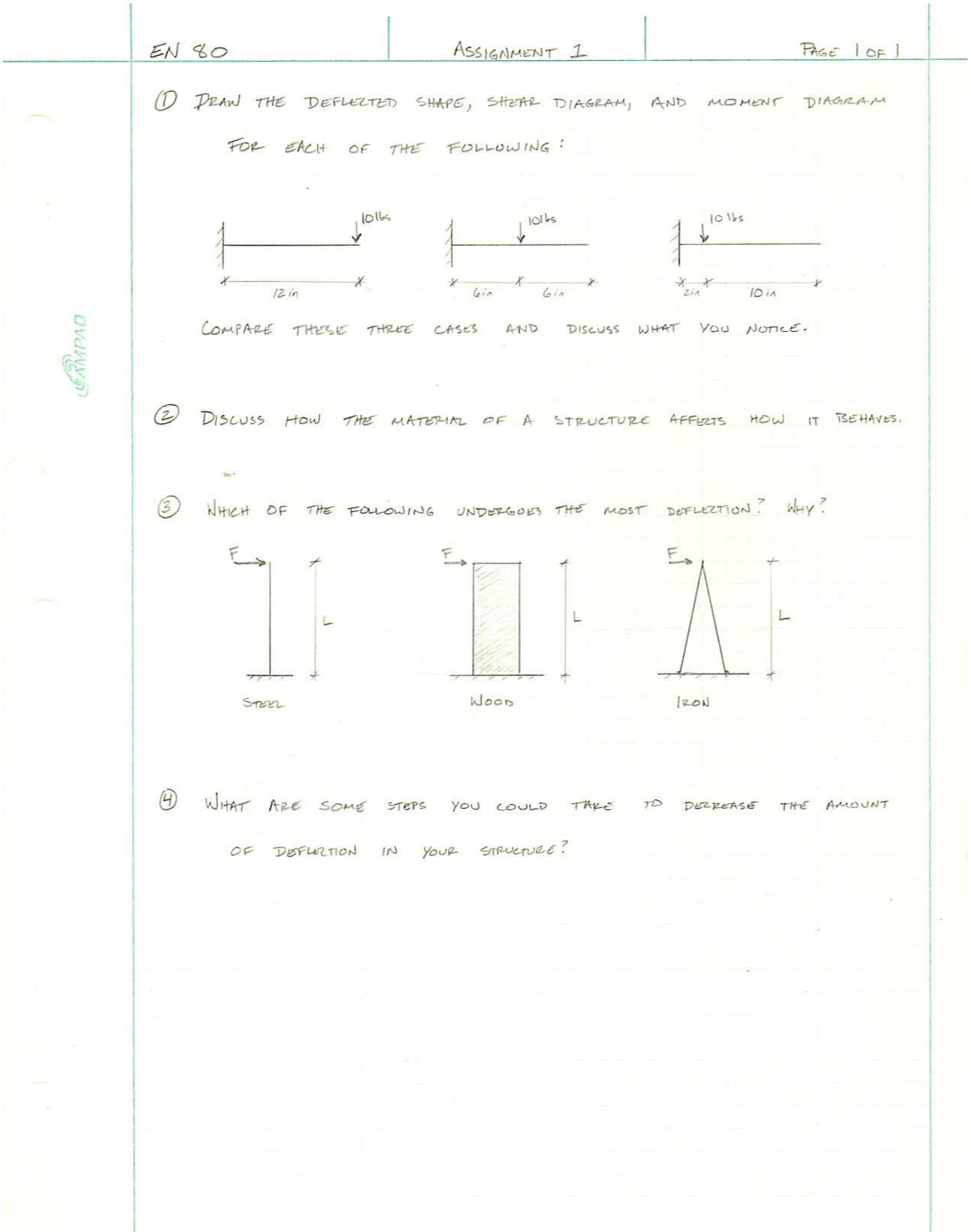
# APPENDIX A – *Structural Art*

## Homework Assignments



EN 80 | ASSIGNMENT 1 | PAGE 1 OF 1

(1) DRAW THE DEFLECTED SHAPE, SHEAR DIAGRAM, AND MOMENT DIAGRAM FOR EACH OF THE FOLLOWING:

10lbs — 12 in
10lbs — 6 in, 6 in
10 lbs — 2 in, 10 in

COMPARE THESE THREE CASES AND DISCUSS WHAT YOU NOTICE.

(2) DISCUSS HOW THE MATERIAL OF A STRUCTURE AFFECTS HOW IT BEHAVES.

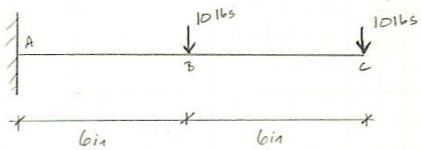
(3) WHICH OF THE FOLLOWING UNDERGOES THE MOST DEFLECTION? WHY?

F, L — STEEL
F, L — WOOD
F, L — IRON

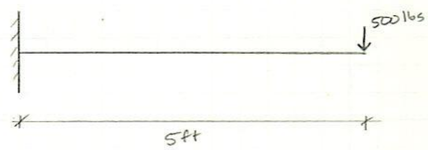
(4) WHAT ARE SOME STEPS YOU COULD TAKE TO DECREASE THE AMOUNT OF DEFLECTION IN YOUR STRUCTURE?

① DRAW THE DEFLECTED SHAPE, SHEAR DIAGRAM, AND MOMENT DIAGRAM FOR EACH OF THE FOLLOWING:

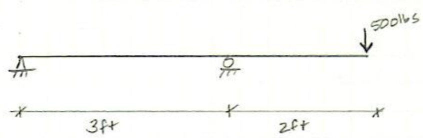
a)



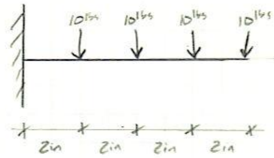

b)



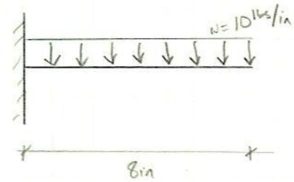

c)



①

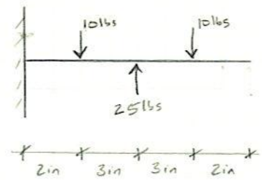



②

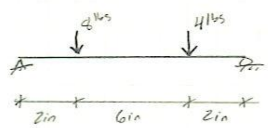



NOTE: THIS IS A DISTRIBUTED LOAD. THERE IS 10lbs OF FORCE AT EVERY PART OF THE BEAM.

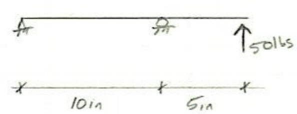
③



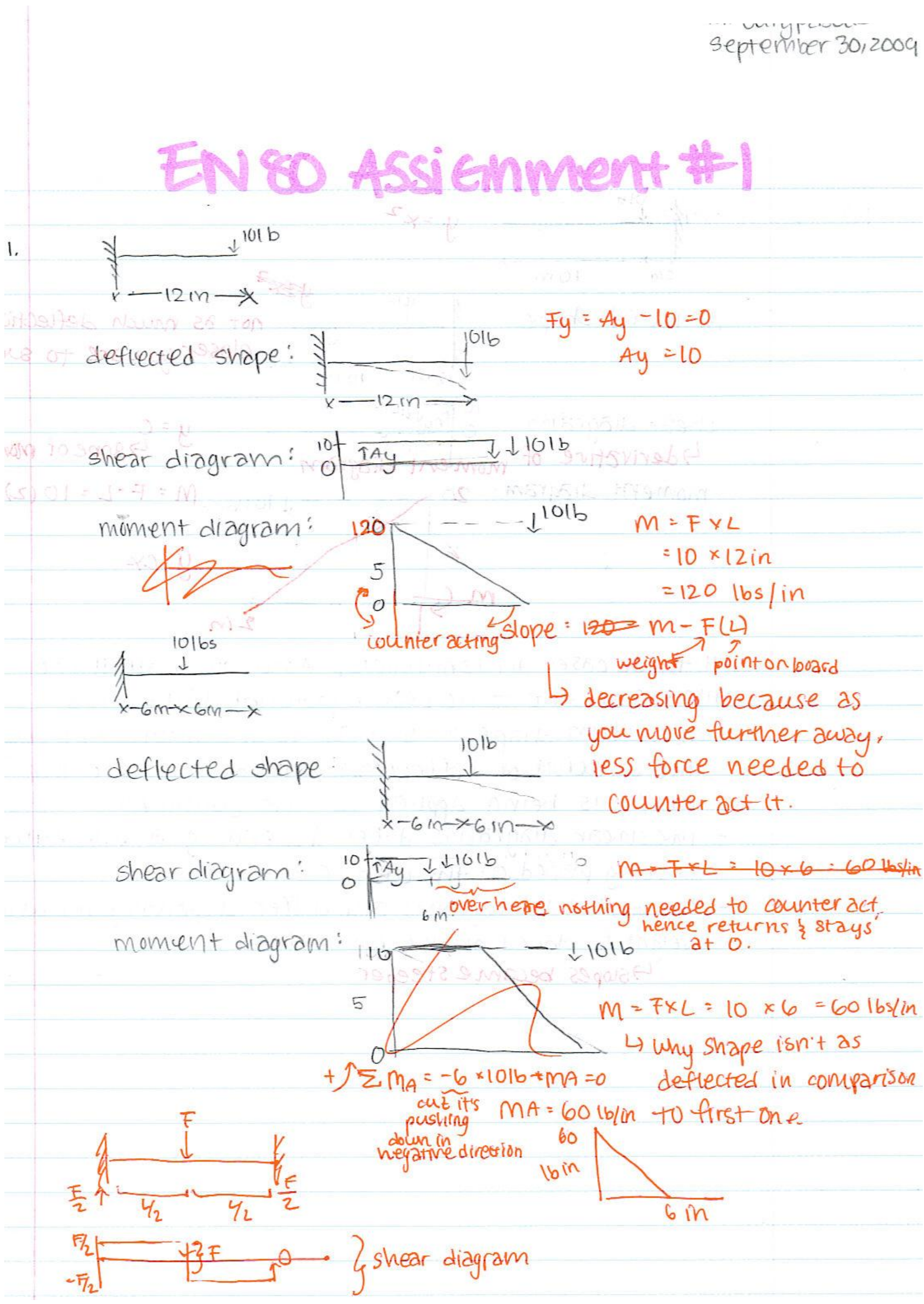

④




⑤



**Student Work**



September 30, 2009

EN 80 Assignment #1

1\. 10 lb

12 in

deflected shape: 10 lb

12 in

Fy = Ay − 10 = 0

Ay = 10

shear diagram: 10 0 ↑Ay ↓10 lb

moment diagram: 120 5 0 10 lb

M = F × L

= 10 × 12 in

= 120 lbs/in

counter acting

slope: ~~120~~ m − F(L)

weight point on board

↳ decreasing because as you move further away, less force needed to counter act it.

10 lbs

6 in 6 in

deflected shape 10 lb

6 in 6 in

shear diagram: 10 0 ↑Ay ↓10 lb

~~M = F × L = 10 × 6 = 60 lbs/in~~

6 in over here nothing needed to counter act, hence returns & stays at 0.

moment diagram: 10 5 0 10 lb

M = F×L = 10 × 6 = 60 lbs/in

↳ Why shape isn't as deflected in comparison to first one.

+↺ Σ M_A = −6 × 10 lb + MA = 0

cuz it's pushing down in negative direction

MA = 60 lb/in

60 lb in

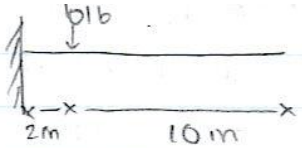
6 in

F

F/2 L/2 L/2 F/2

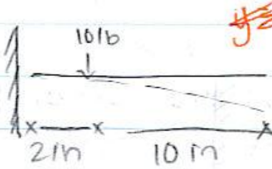
F/2 −F/2 F 0

} shear diagram



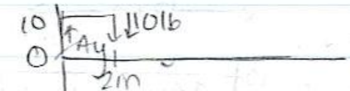

$y = x^2$

deflected shape:




not as much deflection the closer you are to support.

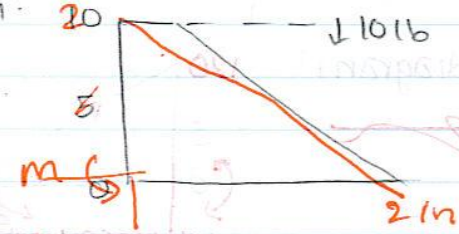
shear diagram:




$y = c$
↳ slope of moment diagram

↳ derivative of moment diagram

moment diagram:




$M = F \cdot L = 10(2) = 20$

$y = cx$

All three cases are cantilevers. Assuming all three cantilevers are the same (same material, build, etc)...

- deflection shape is similar to one another, though the amount of deflection depends on where the weight is being applied on the cantilever
- the shear diagrams differ depending on where the weight is being placed on the cantilever.
- the moment diagrams also differ depending on where the weight is placed on the cantilever.
  ↳ slopes became steeper

Design for purpose.

Strength ≠ stiffness but they are closely related

need appropriate material for type of structure

High elasticity - more energy needed to bend it

Low elasticity = more tendency to deflect ex: wood

Assuming linearly elasticity = if bent, will go back to its original point

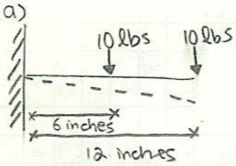
2. The material of a structure affects the structures behavior because the structure depends partly on the properties of the material used to build it. For example, a wooden cantilever is going to be different from an iron cantilever because of the different properties of the material. The wooden cantilever is going to be less stiff and have a greater moment of inertia in comparison to iron. Wood is also more flexible than iron. As such, wood's modulus of elasticity is less than that of iron. If these two materials were to be compared when used in a structure, the wooden structure would be less rigid and mo susceptible to external forces such as weather. Depending on how th structure was built, the wooden one might be more prone to oscillation from the wind as there is greater elasticity. The iron structure, on the other hand, would be more rigid and not as flexible to external forces due to its properties.

3. The steel cantilever undergoes the most deflection due to its thickness. Although steel is stronger and more rigid/inelas than wood, the wooden cantilever is thicker and has more area for balance and support. The thickness of the steel cantilever structure does not aid in giving it the proper area space and balance it needs to resist the force applied to it. Although the iron structure is composed of iron that appears to have the same thickness as steel, the formation of the two iron pieces causes the structure to be very strong and resistant to external forces as the weight is evenly distributed in the base, where there is greater area of support in comparison to the steel cantilever.

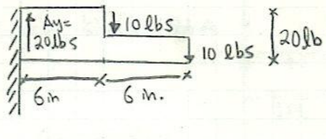
wide base - weight more evenly distributed.

# Problem Set 2

a)

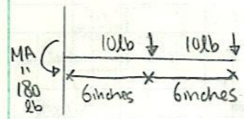



Deflected Shape



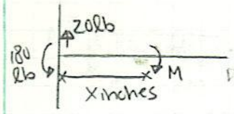

Sheer Diagram

$+\uparrow \sum = Ay - 2(10) = 0$
$Ay = 20$ lbs



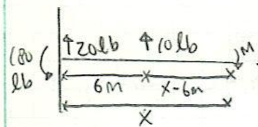

$+\circlearrowleft \sum M_A = -(6)(10) - (12)(10) + MA = 0$
$MA = 180$ lb in.

Internal Force before the 6 inches (where the first force is applied)

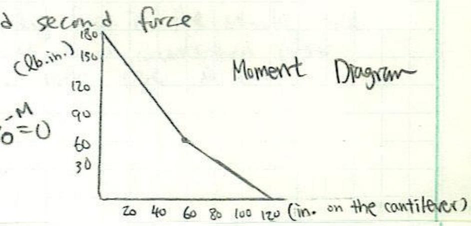



$\sum M = 180 - 20X - M = 0$
$M = 180 - 20X$

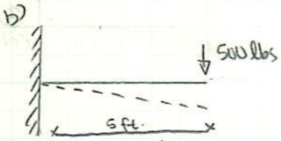
Internal Force between the first and second force



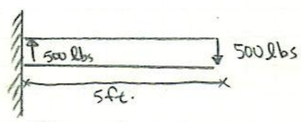

$\sum M = 10(X-6) - 20(X) + 180 - M = 0$
$M = -10X + 120$




b)



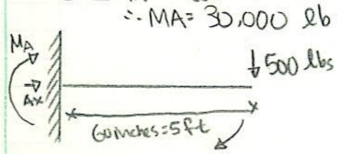

Deflected shape




sheer diagram

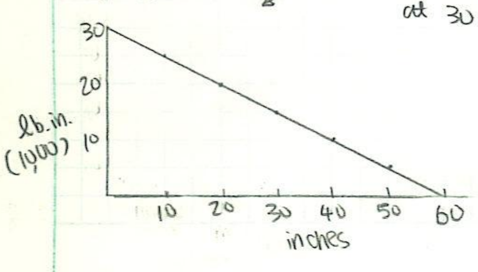
5ft. = 60 inches

$+\circlearrowleft \sum M_A = -(60)(500) + MA = 0$
$\therefore MA = 30{,}000$ lb in.




general formulae: at x inches, $M_A = MA - Ay(x)$

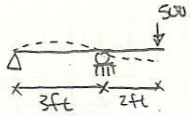
at 0: $M_A = 30{,}000 - (500)(0) = 30{,}000$
at 10 $M_A = 30{,}000 - (500)(10) = 25000$
at 20 $M_A = 30{,}000 - (500)(20) = 20000$
at 30 $M_A = 30{,}000 - (500)(30) = 15{,}000$
at 40 $MA = 30{,}000 - (500)(40) = 10{,}000$
at 50 $MA = 30{,}000 - (500)(50) = 5000$
at 60 $MA = 30{,}000 - (500)(60) = 0$



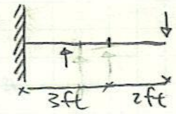

$M_A = 30{,}000 - (500)(x)$
$0 < x < 60$

moment diagram

c)

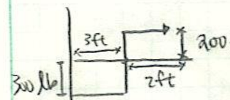



It looks kind of like



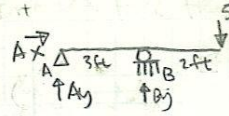

but this is a fixed support so when you draw shear / moment diagram they are different

$+\uparrow \sum = Ay - 500\ lb = 0 \quad Ay = 500\ lb$




Sheer Diagram (?)

weight distributed between the 2 parts therefore; first part is negative 300 lbs and second is 200 lbs




sum of moment

$+\circlearrowleft \sum M_A = (-500)(5) + (By)(3) = 0$

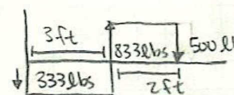
$By = 833\ lbs$

$+\uparrow \sum F_y = -500 + 833 + Ay = 0$

$Ay = -333\ lb$

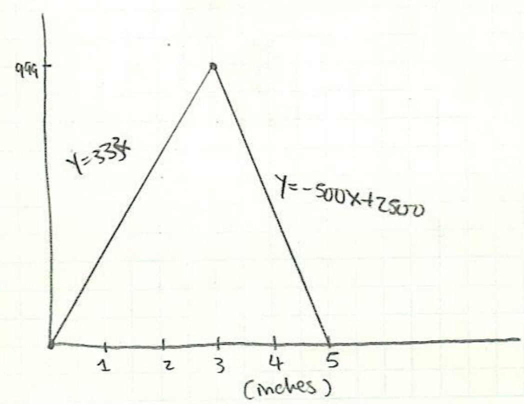
(negative Ay because big force in the middle, the pin wants to go up so a downward force is needed to maintain the A end)

Redrawing Shear Diagram:




Moment Diagram:

A pin and roller cannot sustain any moment ∴ it starts at 0

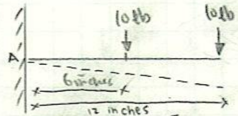



first part of the moment:
$(3\ ft)(333\ lb) = 999$
$Y_1 = 333x$

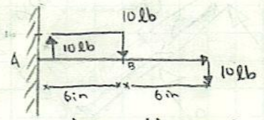
second part of the moment:
$Y_2 = -500x + 2500$
because 500 lbs is how much force thats actually applied (833 lbs is only a jump)

# Attempt # 1

① a)




Deflected Shape



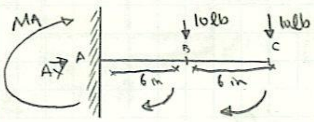

sheer diagram

$+\curvearrowleft \sum M_A = -(6)(10) - (12)(10) + MA = 0$

$MA = 180$ lb in.

$0 < x \leq 6$: $180 - 10x - 10x$

$6 < x \leq 12$: $180 - 10(6) - 10x$




general formulae: at X inches, $M_A = MA - Ay(x)$

at 0: $M_A = 180 - (10)(0) - (10)(0) = 180$

at 1: $M_A = 180 - (10)(1) - (10)(1) = 160$

at 2: $M_A = 180 - (10)(2) - (10)(2) = 140$

at 3: $M_A = 180 - (10)(3) - (10)(3) = 120$

at 4: $M_A = 180 - (10)(4) - (10)(4) = 100$

at 5: $M_A = 180 - (10)(5) - (10)(5) = 80$

at 6: $M_A = 180 - (10)(6) - (10)(6) = 60$

at 7: $M_A = 180 - (10)(6) - (10)(7) = 50$

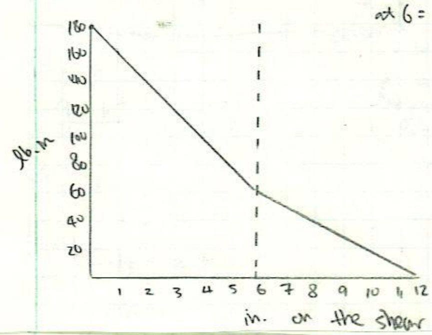
at 8: $M_A = 180 - (10)(6) - (10)(8) = 40$

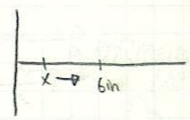
at 9: $M_A = 180 - (10)(6) - (10)(9) = 30$

at 10 $M_A = 180 - (10)(6) - (10)(10) = 20$

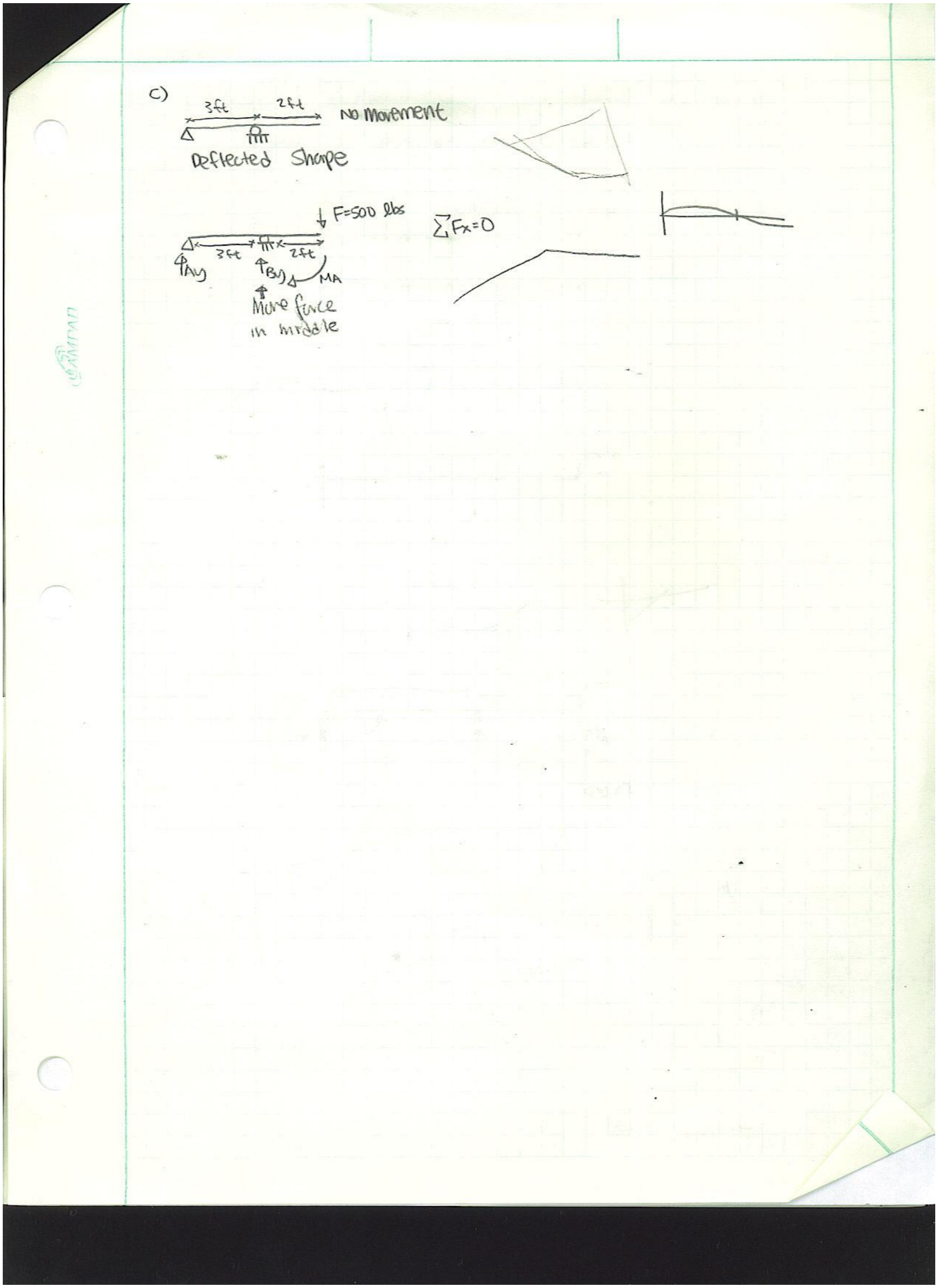
at 11 $M_A = 180 - (10)(6) - (10)(11) = 10$

at 12 $M_A = 180 - (10)(6) - (10)(12) = 0$

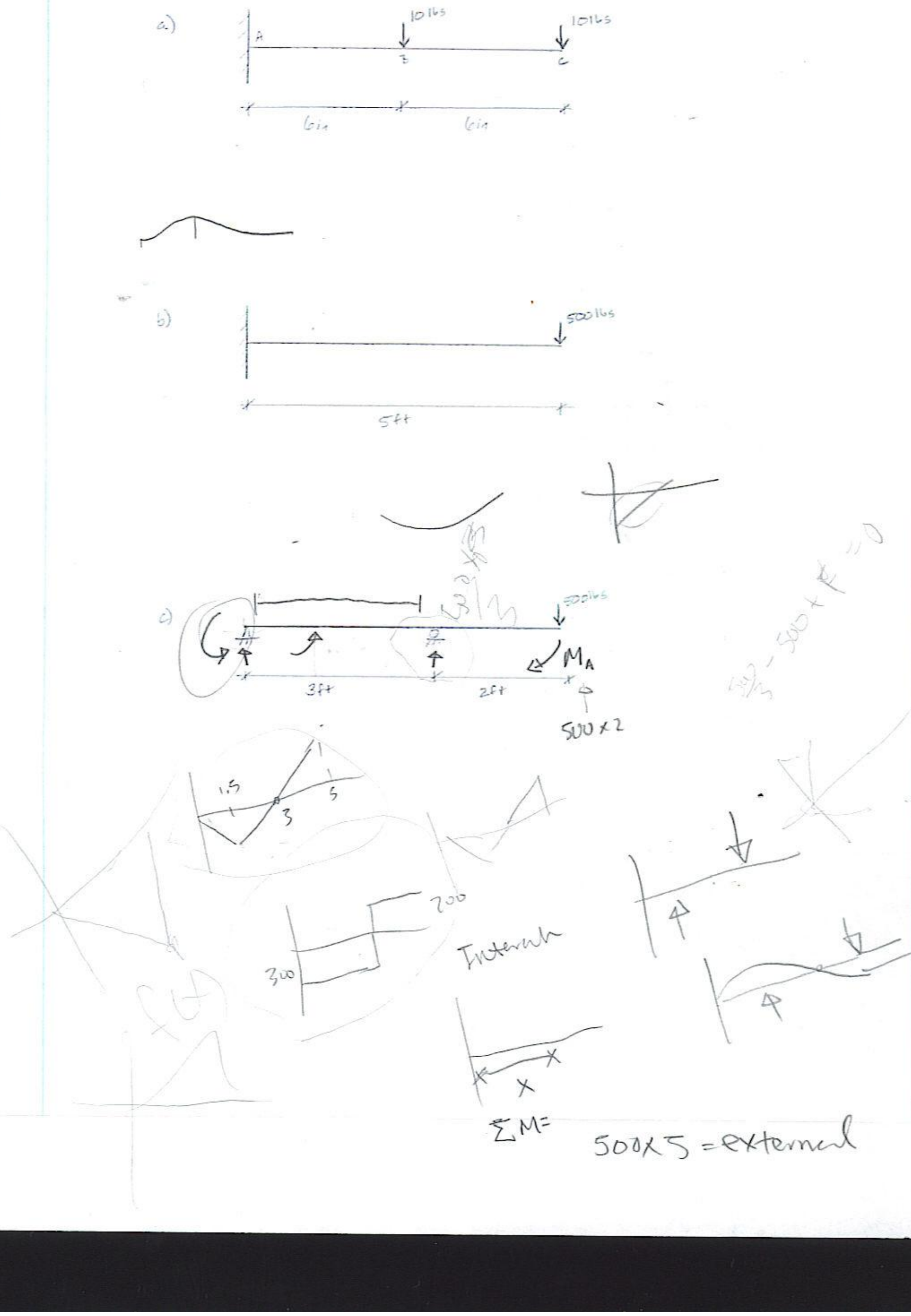


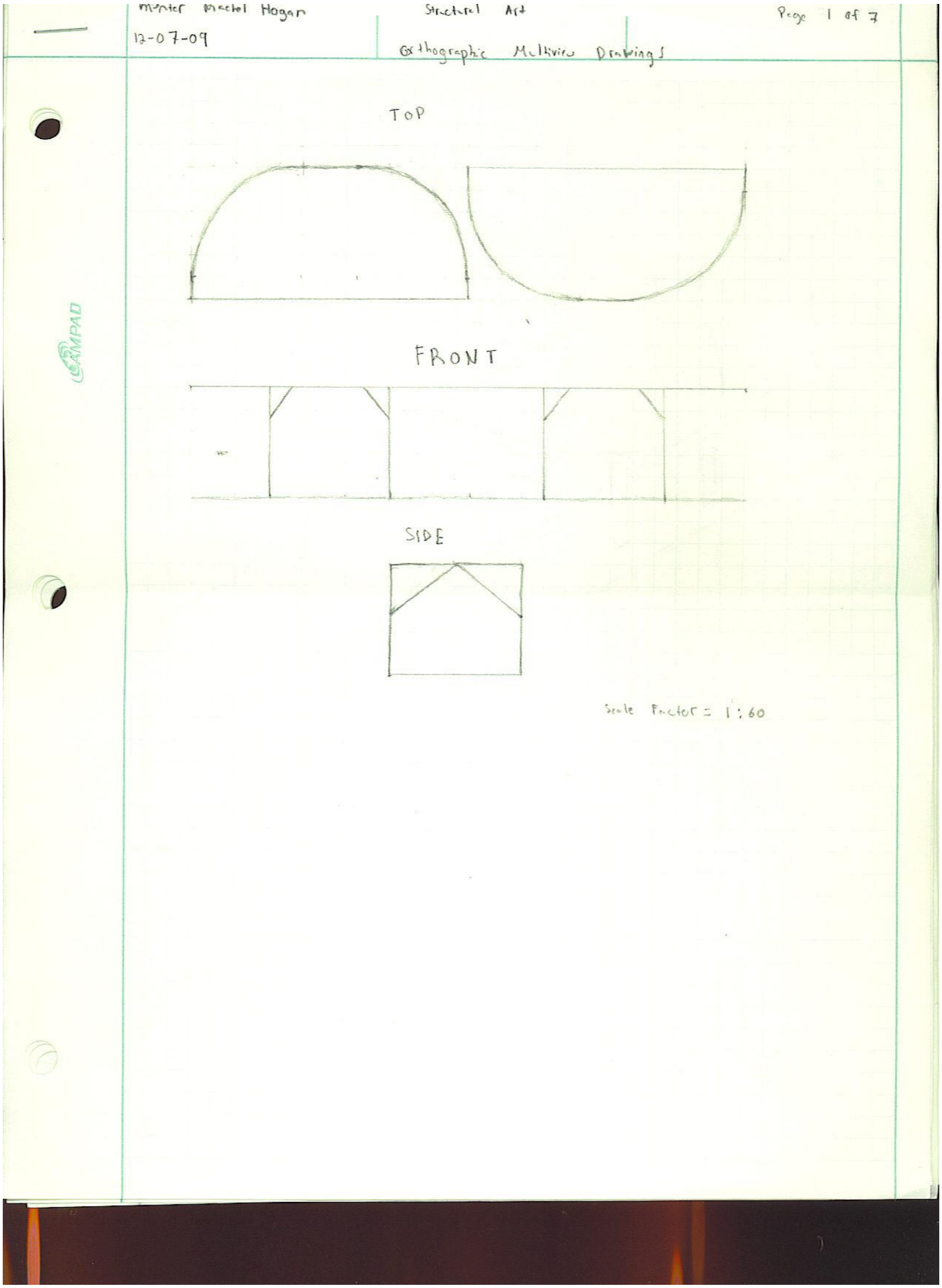

Moment diagram

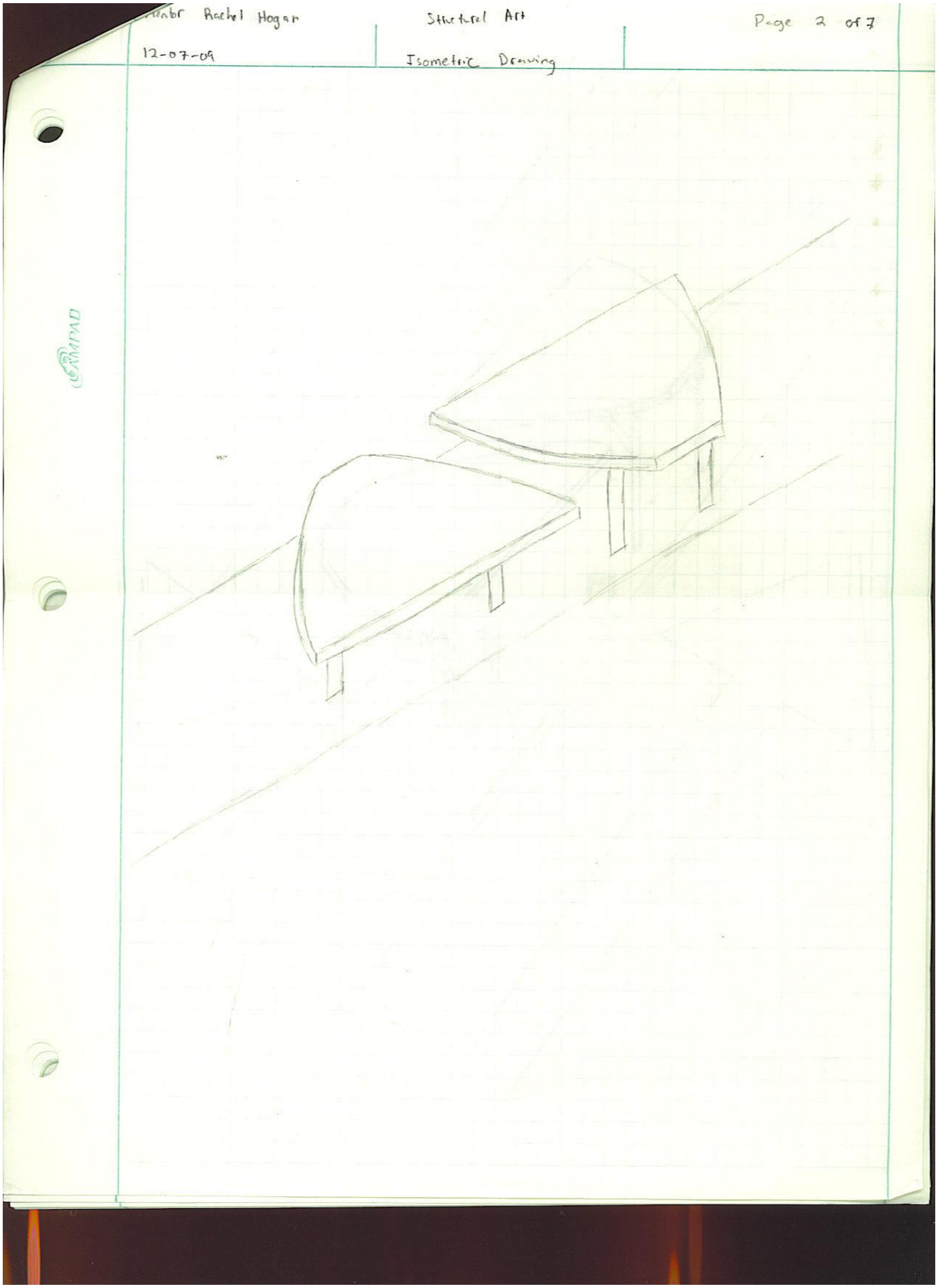

c)
3ft
2ft
No Movement
Deflected Shape
F=500 lbs
ΣFx=0
3ft
2ft
Ay
By
MA
More force
in middle

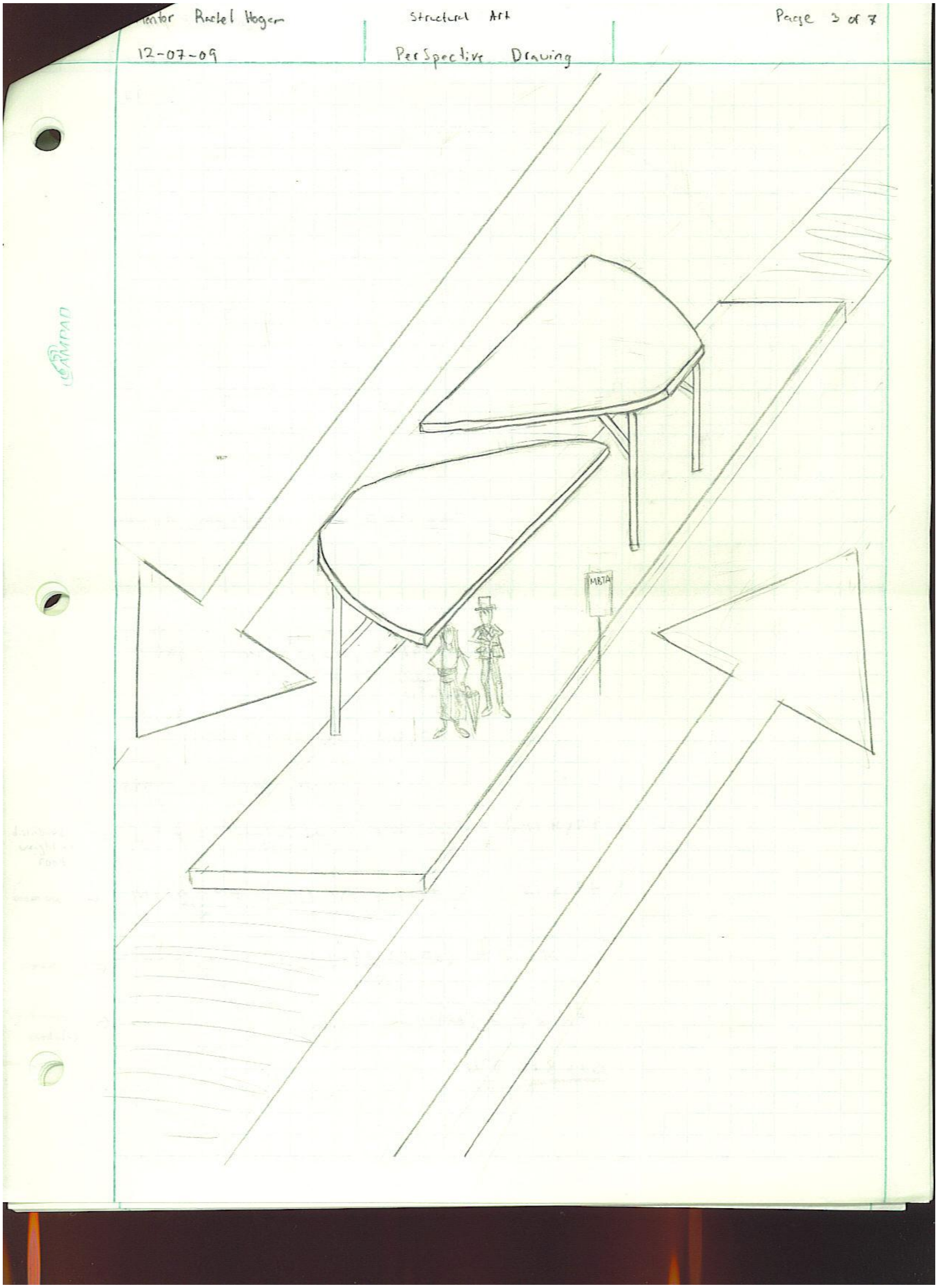
① DRAW THE DEFLECTED SHAPE, SHEAR DIAGRAM, AND MOMENT DIAGRAM FOR EACH OF THE FOLLOWING:



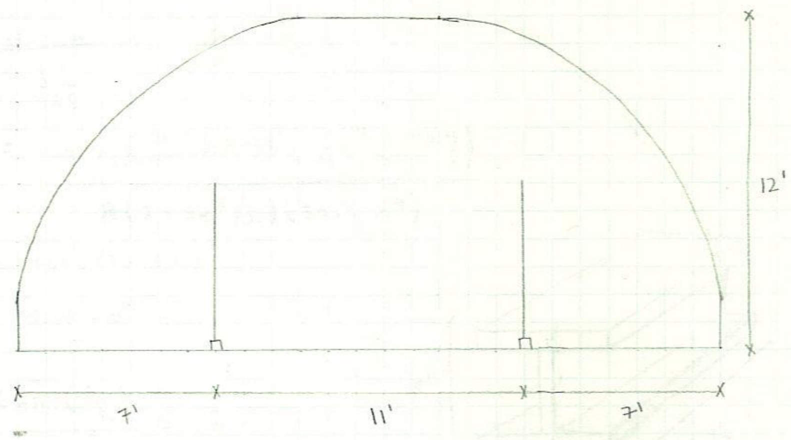
## Calculation Package for Canopy Design




Rachel Hogan
Structural Art
Page 2 of 7
12-07-09
Isometric Drawing


Rachel Hogan
Structural Art
Page 3 of 7
12-07-09
PerSpective Drawing
MBTA

ROOF:




AREA OF ROOF: $100 + 50\pi \ ft^2$

LOADS

DEAD: CONC + DECK = 48 psf

PONDING = 5 psf

53 psf

LIVE:

MUST SUPPORT 60 psf

BEAM DESIGN STRENGTH

distributed weight of roof ⇒ $q = \frac{(60psf + 53psf)(12.5ft)}{1000\ lb/k} = 1.41\ k/ft$

moment ⇒ $M = \frac{q l^2}{8} = \frac{(1.41\ k/ft)(11\ ft)^2}{8} = 21\ k \cdot ft$

shear ⇒ $V = \frac{q \cdot l}{2} = \frac{(1.41\ k/ft)(11\ ft)}{2} = 7.8\ k$

section modulus ⇒ $S = \frac{M}{\sigma_{max}} = \frac{21\ k \cdot ft}{33\ ksi} \cdot (12\ in/ft) = 7.6\ in^3$

USE W 8 x 10

Cantilever Beam - Uniformly Distributed Load = W 8 x 10

$I = 30.8\ in^4$

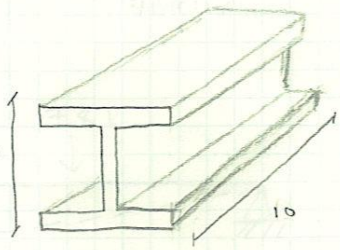
Beam Deflection

$$\Delta T_{max} = \frac{q l^4}{8IE}$$

$$= \frac{(1.4\ k/ft)\left(\frac{1ft}{12in}\right)(12\ ft)^4\left(\frac{12\ in}{ft}\right)^4\left(1000\ \frac{lb}{k}\right)}{8(29 \times 10^6\ psi)(30.8\ in^4)}$$

$= .0040626959\ in$

$\approx 4.06 \times 10^{-3}\ in$




$$\frac{l}{120} = \frac{(12ft)\left(\frac{12in}{1ft}\right)}{120} = 1.2\ in$$

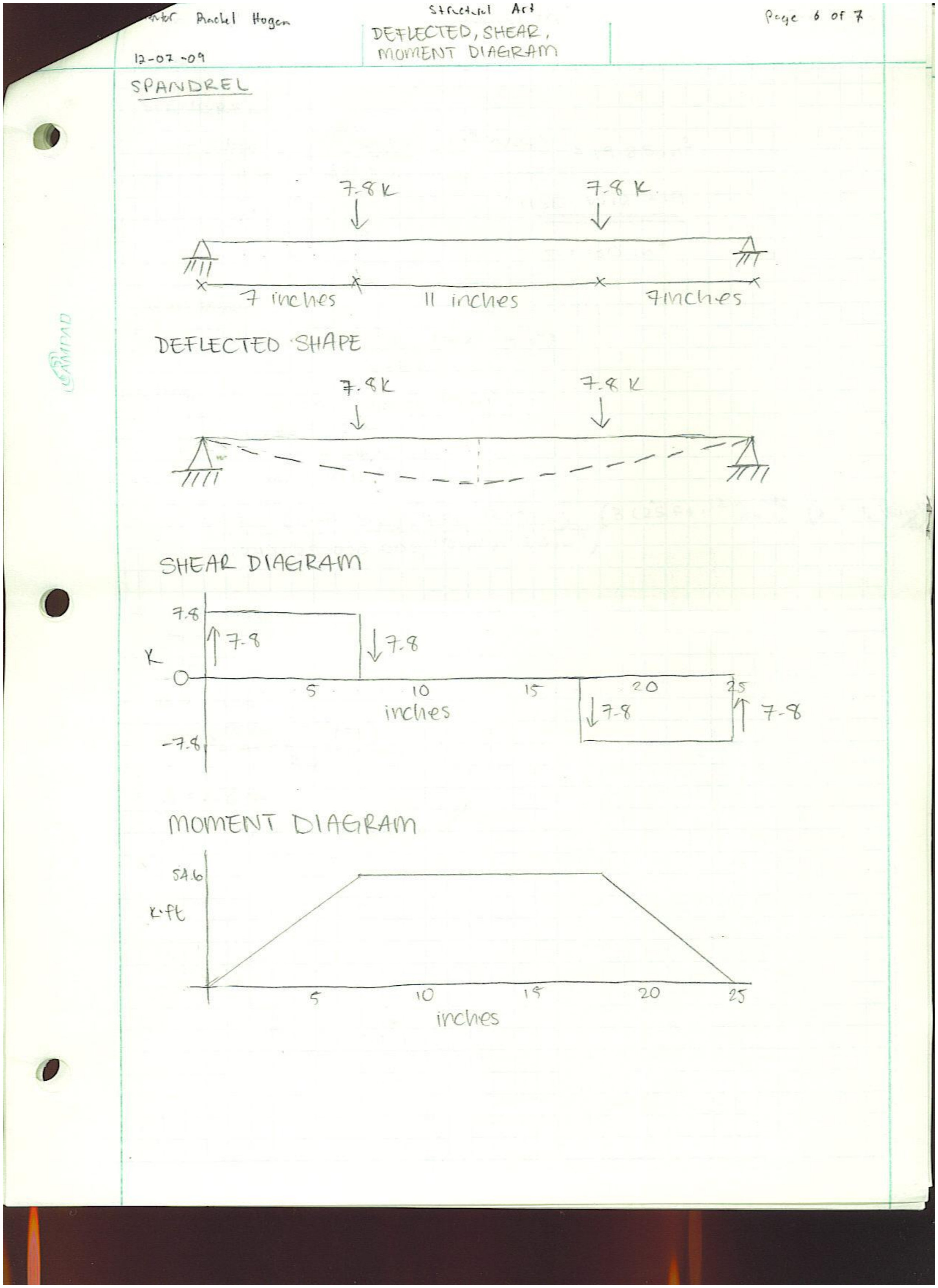
$4.06 \times 10^{-3}\ in < 1.2\ in$ ✓

Column

W 10 x 33

capacity = 276 kip

our V = 7.8 k < 276 k ✓


ntor Rachel Hogan
Structural Art
Page 6 of 7
DEFLECTED, SHEAR, MOMENT DIAGRAM
12-07-09
SPANDREL
7.8K
7.8K
7 inches
11 inches
7inches
DEFLECTED SHAPE
7.8K
7.8K
SHEAR DIAGRAM
7.8
K
0
-7.8
7.8
7.8
5
10
15
20
25
inches
7.8
7.8
MOMENT DIAGRAM
54.6
k-ft
5
10
15
20
25
inches

SPANDREL:

$$S = \frac{M}{\sigma_{max}} = \frac{54.6\ k\cdot ft}{33\ ksi} \cdot (12\ in/ft) = 19.85\ in^3$$

USE W12 x19

$I = 130\ in^4$

Cantilever

$$\Delta_{max}\ (\text{at center}) = \frac{Pa}{24EI}(3\ell^2 - 4a^2)$$

$E = 29{,}000{,}000\ lb/in^3$
$P = 7.8\ k$
$a = 7\ ft$
$I = 130\ in^4$

$$= \frac{(7.8k)(1000\ lb/k)(7ft \cdot 12\ in/ft)}{(24)(29{,}000{,}000\ lb/in^2)(130\ in^4)} \cdot (3(25ft \cdot 12 in/ft)^2) - (4(7ft \cdot 12 in/ft)^2)$$

$\Delta_{max} = 1.75\ in$

$\Delta = L/120$

$$= \frac{(25ft \cdot 12\ in/ft)}{120}$$

$\Delta = 2.5\ in$

$1.75\ in < 2.5\ in$ ✓

**Lab Assessments**

1.) Please give a short analysis of the lab. Did you think that it was successful? Why or why not? What was the highlight of the lab for you? What was your least favorite part?

2.) Did you take away from the lab what you expected to get out of it at the beginning of the semester? Were all topics covered that were outlined to be covered? Do you wish anything had been covered more in depth?

3.) What methods of teaching do you feel you respond best to? Were any of these used in the lab? If so, how did they help you to understand the material? If the methods you prefer were not used, how might those methods have been used to convey the topics covered?

4.) How did you feel about the pace of the lab? Was it too fast or too slow?

5.) How do you feel about your lab compared to that of your peers? Do you feel like you learned more or less than them? Why or why not?

6.) Do you feel like you understand all of the material presented in the lab? If not, which topics did you not feel comfortable with? What do you think helped you to understand some topics? What was missing when you didn't understand a topic?

7.) How do you feel about the use of models and visual aids to teach concepts in these kinds of classes? Do you feel like they should be used more or less often in your other classes of this nature?

8.) What was different about this lab than your other engineering classes? In regards to teaching methods, do you wish anything was done differently in your other engineering classes?

9.) Do you feel like you were adequately prepared to complete the final project? Aside from not being fully comfortable with the more complex equations used for beam analysis, did you feel as though you understood the concepts well enough to create a sufficient design?

10.) Would you like to see more use of the teaching techniques that were attempted in this lab in your other engineering classes? Why or why not?

11.) Other comments?

**Student 1:**

1. I think, overall, the lab was successful. Having the opportunity to work in a small group for such a large class helped me to better understand the material. I enjoyed meeting with the group because the leader (as a senior) could relate to any problems I encountered. I felt comfortable discussing the material with the members in my group, as well as the leader. The highlight of the lab was building models and sharing ideas with the group. It showed everyone's creativity and reinforced the concepts that we were learning about. My least favorite part was going over some of the equations towards the end of the semester. I felt a little rushed trying to understand the meanings of the equations, however, that may have been due to the short amount of time between Thanksgiving and finals.
2. The lab allowed topics covered in Professor Hines's lectures to be explored in more detail. I really enjoyed this because, for example, trying to understand the concepts of cantilevers from a lecture is difficult; however, learning about them in the lab helped me to comprehend the equations behind the cantilevers. The lab covered everything on the syllabus, maybe not in the allotted time frame, but every topic was explored. I wish the equations for beams had been discussed more, however, I feel as though I understand the general idea of them.
3. The most effective teaching method for me is when a teacher can demonstrate something to prove a point. This method was used frequently in the lab (i.e. cantilevers, canopies) when building models and testing them under loads. These models helped because if they could not carry loads as models they probably could not carry loads as real structures
4. Throughout the semester, the lab moved at a nice pace. It was especially helpful to move at a slow pace when first learning how to draw/calculate shear, moment, and deflection diagrams. Although, the lab felt a little rushed at the end, overall, the pace was good.
5. I felt very fortunate to be in this lab because I felt that my leader really cared about my progress and understanding of the material. Meeting twice a week also contributed to understanding the material better. The homework/problem sets were just the right amount of work without feeling overwhelmed. I feel as though I learned more than my peers (in other groups) because I learned how to do problems that could be applied to many situations. Other groups did problems from a packet that focused on the reading; however, my group did multiple problems related to one subject, but could be applied to different situations.
6. I feel as though I understand most of what was covered in the lab. I have a good understanding of cantilevers, however, I would like to better understand beams and their deflections. Building model cantilevers and doing multiple practice problems contributed to my comprehension of them. Time was a factor when learning about beams – there was only so much that could be done in a short amount of time.
7. The models really helped my comprehension of the material, and I think other classes of this nature should use models. When learning about cantilevers, the models showed how they deflected, making it easier to see what the equations were trying to solve. Having visual/physical aids was one of best parts of the course.
8. This size of the lab contributed to my learning of the material. It was easy to seek help when I needed it, and the other members of the group provided assistance, as well.

Having such an intimate group to work with is something I have yet to experience in my other engineering courses. I wish my other engineering courses also offered the opportunity to work in small groups with a group leader who is a student. Working with a student, rather than a TA, makes me feel more comfortable when I need help with a problem or advice.

9. I'm really happy with the way our final project turned out. I feel as though it really reflects what we learned over the semester. Besides the equations for the beam analysis, I felt comfortable solving other equations. The canopy was simple and I think our group worked hard to make sure everything worked out in the canopy equations. Everyone contributed his or her time and effort to the project and this showed in the final product.
10. I would like to see more use of the teaching techniques that were used in this lab in my other engineering classes. I had a great experience in this lab and class, and I wish other classes would consider having small groups. Having the small groups made it easy to seek help when I needed it, whether it be from the student leader or another member of the group. Small groups with other students also provide the opportunity for other student members to share their ideas and sometimes explain concepts in a different way that can help contribute to the understanding of the subject.
11. I really enjoyed this class and lab. I thought the material of the course was very interesting and the professor showed a genuine interest for the subject and students. Having the opportunity to learn the subject in a small group also contributed to my happiness with the class. I made new friends, and having a senior leader is helpful especially if I need advice for future classes. I'm very glad I took this class and I think all classes (engineer and liberal arts) should consider having small lab groups.

**Student 2:**

1. I thought the lab was successful. I know that the objective of our group was to learn the same material but through an alternative approach. I think this was the most challenging part of the lab, but also the most valuable part.
2. Given the short period of time (one semester) I think we covered a lot. I didn't necessary master anything, but the lab definitely provided me with an overall understanding. I think this is a perfect course to introduce you to more advanced engineering courses.
3. I don't exactly know how to answer this question, but I would think the teaching methods used were sufficient. I learned the material, and Rachael does a good job at explaining things. I think the method of explaining engineering concepts with out doing the math is really helpful. I come from a math background. When doing pure math, it is rare that I understand the application of it, so I appreciated the emphasis on understanding the basics before using any equations.
4. I thought the pace was fine. We had a lot to cover in one semester.
5. I can't say I know anyone else in the class, so I don't know!
6. I definitely understand basic concepts; shear, moment, deflections, etc. There are a few things I don't completely understand, but I think that is because of my inexperience. For example, when we use set parameters like sigma max=33, I don't know where that comes from, but I am sure this is because I don't have an engineering background.
7. I thought the use of models was very beneficial. Specifically, I remember learning about deflection and moments with a wood frame model. Having the visual example helped

bridge the equations with what we were actually calculating. In other words, it helped me make a connection between the math and reality, if that makes sense...

8. I don't know if I can answer this question very well. I guess the main difference is the one on one teaching versus lecturing, but I am kind of stating the obvious here.
9. I definitely understood concepts, but I am not sure if I always understood the technical aspect of things. Given the goal of this course, I think it's normal to not have the technical knowledge. I think I was prepared to create a sufficient design, but I couldn't do a thorough structural analysis of my design without a lot of help from my mentor.
10. Yes, definitely! I think understanding engineering in a non-technical sense before learning the mathematical approach is worthwhile. By learning the math first it is difficult to understand how to apply it, whereas if you understand the basic concept of the problem first it is easier to know how to solve it.
11. I enjoyed the lab and found it very beneficial. My only compliant is that it was frustrating at times because it added a significant amount of work to a half credit course, but I am grateful of it because I learned a lot and established a basic understanding of structural engineering. Despite the extra work load, I would recommend this method of teaching again.

**Student 3:**

1. I think the lab was successful in that I was able to understand the concept of bridges and the math behind it more in-depth than I would have had I not had this lab. It was great to sit to hear the more "artsy" side of structural art during Professor Hines' lecture and learn and apply the more mathematical side of this engineering discipline on various kinds of structures such as beams and cantilevers. It helped further my understanding of the course.

   The highlight of the lab was probably when we were all collectively working on problems together on the board because it helped me understand a lot better had I just tried to work out the answer by myself. The fact that it was such a small group, it was nice to try to solve a problem together and figure out where we went wrong and etc. My least favorite part of lab was building models just because it sometimes takes up a lot of time that I don't have. But that's my only and main complaint.

2. I did take away from the lab what I had originally expected to get out of it at the beginning of the semester. At the end of the semester, I feel like I am more confident in analyzing beams, bridges, cantilevers and etc.

3. I think all the topics that were outlined were covered, though I wish we had discussed arches more, especially in terms of how to analyze them.

4. I respond best to methods of teaching that have a lot of visuals to accompany it. There were a lot of visuals and pictures used in the lab, and it did help me further my understanding. However, the reason I understood the material covered in lab so well was probably due to the interaction between all of us in lab: everyone was building off one another when trying to solve a problem and we all contributed and critiqued each other's

ideas. I felt that in this particular course, interactive discussion like what we had during lab was the best way to learn the course material.

5. I'm a slow learner normally, so I think that all my classes - not just Structural Art - were too fast for me. However, it helped that we kept doing problems that were similar in nature to one another because it allowed me to review what we had done and slowly understand what was going on.

6. I think I understand some aspects of bridge analysis more so than my peers, specifically in the areas of deflection, moment and shear diagrams because I think we did more examples and problems than they did. Also, the fact that we met more frequently allowed us to have more discussions and further my understanding of the subject matter.

   I feel like I understand most of the material presented in lab. I'm still uncomfortable with calculations on bridges that aren't cantilevers, but I do understand for the most part the concept behind. I think the reason that I'm not as comfortable analyzing non-cantilever bridges is because we spent more time with cantilevers than we did with beams. We didn't spend as much time covering beams and doing practice problems. So the main thing missing out in my understanding of the other topics is lack of time, which sadly isn't something that can be easily fixed.

7. I love the fact that we used models and other visual aids because I'm a visual learner. I think in classes like EN80, more models and visual aids should be used because it definitely helps further understanding and allows us to see a real-life example instead of just pictures drawn on the board.

8. The main difference about this lab than my other engineering class is that I had a lot more practice with various real-life situations in regards to bridge analysis. Also, there was more model construction and learning through trial-and-error. I wish there was more opportunities to practice concepts taught in my other engineering classes and that there was more room for trial-and-error, but sometimes that's not realistic due to time constraints.

9. I didn't feel prepared to do the final project just because our canopy design was slightly complex. I felt very lost when trying to do the calculations. However, asides from the calculations, I think I had enough sufficient knowledge to create a good design.

10. I would like to see more use of the teaching techniques that were used in this lab in my other engineering classes, because I think it would definitely further my understanding of the topics being covered in those classes, despite it taking up a lot of time.

11. Thanks for being such a great mentor and patiently answering mine/our questions throughout the semester! :)

**Student 4:**

1. I have mixed feelings about the success of our lab. While I feel that what we were doing was very useful and helpful in the understanding of the material, I feel that we missed out in some concepts from the other groups in not doing what the rest of the class was doing, which hurt us in the end for the final project. In our lab period we primarily focused on bending, sheer, moment diagrams which is very important and useful in the design process. I feel that we gained a lot from making models and being able to visualize the bending and forces, which was one of my favorite things in the class. However, I learned these graphs for the most part and es-5, and while this reinforced the ideas and definitely gave me a better understanding for them, I don't think it was necessary to spend so much time doing them. Most people didn't even know what a moment/sheer force was coming into the class, and this idea would have been learned in a week in sophomore year if everyone had the proper mathematical background. Overall, I enjoyed the lab, liked getting to know everyone, and learned a lot, but I feel that we just went too far off from the rest of the class.

2. I wish that we had done some more calculations relating more specifically to the project throughout our project. Once we got to the project, I at least felt very unable to do any calculations independently which made our group very rushed in the end, and in my opinion unable to do as well on the project as we could have done.

3. I learn best when I can see many examples of things, practice, and try and get a very good fundamental understanding of the concept. This actually made this class sort of difficult for me, because so much of the material was over our heads. I got very frustrated by the fact that we were expected to do out work that I didn't understand what was going on a lot of the times, which makes me feel like I am not learning much. This is why I feel that what we were doing in our lab was useful because it was fundamental and got back to the basic understanding. However, this is not what we needed to know for the final project and in some ways hurt us in the end.

4. I thought we didn't need to spend so much time on sheer moment diagrams. I just feel like we could have done them in two weeks and then moved onto some other concepts. Although, this is a half credit class and with the simple amount of time we were spending meeting, I wouldn't have wanted to go at an incredibly fast pace because I do have other work that really needed a lot of my attention.

5. I feel mixed for many of the reasons stated above. While I liked what we did, I feel like we missed out on a lot of things by not doing what everyone else was doing.

6. I feel like I understand all of the material done in the lab up until the project in which I started to feel very lost. I feel that what we were doing earlier wasn't necessarily working up to the project, which just hit me very fast. I don't even feel like I or the group put off working on the project, we just weren't in many ways equipped to do a lot of it as independently as we were working on it.

7. I do feel like models were useful in the helping of learning in this type of class. So much of this is based on visual analysis and I feel that it is a great idea that many civil engineering classes could benefit from.

8. I find it hard to compare this lab period to one of my other engineering classes. It was just a lab period, although we met a lot. However, I would say that the discussion aspect of the lab was very different from all of my other classes. We were really able to interact which was a nice switch from many of my other courses.

9. I guess we were pretty well prepared besides the calculations, but I think that is a difficult statement to make because so much of the final project revolved around the calculations. If we were just told to make a canopy I feel that I could have made something really neat, however, we were told to make and alalyze one and I was not really prepared for that. I feel that the project was over our heads in many ways, and in order to complete it we really needed you to walk through our calculations and the various steps of our actual project with us.

10. Yes, I would, but only to a certain extent. While many of our strategies were useful, I think it would be difficult to teach a class with only these methods. A lot of the standard teaching techniques are necessary and if one is going to use this style, I think there really needs to be a balance between how much they use these types of models and discussion and lecturing and more standard methods.

11. Thanks for all the work with us.

**Student 5:**

1. I think the lab is very informative in the subjects related to Structural Art and how to calculate structural analysis. I think that it was very successful, particularly in the beginning when we would do more experimentation and stuff. My highlight would be the first few classes that we've had in the beginning when I first learned about shear force and moment diagrams, etc. I think that I really learned a lot from it and from building the models etc. However, I kind of feel that towards the end there was just too much information given at one time and I felt that I am not as confident in the materials later on as I am with the things that were taught in the beginning. However, I do enjoy the interactions we've had and I think it's been a great semester.

2. I had no idea what to expect when coming into the class. I thought the class would focus a lot more on the aesthetics than on the calculations. But I guess it sort of makes sense given that the whole point of the class was kind of on how the efficient use of materials makes certain structures beautiful. Therefore, not knowing what to gain from the class makes everything I learned really fun. I think that most of the topics outlined were covered. I kind of wished that the topics that were covered in the end, such as the whole distribution stuff can have more time spent on it, but I think the way it is has been fine and really good.

3. I respond best to having discussions over the materials we learn in class. I think that we did really well in our classes. We always go over the things, like our homework, in class and that contributed to my understanding of the material because I internalize the information. I also like building models because it helps me visualize the concepts that were taught. I think that I really appreciate all the methods that have been used to cover the topics and there's not really a suggestion I can make in regards to that.

4. I think the pace is perfect. If I were to design a class like this I couldn't do it better. The pace is comfortable for someone who has no background in the subject (not even physics) to follow and learn a lot from it.

5. I think that our lab is definitely more thorough that those of my friends. We meet a lot more times than them therefore we cover materials more in-depth than they did. Also, I think that we are the only lab that did models to enhance our understanding. I am not sure about other people but that method really works for me.

6. I feel that I understand most of the materials that we present during the presentation. However, I am less comfortable with the calculations than I am with other things, such as the development of design, etc. I think that the labs we've had really helped. Having Professor Hines coming to one of our labs really helped too. And I think that it supplemented what was covered in class. I don't think anything was missing when I didn't understand the topic because I could always just shoot Rachael an e-mail as she is readily available for us :)

7. I think the use of models and visual aids was very effective in teaching the class. I think that they should be used more in my other classes in the nature because it really visualize concepts that seem very theoretical and mathematical.

8. I am not an engineer so I cannot really say to this.

9. I feel that we are decently prepared to complete the final project. I did feel that I did understand the concepts well enough to create a sufficient design.

10. I am not an engineer so I cannot really say to this.

11. Thank you Rachael. You have been an amazing teacher!

## APPENDIX B – *Introduction to Civil Engineering*

### Laboratory Assignments

| LeMessurier Consultants<br>Structural Engineers | By: [illegible] | Date: 1/9/10 | File No.: LAB #1 | Sheet No.: 1/1 |
|---|---|---|---|---|
| | Subject: CEE-1 | SIMPLE BEAM / DEFLECTIONS | | |

CHALLENGE

DEVELOP AN EQUATION TO PREDICT THE ELASTIC FLEXURAL DISPLACEMENT OF THE SIMPLY SUPPORTED BEAM SHOWN IN FIGURE 1.

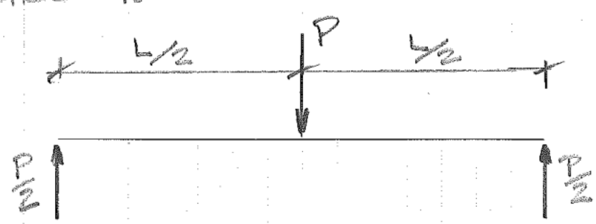


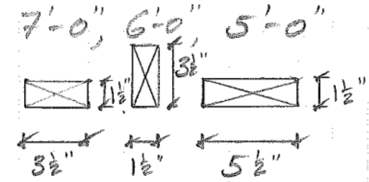

FIGURE 1. SIMPLY SUPPORTED BEAM W/ POINT LOAD AT CENTER SPAN

APPROACH

MEASURE THE DISPLACEMENT AT CENTER SPAN UNDER AT LEAST THREE DIFFERENT LOADS ON THREE DIFFERENT BEAMS OF THREE DIFFERENT LENGTHS. PLOT THE FORCE - DISPLACEMENT RESULTS AND USE THESE RESULTS AS THE BASIS FOR YOUR PROPOSED EXPRESSION.

RECOMMENDED LENGTHS = 7'-0", 6'-0", 5'-0"

SECTIONS =




LOADS = 70#, 140#, 210#

30 by 38 blocks at .25 inches

| LeMessurier Consultants<br>Structural Engineers | By EVH | Date 1/10/10 | File No. LAB # 2 | Sheet No. 1/1 |
|---|---|---|---|---|
| | Subject CEE-1 | CANTILEVER DEFLECTIONS | | |

CHALLENGE

DEVELOP AN EQUATION TO PREDICT THE ELASTIC FLEXURAL DISPLACEMENT OF THE CANTILEVER SHOWN IN FIGURE 1.

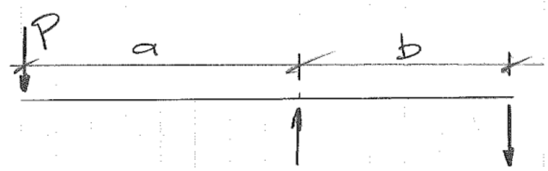



FIGURE 1. CANTILEVER W/ PT LOAD AT EXTREME END.

APPROACH

SIMILAR TO LAB #1. MEASURE DISPLACEMENT AT P.

RECOMMENDED LENGTHS

| a | b |
|---|---|
| 4'-0" | 3'-0" |
| 3'-6" | 3'-6" |
| 3'-0" | 4'-0" |
| 2'-0" | 5'-0" |

30 by 38 blocks at .25 inches

**LeMessurier Consultants**
Structural Engineers

| By | Date | File No. | Sheet No. |
| --- | --- | --- | --- |
| EMH | 1/10/10 | LABS #3 #4 | 1/1 |

Subject: CEE-1 , 14'-0" SPAN

CHALLENGE

LAB #3) DESIGN A 2x4 TO SPAN 14'-0" WITH A PT LOAD OF 140# AT CENTER SPAN.

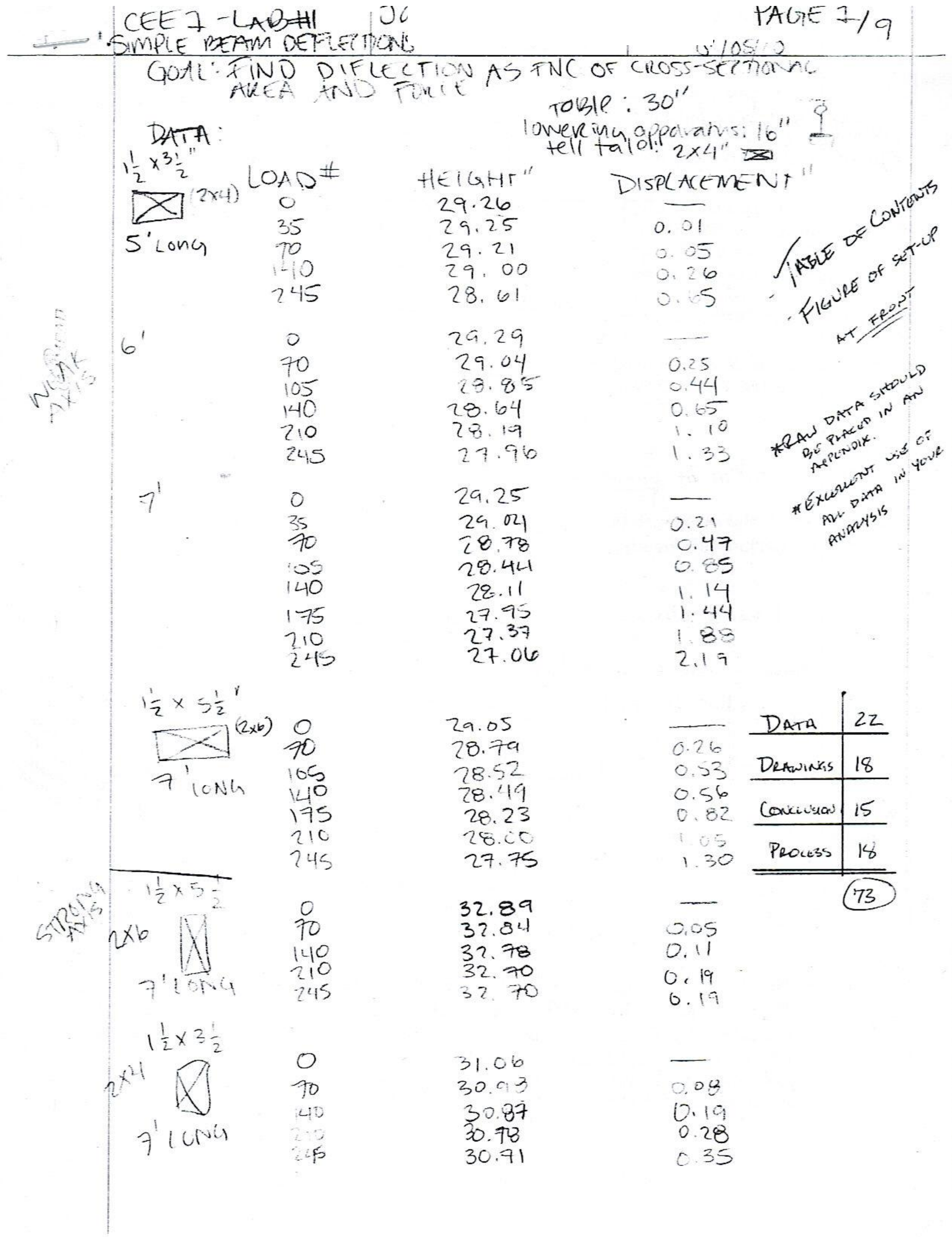
LAB #4) DESIGN A MEMBER TO SPAN 14'-0" WITH A PT LOAD OF 350# AT CENTER SPAN AND A MAXIMUM DEFLECTION AT CENTER SPAN OF 1/2." MEMBER SHOULD BE AS LIGHT AS POSSIBLE.

APPROACH

ALLOWABLE MATERIALS: 2x4 MEMBERS UP TO L=8'-0"
1/2" PLYWOOD
SCREWS
CHAIN
THREAD ROD
OTHER MATERIALS W/ PERMISSION OF INSTRUCTOR

30 by 38 blocks at .25 inches

# Example of Laboratory 1 Report



CEE 1 - LAB #1 JC PAGE 1/9

SIMPLE BEAM DEFLECTIONS 5/10/5/10

GOAL: FIND DEFLECTION AS FNC OF CROSS-SECTIONAL AREA AND FORCE

table: 30"
lowering apparatus: 16"
tell tale: 2x4"

DATA:

| | LOAD # | HEIGHT " | DISPLACEMENT " |
|---|---|---|---|
| $1\frac{1}{2} \times 3\frac{1}{2}$" (2x4) 5' LONG | 0 | 29.26 | — |
| | 35 | 29.25 | 0.01 |
| | 70 | 29.21 | 0.05 |
| | 140 | 29.00 | 0.26 |
| | 245 | 28.61 | 0.65 |
| 6' | 0 | 29.29 | — |
| | 70 | 29.04 | 0.25 |
| | 105 | 28.85 | 0.44 |
| | 140 | 28.64 | 0.65 |
| | 210 | 28.19 | 1.10 |
| | 245 | 27.96 | 1.33 |
| 7' | 0 | 29.25 | — |
| | 35 | 29.04 | 0.21 |
| | 70 | 28.78 | 0.47 |
| | 105 | 28.44 | 0.85 |
| | 140 | 28.11 | 1.14 |
| | 175 | 27.95 | 1.44 |
| | 210 | 27.37 | 1.88 |
| | 245 | 27.06 | 2.19 |
| $1\frac{1}{2} \times 5\frac{1}{2}$" (2x6) 7' LONG | 0 | 29.05 | — |
| | 70 | 28.79 | 0.26 |
| | 105 | 28.52 | 0.53 |
| | 140 | 28.49 | 0.56 |
| | 175 | 28.23 | 0.82 |
| | 210 | 28.00 | 1.05 |
| | 245 | 27.75 | 1.30 |
| STRONG AXIS $1\frac{1}{2} \times 5\frac{1}{2}$ 2x6 7' LONG | 0 | 32.89 | — |
| | 70 | 32.84 | 0.05 |
| | 140 | 32.78 | 0.11 |
| | 210 | 32.70 | 0.19 |
| | 245 | 32.70 | 0.19 |
| $1\frac{1}{2} \times 3\frac{1}{2}$ 2x4 7' LONG | 0 | 31.06 | — |
| | 70 | 30.98 | 0.08 |
| | 140 | 30.87 | 0.19 |
| | 210 | 30.78 | 0.28 |
| | 245 | 30.71 | 0.35 |

WEAK AXIS

- TABLE OF CONTENTS
- FIGURE OF SET-UP AT FRONT

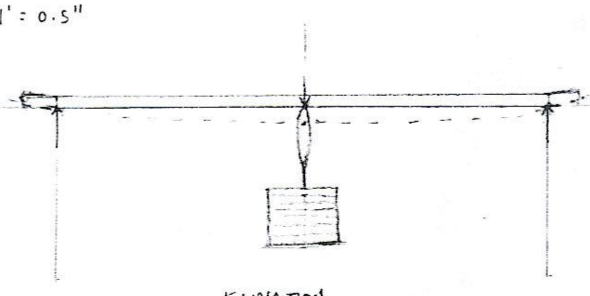
*RAW DATA SHOULD BE PLACED IN AN APPENDIX.

*EXCELLENT USE OF ALL DATA IN YOUR ANALYSIS

| | |
|---|---|
| DATA | 22 |
| DRAWINGS | 18 |
| CONCLUSION | 15 |
| PROCESS | 18 |
| | 73 |

CEE-1 LAB 1 | SCALE DRAWINGS OF LAB SET-UP | PAGE 2/9

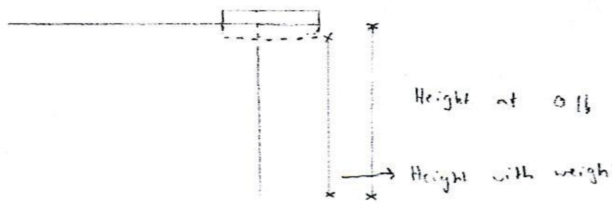
Scale Factor = 1' : 0.5"



ELEVATION ~~FRONT VIEW~~

~~TOP VIEW~~ PLAN VIEW

Picture is drawn for the 7' long 2x4 with a load of 245#




SIDE VIEW

*LABEL DRAWINGS
*DESCRIPTION OF OBJECTIVE OF LAB SHOULD COME AT THE BEGINNING OF THE REPORT

The above drawings illustrate the experimental set-up for our tests. 35-lb weights were loaded to a platform attached at the mid-span of a wooden board propped on two tables. The support reactions of the tables on the board were approximated as pin-type. Measuring the height of the displaced midspan was assisted by the use of a tell-tale positioned on top of the board.

CEE 1 - LAB #1
SIMPLE BEAM DEFLECTIONS

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OBSERVATIONS:

6' 1½ x 3½"

LOAD 105#


- ends bow up
- applying pressure on ends decreases deflection
- tell tale held by clamp.

LOAD 210#


- ends bow up more
- deflection more pronounced
- "pin & roller" support
- Resists pressure applied to ends more

Resembles Pin support

* △ vs. ▭ changes deflection

LOAD 245#

- heard "crack" when applied force to center

7' 1½ x 3½" - beam is already not returning to initial height

LOAD 70#

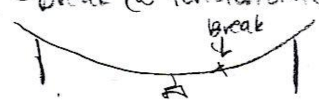
- ends resemble fixed points
- slight deflection - smaller slope

LOAD 105#

- ends bowed

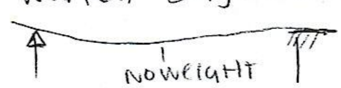
LOAD 210# - cracked wood, defined flair at ends


LOAD 245# - break @ tension side, 8" from center




*OBSERVATIONS SHOULD BE PLACED WITH RAW DATA

2x6 (1½ x 5½) - warped Lengthwise



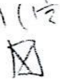

LOAD 140# - less deflection noticed compared to thinner beam

2x6 (1½ x 5½)

LOAD 210#

- deflection barely noticable to naked eye.
- we drilled the tell tale with 2 screws.

2x4 (1½ x 3½)



LOAD 140# - No visible deflection, heard "crack"

LOAD 210# - slight Bowing, another "crack"

CEE 4 LAB 4 - SIMPLE BEAM DEFLECTIONS

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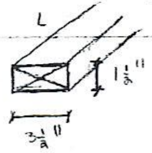
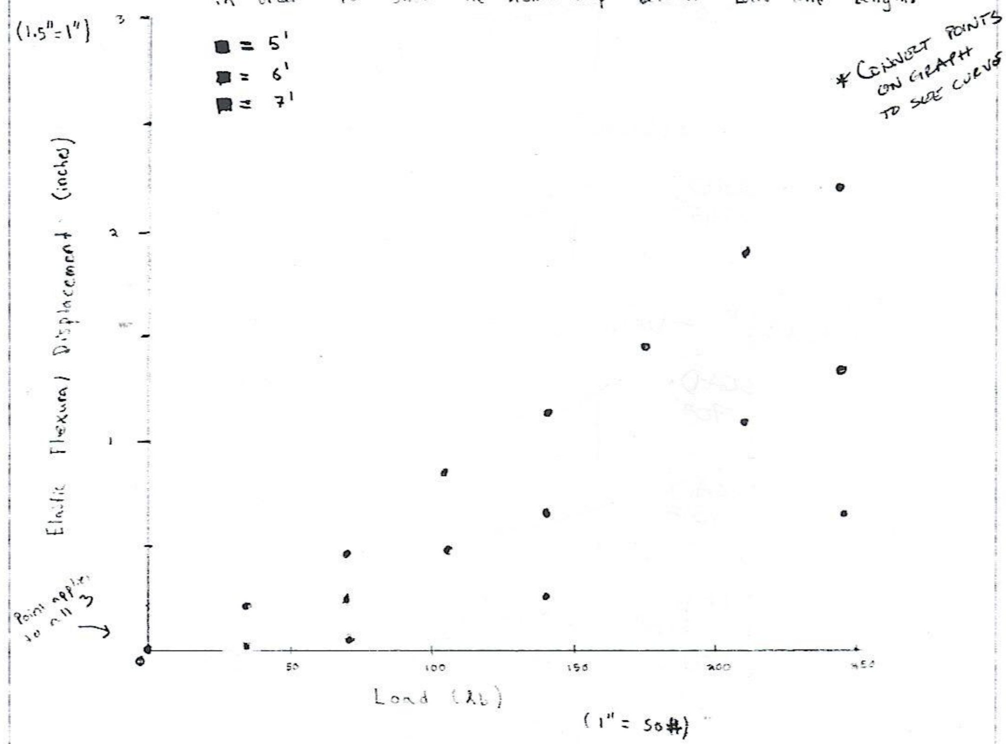



⇒ only thing that changes for individual lines (red, blue, and black) is P (load).

⇒ Comparing 5', 6', and 7', only thing that changes is height.

Graph Showing Elastic Flexural Displacement (in) versus Load (lb) in order to show the Relationship Between Load and Length.




Using the Same 2x4, everything is held constant besides the load. The graph Shows a linear relationship between load and elastic ~~flexural~~ FLEXURAL displacement. To see this look at 5', 6', or 7' curves individually. As load goes up, the displacement goes up linearly.

<u>Conclusion</u> ⇒ $\Delta \sim P$ (load) ✓ * SHOW NUMERICALLY

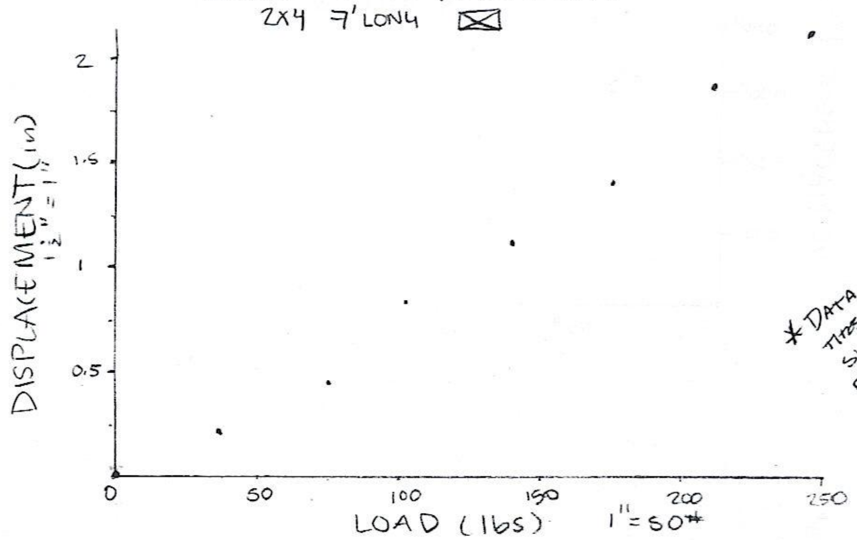
Using the Same 2x4, everything is held constant besides length. The graph shows an apparent direct relationship between length and displacement. Looking at a single load (ex = 245#), the longer the length the greater the displacement. So, 245# ⇒ 5' having smallest Δ, then 6', and 7' has the largest Δ.

<u>Conclusion</u> ⇒ $\Delta \sim L$ ✓ (Must go to other gr— ?

*HOW DID YOU COME TO THIS CONCLUSION? YOU MAKE A DIFFERENT ASSUMPTION LATER ON

LOAD(#) vs. DISPLACEMENT('')

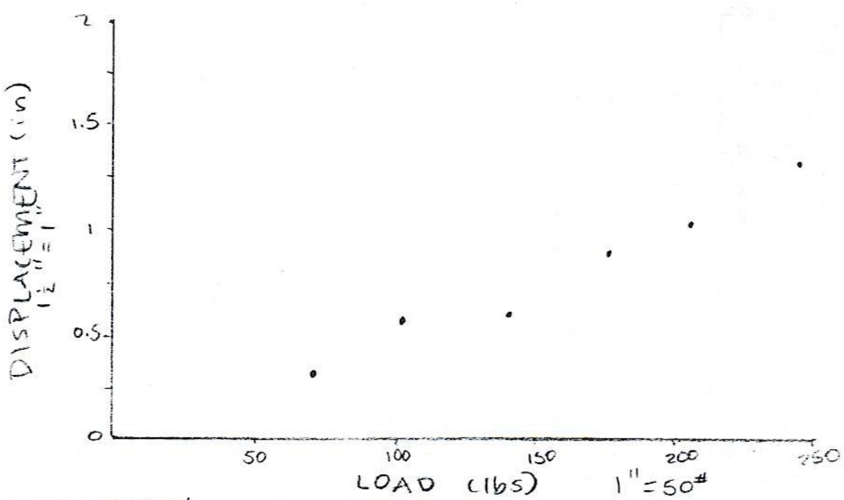
2X4 7' LONG ☒




*DATA FROM THESE TWO TESTS SHOULD BE PLACED ON THE SAME GRAPH

LOAD(#) vs. DISPLACEMENT('')

2X6 7' LONG ☒

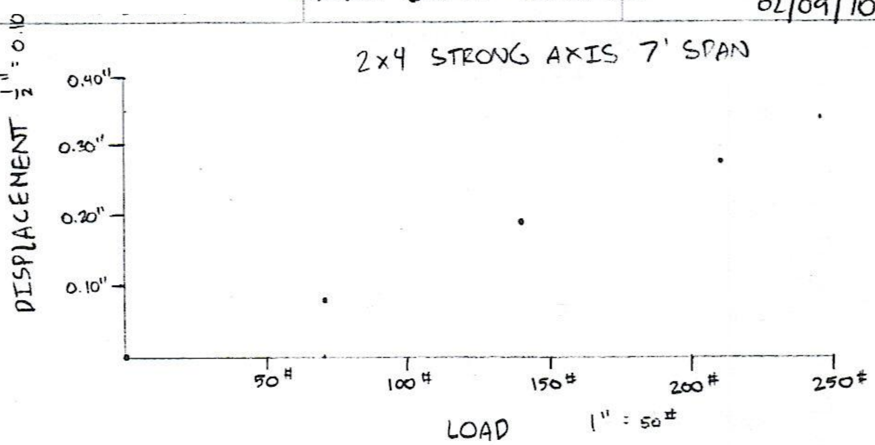


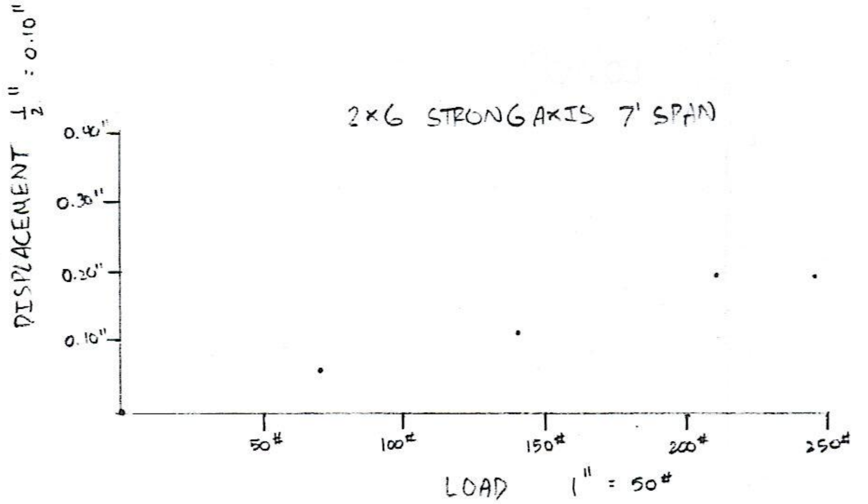

OBSERVATION:

For these two graphs, the length and height are constant. By comparing the points of displacement for the same load on each graph, we see that the displacement is greater for the smaller base.

CONCLUSION:

$$\Delta \sim \frac{1}{b}$$

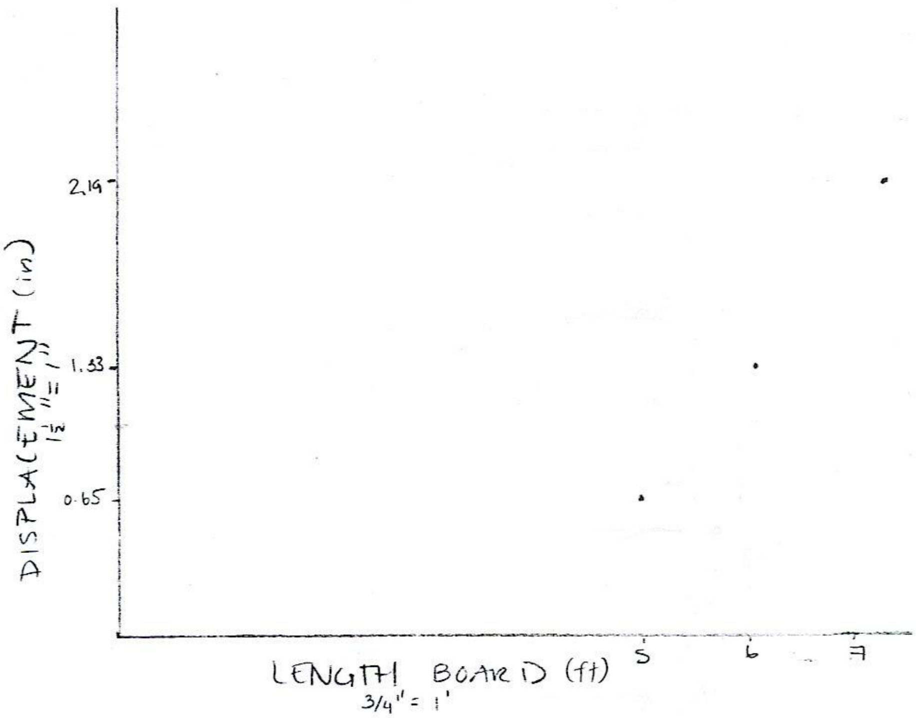



By comparing the above two graphs, it is shown that varying the height of the board, when aligned on its strong axis, affects the displacement. keeping base length, load, and span constant, it is seen that a larger board height causes smaller displacement.

Conclusion: $\Delta \sim \frac{1}{h}$.

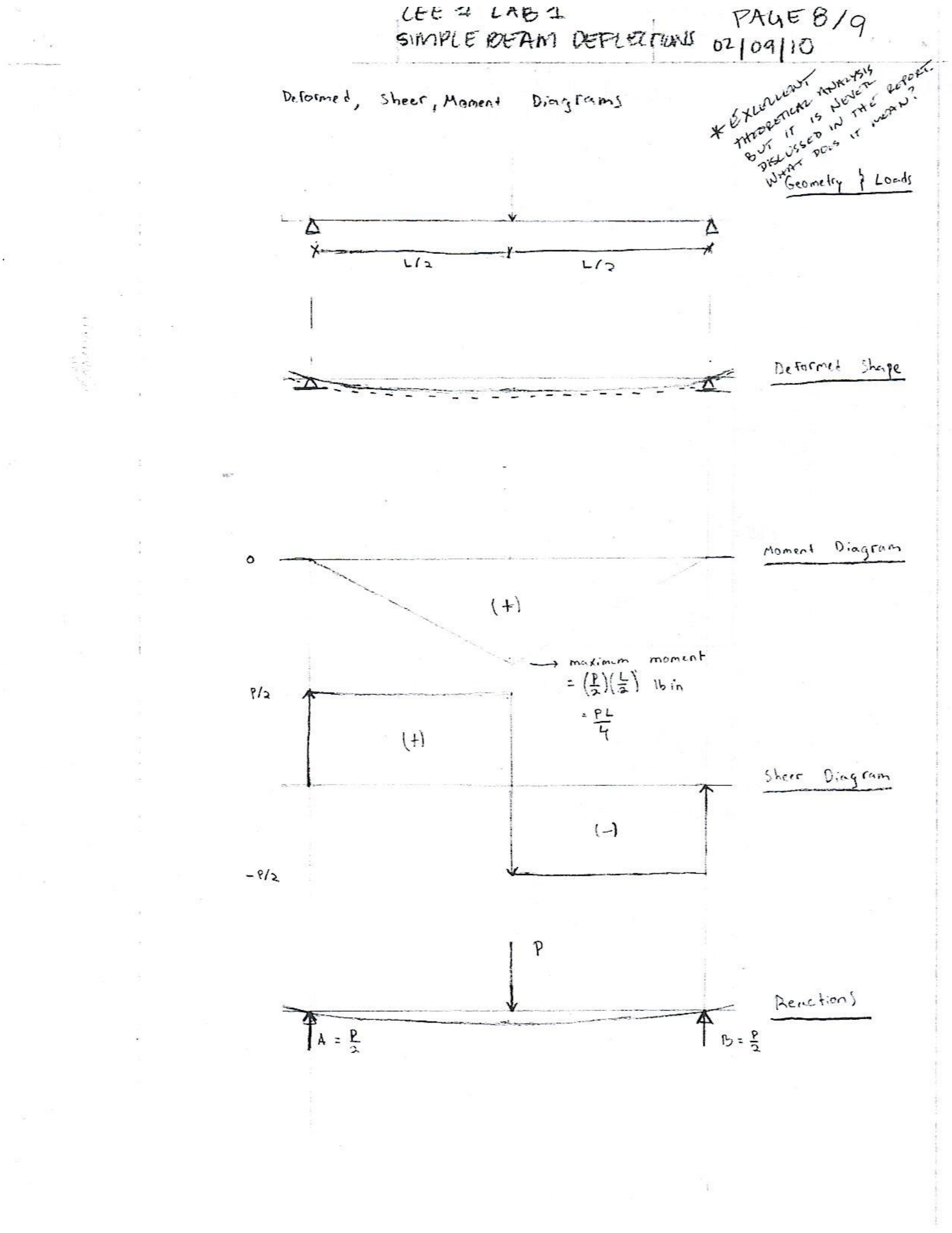
LENGTH VS DISPLACEMENT
2x4 ☒ 245#




OBSERVATION:
when holding all factors constant except for the length of the board (graphed above) we see that the length and the displacement are exponentially related.
CONCLUSION:

$$\Delta \sim L^K \quad \text{where } k = \text{some constant}$$

We need further testing to experimentally determine the value of k.


CEE 4 LAB 1
PAGE 8/9
SIMPLE BEAM DEFLECTIONS 02/09/10
Deformed, Sheer, Moment Diagrams
* EXCELLENT THEORETICAL ANALYSIS BUT IT IS NEVER DISCUSSED IN THE REPORT. WHAT DOES IT MEAN?
Geometry & Loads
L/2
L/2
Deformed Shape
Moment Diagram
0
(+)
maximum moment = (P/2)(L/2) lb in = PL/4
P/2
(+)
Sheer Diagram
(-)
-P/2
P
Reactions
A = P/2
B = P/2

Putting Conclusions Together

$\Delta \sim P$ (load)

$\Delta \sim L^k$

$\Delta \sim \frac{1}{E}$

WHERE DID YOU GET THIS?

$\Delta \sim \frac{1}{h^n}$

$\Delta \sim \frac{1}{b}$

$\Rightarrow \Delta \sim \frac{1}{I}$

we know I for a rectangular rod is $\frac{1}{12} b h^3$, so we can conclude $\Delta \sim \frac{1}{h^3}$, and $\Delta \sim \frac{1}{I}$

$$\Delta = \frac{PL^k}{IE}$$

Looking at units

$$\Delta = \frac{PL^k}{IE}$$

know: $P = lb$, $L = in$, $E = \frac{lb}{in^2}$, $I = in^4$, $\Delta = in$

*OK TO USE UNIT ANALYSIS BUT NEEDS TO BE RELATED TO THE DATA YOU GATHER. DOES YOUR DATA FIT THIS EQUATION? HOW DO YOU KNOW IT IS CORRECT

$$in = \frac{lb \cdot in^k}{in^4 \; lb/in^2}$$

$$in = \frac{lb \cdot in^k}{in^2 \, lb}$$

$$in = \frac{in^k}{in^2} \Rightarrow k = 3 \Rightarrow \Delta \sim L^3$$

- agrees with our earlier exponential looking graph

$$in = \frac{lb \; in^3}{in^4 \; lb/in^2}$$

$\Rightarrow in = in$ ✓

⇓

Final equation for elastic flectual displacement $\Rightarrow$ $\Delta = \frac{PL^3}{IE}$

where, P = load, L = length, I = moment of inertia, E = Young's modulus of elasticity

COMPARING EXPERIMENTAL VALUE OF E TO A REFERENCE VALUE:

Plugging in values from several loading situations into our derived equation, we were able to determine an estimate of E, Young's Modulus, for the wood used in the laboratory.

Based on these samples, we approximate:

$$E \approx 7.0 \times 10^7 \; lb/in.^2$$

Consulting an online reference, we found a published value of E for spruce wood:

$$E_T \approx 1.5 \times 10^6 \; lb/in.^2$$

Because our experimentally derived value for E is within a similar order of magnitude, we can feel confident about our result.

## Example of Laboratory 4 Report (Same Group)

PAGE 1/8

LABORATORY #4 REPORT



| | |
|---|---|
| DATA | 23 |
| DWGS | 25 |
| CONC | 20 |
| PROCESS | 25 |
| | (93) |

GOAL: The goal of this lab is to create a member that spans 14'-0" with a point load of 350# at center span. We want this member to deflect no more then 1/2".

INTRODUCTION

APPROACH #1 - DESIGN 1

REFERENCE PG. NUMBER

In our first approach (Design 1) we aimed to use a shock absorber approach (see 14' span design 1). We hoped this would be an efficient method of minimizing deflection with a simple design. It did not work out as we aimed, which forced us to re-evaluate our design and see where we went wrong.

APPROACH #2 - DESIGN 2

Our second approach (Design 2) aimed to fix the problems in design 1. Our main concern was improving the stiffness of the cantilver by adding extra support on the sides of the span. This did cause improvement but not to the extent we hoped for. We realized further work could still be done.

APPROACH #3 - DESIGN 3

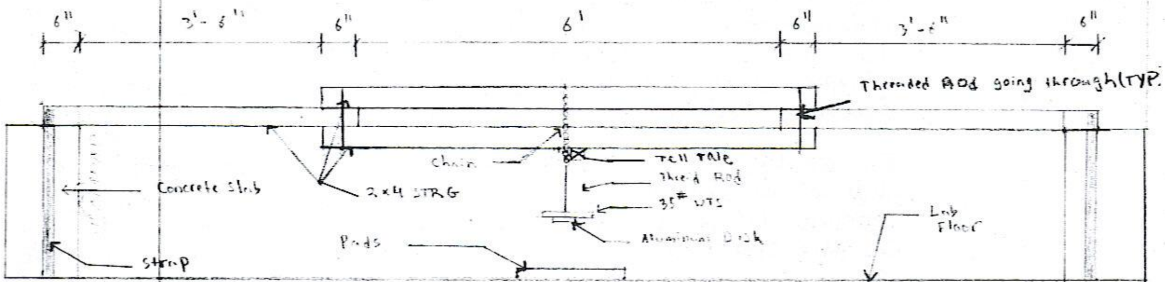
Our final approach (Design 3) aimed to both reinforce the ~~cantilever~~ BEAM stiffness further and to also do a better job of transferring stress from the top member into the entire design. We observed even more improvement but still were unable to achieve a 1/2" deflection at 350#. We now found new stability issues that we did not have time to address.

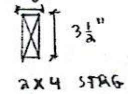
MAYBE PLACE A PICTURE ON THIS PAGE

## 14' SPAN DESIGN 1

**GOAL:** To design a member to span 14'-0" with a point load of 350 # at center span.

### FIGURE 1 DESIGN 1 SETUP ($\frac{1}{2}$" = 1'-0")

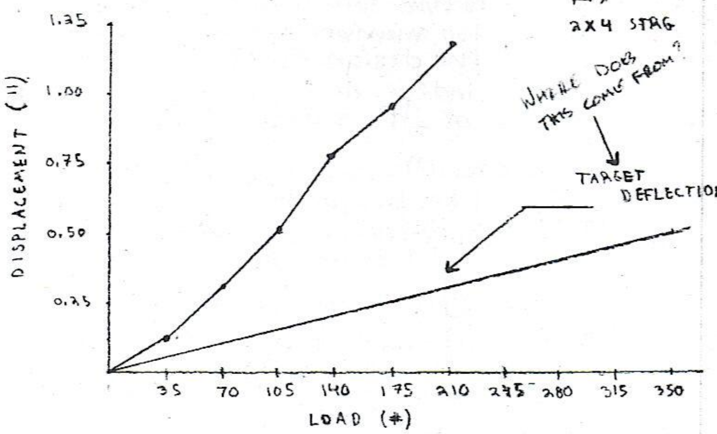



### TABLE 1.

| LOAD (#) | Δ (") |
|---|---|
| 0 | — |
| 35 | 0.13 |
| 70 | 0.31 |
| 105 | 0.53 |
| 140 | 0.77 |
| 175 | 0.97 |
| 210 | 1.18 |

### FIGURE 2




### INITIAL APPROACH:

We wanted to use our thread rod connection, experimented with in lab #3, to create a joint with 2x4's on their strong AXES. We hoped that the top 2x4 (Figure 1) would act as a "shock absorber" that could minimize measured deflection.

### THINGS LEARNED:

IS IT A QUESTION OF STRENGTH OR PLACEMENT?

- The thread rods were not strong enough to transfer the stress from the 2x4 member to the rest of the design.
- When designing we must look at how the system will work as a whole. In this case the "absorber" design did not work since the force was distributed into the single 2x4's, causing it to act as a normal cantilever.

## 14' SPAN DESIGN 1

DISCUSSION:

Our original design for lab #4, as shown in Figure 1, was created to act as a deflection "absorber". The intention was for the top member of the design to "absorb" the deflection of the load while the height of the bottom member remains in its original position. As can be seen in Table 1, this did not happen.

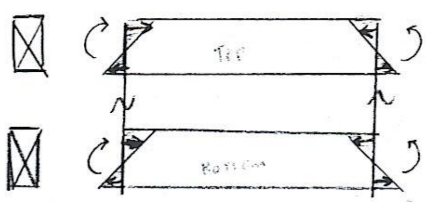
In our discussion with Professor Hines, we discovered that our design did not achieve our goal for two main reasons: (1) we did not consider the system globally and (2) the stress of the top member was not transferred successfully.

Reason (1): We considered only the deflection of the top member. As can be seen in Figure 1, the top member is directly connected to the two side cantilevers. The force of the load on the top member was transferred to the cantilevers on the sides of the design. This force caused the cantilevers to deflect independently, which contributed to the total deflection of the system.

Picture — Reason (2): In theory, our design was supposed to behave much like Brunel's Saltash Bridge: the top member (or arch in Brunel's case) would be compressed under load and the bottom member would undergo tension.

To develop this theory, we first examined the stress distribution of the top and bottom members. Our first idea was that the members would act separately under the stress as such:

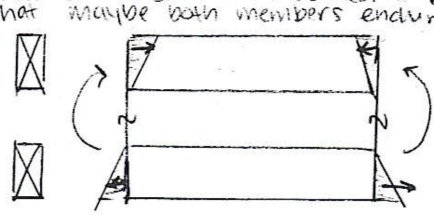
Theory 1.




this theory is not correct, both members would deflect separately if this is how they behaved, which as shown by Table 1 is not the case.

Since both members are connected by a threadrod, we thought that maybe both members endured the stress together.

Theory 2.

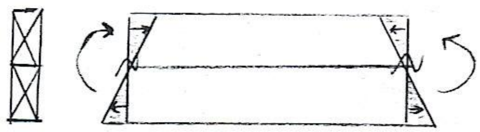


This theory is also not correct.

# 14' SPAN DESIGN 1

DISCUSSION CONTINUED:

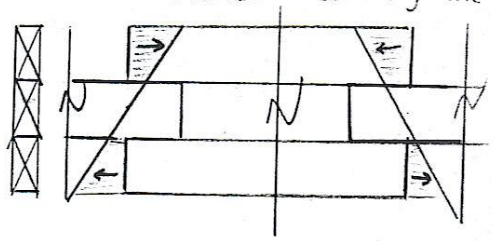
Theory 2 implies that there is no separation between the top and bottom members. This would mean that the stress distribution would essentially be:



Theory 2. totally disregards our cantilevers.

Eventually, we realized that our design worked with all three members sharing the stress distribution:

Theory 3.



This theory is how the system behaves.

NICE!

Theory 3 indicates that the increased strain on the top member means higher compression and thereby more stiffness and less deflection (from our lab 1 equation, we know that stiffness → $E \sim \frac{1}{\Delta}$).

From the set-up of theory 3, we calculated the moment of inertia of the system using the parallel-axis theorem; for 2 beams together:

$$I = \frac{1}{12} \cdot 2bh^3 + 2Ay^2 = \frac{\frac{2}{12}(1.5'')(3.5'')^3}{12} + 2(5.25''^2)(3.5'')^2 = 132''^4$$

This ~~inertia~~ M.O.I. should decrease the deflection of our system, but from Table 1 we see that this didn't happen. Since the beams weren't the problem, we calculated the shear created by the system on the threadrods:

$$V = \frac{M}{L} = \frac{210^{\#}(7')(12'')}{7'} = 2520^{\#}$$ Force on the threadrod.

This force is too much for the threadrod to handle (by intuition) so the system of compression-tension failed and therefore accounted for our deflection measured. There are two ways to reduce the stress on the threadrod: (1) transfer some stress from the top member to the bottom or (2) reinforce the threadrod.

In our following designs & tests we decided to try to transfer the stress with a plywood sheet and also correct the cantilever deflection that was disscussed as problem (1).

## 14' SPAN DESIGN 2

**GOAL:** TO IMPROVE THE STIFFNESS OF THE CANTILEVERS ON BOTH ENDS OF OUR DESIGN BY INCREASING THE MOMENT OF INERTIA AT THESE REGIONS.

FIGURE 3: DESIGN 2 SETUP

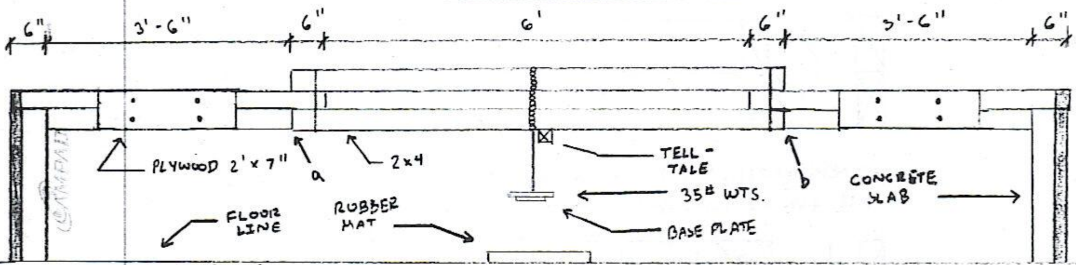
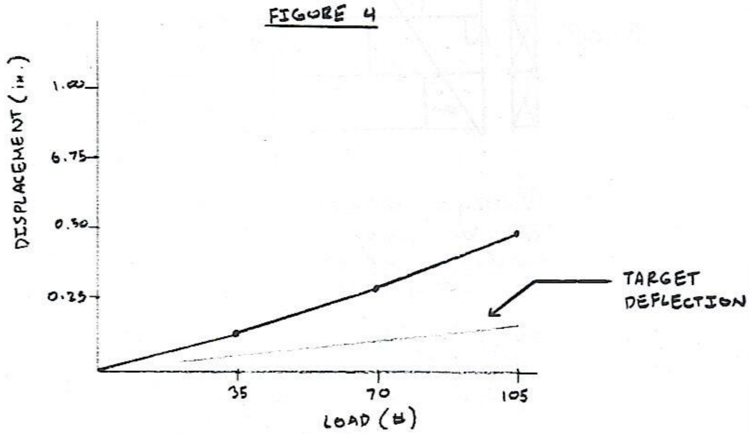



TABLE 2

| LOAD (#) | Δ (in.) |
|---|---|
| 0 | 0 |
| 35 | 0.12 |
| 70 | 0.29 |
| 105 | 0.49 |

FIGURE 4




**APPROACH:** WE KNOW THAT DEFLECTION IS INVERSELY PROPORTIONAL TO I, SO WE ADDED A SECOND 2×4 TO EACH END TO INCREASE THE HEIGHT.

DESIGN 1: $I = \frac{1}{12}(1.5)(3.5^3) = 5.36 \text{ in.}^4$

DESIGN 2: $I = \frac{1}{12}(1.5)(7.0^3) = 42.88 \text{ in.}^4$

SECURING THE BOARDS WITH PLYWOOD SIMULATED ONE CONTINUOUS 2×7 WITH A MOMENT OF INERTIA 8 TIMES LARGER THAN DESIGN 1.

**RESULTS:**

- INCREASING I CAUSED DECREASED DEFLECTIONS COMPARED TO DESIGN 1, BUT WE WERE STILL FAR FROM OUR GOAL.
- LARGE GAPS FORMED AT POINTS a AND b (SEE FIGURE 3) WHEN THE DESIGN WAS PLACED UNDER HEAVY LOADING. THIS WAS A MAJOR SOURCE OF DEFLECTION.

## 14' SPAN DESIGN 3

GOAL: TO FURTHER REINFORCE THE CANTILEVER DESIGN AND TO DISTRIBUTE SHEAR FORCES EVENLY THROUGHOUT THE SYSTEM.

FIGURE 5: DESIGN 3 SETUP ½" = 1'

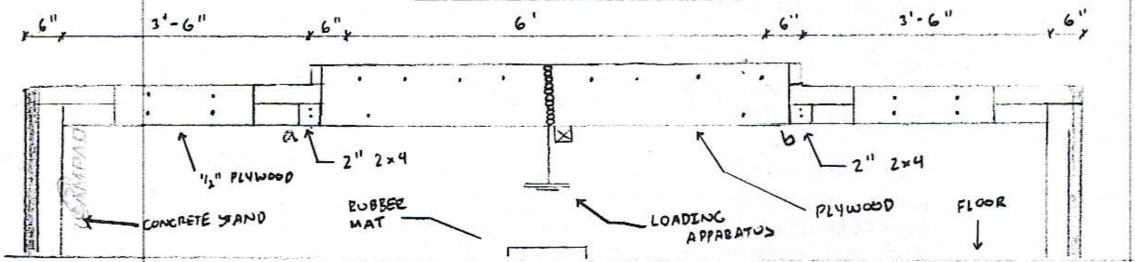
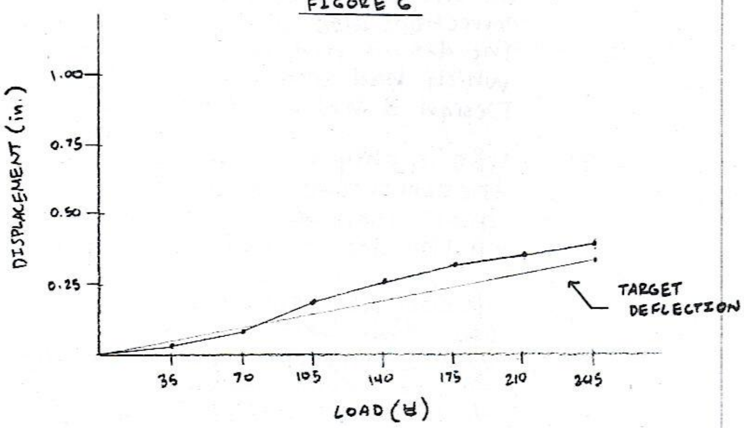



TABLE 3

| LOAD (#) | Δ (in.) |
|---|---|
| 0 | 0 |
| 35 | 0.02 |
| 70 | 0.08 |
| 105 | 0.18 |
| 140 | 0.24 |
| 175 | 0.30 |
| 210 | 0.33 |
| 245 | 0.35 |

FIGURE 6




APPROACH: WE ADDED 2 - 2" 2×4's TO FORM A STRONGER CONNECTION WHERE LARGE DISPLACEMENT OCCURED IN DESIGN 2 (SEE PT. a IN FIG. 4 ALSO ATTACHED A LARGE PIECE OF ½" PLYWOOD TO THE FACE OF THE DESIGN TO CONNECT THE CENTRAL SECTION.

RESULTS:

- AT HEAVY LOADING (~245 #) THE SYSTEM BECAME UNSTABLE AS THE THREAD ROD ALLOWED FOR ROTATION. LATERALLY?
- OVERALL, WE SAW SUCCESS WITH THIS DESIGN:
  - THE HINGE CORRECTION PERFORMED WELL, DESPITE BEING SO SMALL
  - THE PLYWOOD STIFFENED THE MIDDLE SECTION.

14' SPAN DESIGN
FINAL DISCUSSION

Our original design started with the theory that our system would act as a "deflection absorber" for the top member and a stationary bottom member. We measured deflection in Test 1 (Table 1) from the bottom member and did not achieve our goal. WHAT DID YOU GET?
As discussed on Pages 3-4, our design had two major errors: (1) we didn't consider the whole system acting globally and (2) we put too much stress on our threadbolts.

In designs 2-3, we correct our identified problems with the design. As shown in Design 2, Table 3, the cantilever correction did decrease the total deflection but still did not achieve our goal of less than 0.5" deflection. The stress distribution in design 3, along with the cantilever correction, also did not achieve our goal of <0.5" deflection. The design did, however, improve from the original design, which had a deflection of 0.53" under 105#, while Design 3 had a deflection of 0.49" (see Appendix A & B.1)

This is only an improvement of 0.04" for both of the corrections together and less than half of the goal - load of 350#. Clearly the corrections we made on the design did little to correct our identified problems.*

Through observation of the design 3 tests, we saw that the connection between the threadrods and the cantilevers was being split (See Appendix B.3: Hinge Failure). We then came up with Design (4): Hinge correction. We attached 2 2x4s to the splitting hinge and again measured deflection under load. This final design test actually improved our design (See Figure 6). The measured deflection is close to our desired deflection.

*NO MOMENT IN HINGES* We were unable to test our final design to the desired 350# because of instability created by moments in our hinges (Appendix B.1: test 4 observations). However, the corrections did improve our design and we learned to (1) think globally and (2) consider the strength of materials and the way we construct our design's.

*JUST LOOKING AT YOUR GRAPHS IT LOOKS LIKE DESIGN 3 IS AN IMMENSE IMPROVEMENT. TRY KEEPING THE SAME SCALE SO A READER CAN SEE THE DIFFERENCES/SIMILARITIES IMMEDIATELY.

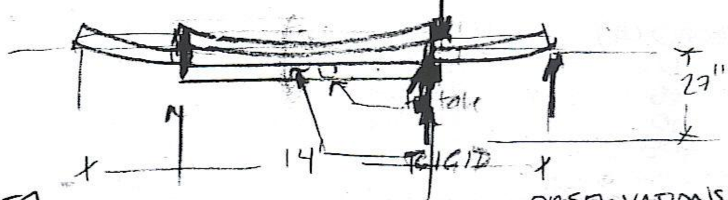
## 14' SPAN DESIGN 1

**OBSERVATIONS**

DURING CONSTRUCTION:

- we considered changing the joint length to 8", decided to stay with 6"
- one of our 2x4s had a knot on it, we chose it to be the top member so it wouldn't snap under tension
- getting the three beams straight at the thread rods was difficult → it would be nice if we had plywood casing
- tell tale - ½" plywood fastened on bottom

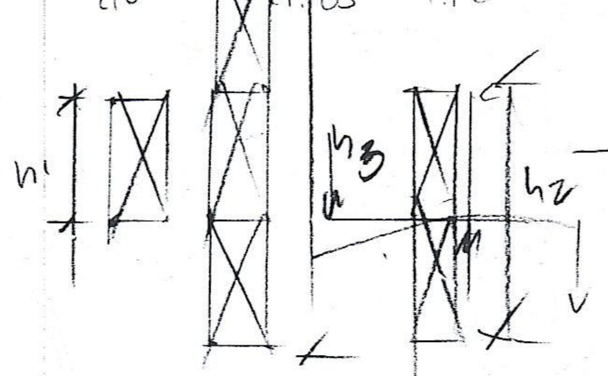
AFTER CONSTRUCTION: - NO Design changes




**TEST 1.**

DEFLECTIONS

| LOAD (#) | HEIGHT ('') | Δ ('') |
|---|---|---|
| 0 | 23.03 | — |
| 35 | 22.90 | 0.13 |
| 70 | 22.74 | 0.31 |
| 105 | 22.50 | 0.53 |
| 140 | 22.26 | 0.77 |
| 175 | 22.06 | 0.97 |
| 210 | 21.85 | 1.18 |




**OBSERVATIONS**

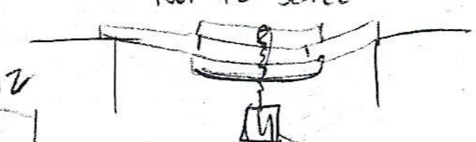
DURING LOAD:

The top member is deflecting considerably more than the bottom - but the bottom is still deflecting

→ need to "lace" beams together

want: 2' 2x4 in middle of center, two 6" 2x4s mid way from center to joint

NOT TO SCALE



→ DURING all loads, all members exhibited clear deflection (0.13 - 1.18")

## 14' SPAN REDESIGN



**TEST 2.** 2X4 DESIGN W/CANTILEVER CORRECTION

| LOAD (#) | HEIGHT (") | Δ (") |
|---|---|---|
| 0 | 25.65 | — |
| 35 | 25.51 | 0.14 |
| 70 | 25.20 | 0.45 |
| 105 | 24.92 | 0.73 |

**TEST 3.** 2X4 DESIGN W/C CORRECTION & STRESS TRASFER PC/

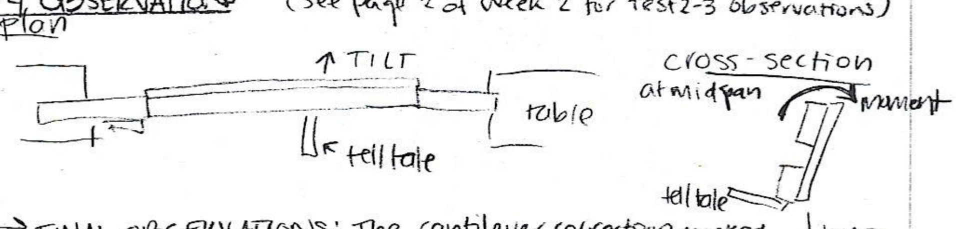
| LOAD (#) | HEIGHT (") | Δ (") |
|---|---|---|
| 0 | 26.05 | — |
| 35 | 25.93 | 0.12 |
| 70 | 25.76 | 0.29 |
| 105 | 25.56 | 0.49 |

**TEST 4.** 2X4 REDESIGN (SEE PAGE 2 FOR SET-UP)

| LOAD (#) | HEIGHT (") | Δ (") |
|---|---|---|
| 0 | 26.14 | — |
| 35 | 26.12 | 0.02 |
| 70 | 26.06 | 0.08 |
| 105 | 25.96 | 0.18 |
| 140 | 25.90 | 0.24 |
| 175 | 25.84 | 0.30 |
| 210 | 25.81 | 0.33 |
| 245 | 25.79 | 0.35 |
| 280 | 25.94 | 0.20 (*) |

(*) total design started to tilt → moved tell tale up and gave us undesired results.

**Test 4 OBSERVATIONS** (see page 2 of week 2 for Test 2-3 observations)




→ FINAL OBSERVATIONS: The cantilever correction worked, the plywood stress transfer board worked, the threadbolt created an undesired hinge. Needs to be redesigned.

## 4' SPAN REDESIGN

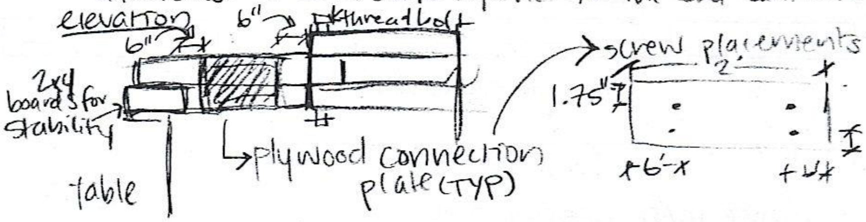
Week 2 PAGE 2/3 |

— NOT TO SCALE

OBSERVATIONS

DURING CONSTRUCTION:

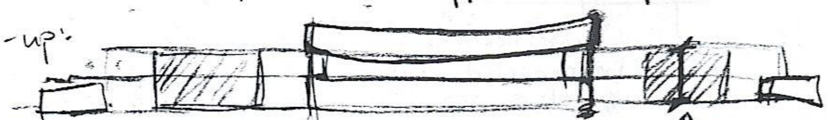
- We cut the 4' LONG 1/2" plywood into two sheets to connect the additional 4' LONG 2x4s together to the end cantilevers.




(*) since we had two problems with our first design (bending of end cantilevers & and connection of the top & bottom members of the middle beam) we decided to correct the cantilevers first, test deflection, and then add the stress-transfer plywood board to connect the two middle members.

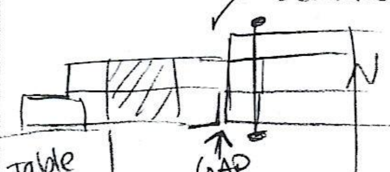
TEST 2 OBSERVATIONS NOT TO SCALE

35# - already deflection apparent on top member




70# - cracks forming

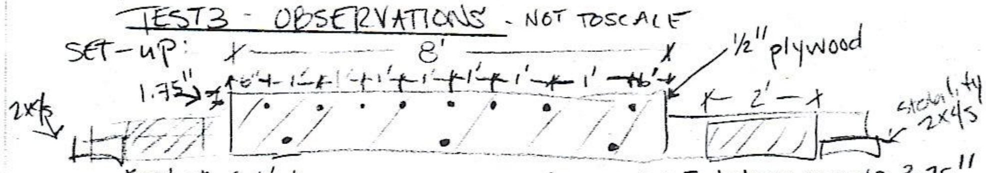
110# - no connection at tension member — GAP
-2 cracks along compression member




NOTE: HINGE AT THREADBOLT NOT CORRECTED

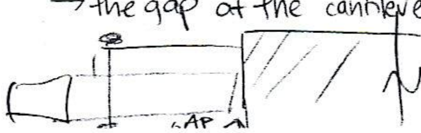
- JUST FIXING THE CANTILEVERS' DID NOT SOLVE THE WHOLE DEFLECTION ISSUE

TEST 3 - OBSERVATIONS - NOT TO SCALE



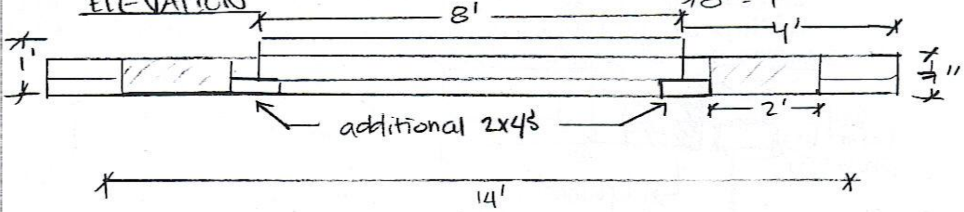

(*) we intentionally placed more screws on the compression side and less on the tension side

→ the gap at the cantilever to thread bolt is still weak



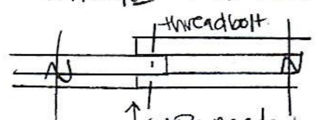

LOAD: 35# - TOP member deflection less visible.

OBSERVATIONS CONT.
FINAL DESIGN:
ELEVATION



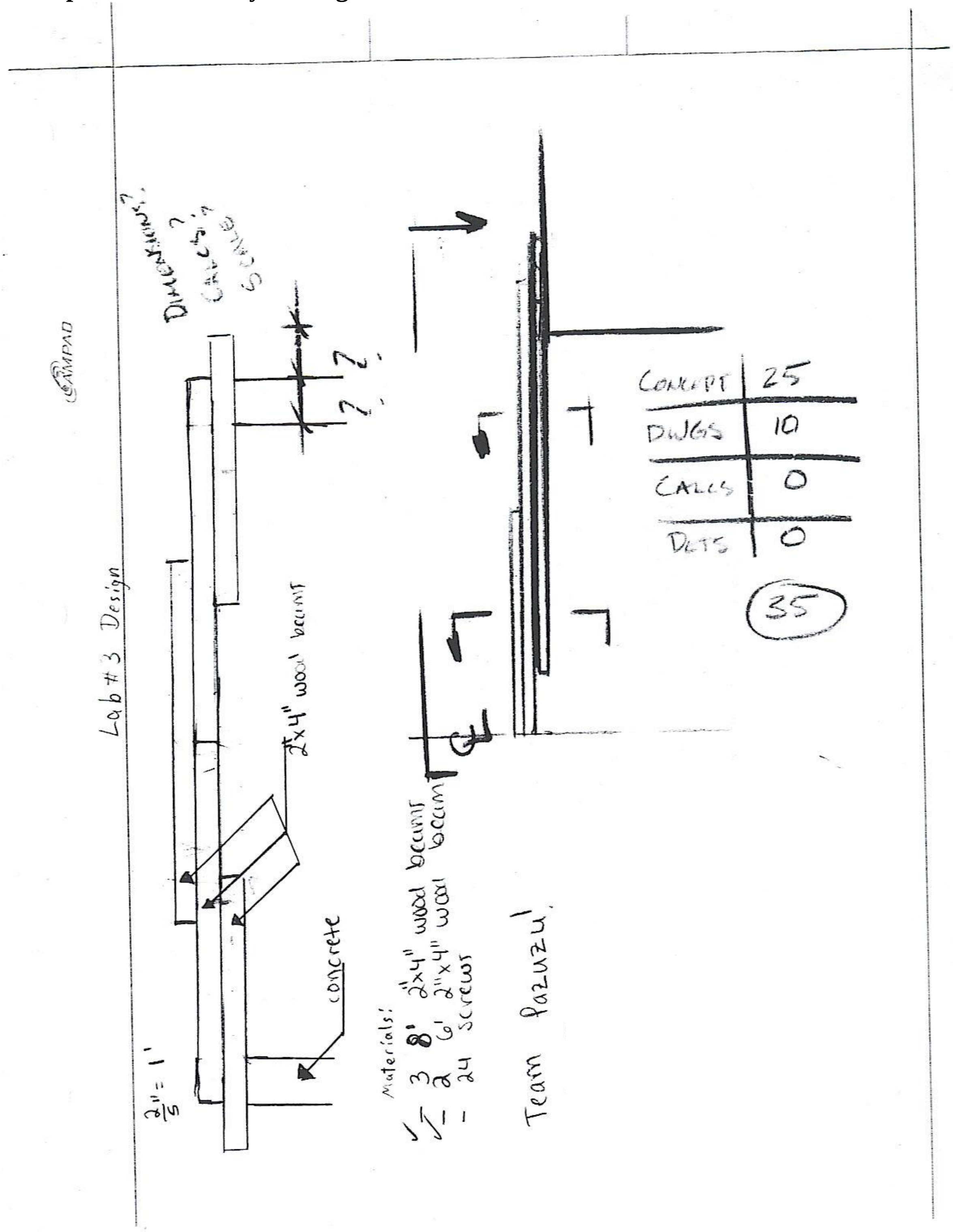

UNDER LOAD OBSERVATIONS:
175#) DESIGN "HOPS" a bit when load is applied
2456#) CRACK heard → maybe creak in connections
280#) DESIGN showing signs of buckling out

HINGE FAILURE:




↑GAP: needs to be connected for tensile forces to be connected instead of separating the 2x4s and therefore making undesired deflection.

**Example of Laboratory 3 Design**



## Laboratory 5 Design

CEE 1 - LABS
CRANE DESIGN
03/04/10
PAGE 1/6

FRIDAY LAB

LABORATORY #5 DESIGN SUBMITTAL

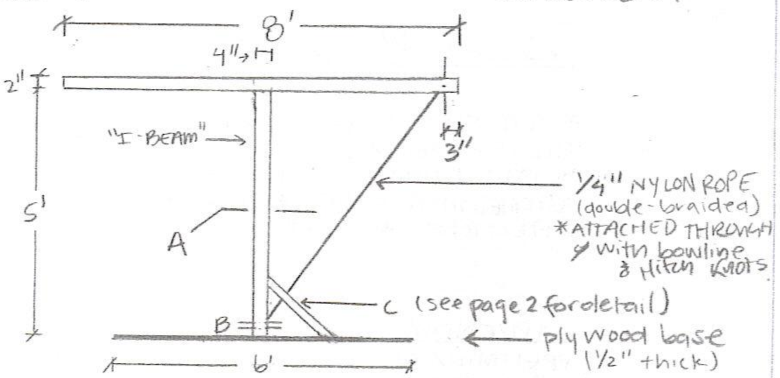


| | |
|---|---|
| CONCEPT | 25 |
| DWGS | 22 |
| CALCS | 20 |
| DETS | 18 |
| | 85 |

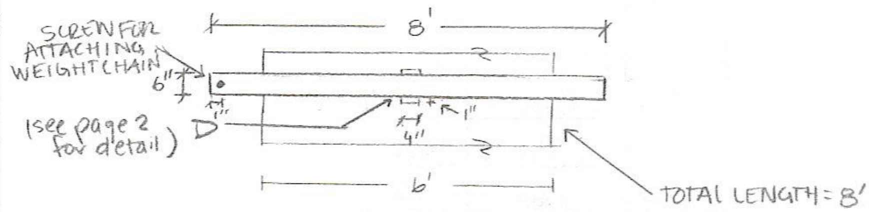
CEE1-LABS DESIGN | 05/03/10 PAGE 2/10

# CRANE DESIGN

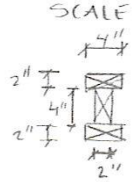
ELEVATION (1) SCALE: 3/8" = 1'



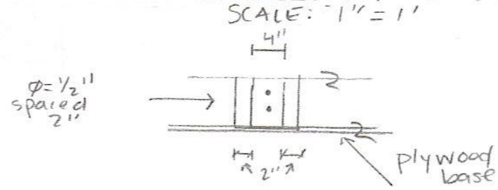

PLAN (2) SCALE: 3/8" = 1'




CROSS SECTION: at POINT A (3)
SCALE: 1" = 1'




SIDE VIEW: at POINT B (4)
SCALE: 1" = 1'




BILL OF MATERIALS

(1) 2x6 8' LONG
(3) 2x4 5' LONG
(1) φ = 1/4" NYLON ROPE - 8' LONG (already have)
(1) 8x6' 1/2" thick plywood (From lab 4 materials)
(2) 2x4 1.4' LONG (AS MARKED IN GREEN) (from lab 4 materials)

BUDGET

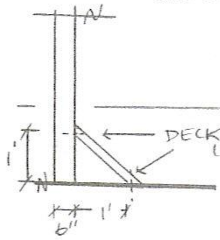
(3) 2x4 @ \$2.50 = \$7.50
(1) 2x6 @ \$5.00 = \$5.00
TOTAL = \$12.50

GOAL OF DESIGN: HOLD 210# FROM FREE-END (END WITHOUT ROPE ATTACHM...

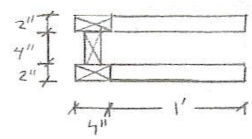
# CRANE DESIGN CONT.

**DETAIL C**: DIAGONAL BASE CONNECTORS SCALE: 3/8" = 1'

ELEVATION (5) SCALE: 3/8" = 1'



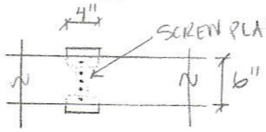

PLAN (6) SCALE: 1" = 1'



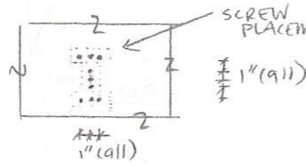

NOTE: THE (2) 2x4 diagonal beams will be attached with screws through the bottom of the plywood base & to the two sides of the I-beam.

**DETAIL D**: I-BEAM TO BASE & TOP MEMBER CONNECTIONS

PLAN (7) SCALE: 1" = 1'

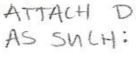



PLAN (8): THROUGH PLY BASE INTO I-BEAM SCALE: 1" = 1'




CONSTRUCTION METHOD

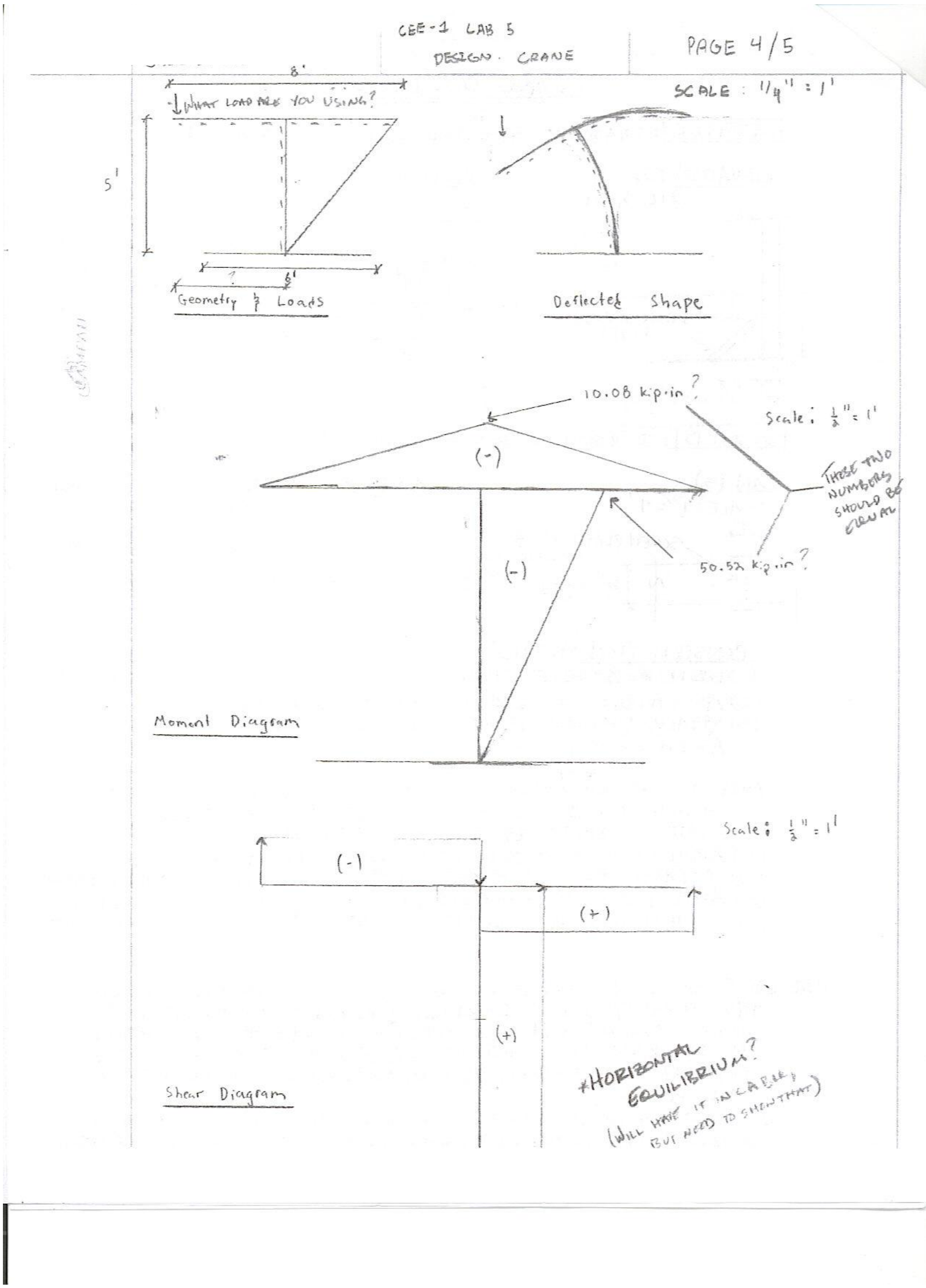
(1) DRILL Ø = 1/2" HOLES THROUGH 2x6 & 2x4 AS SHOWN IN ELEVATION (1).
(2) ASSEMBLE I-BEAM (VERTICAL MEMBER)
(3) ATTACH DIAGONAL BASE CONNECTORS TO TOP OF I-BEAM) AS SUCH:



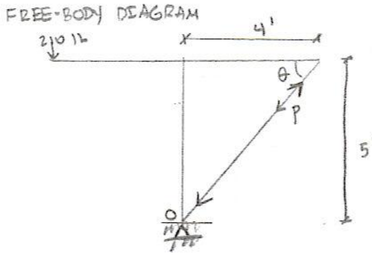
(NOT TO SCALE).
(4) PLACE PLYWOOD BASE ON TOP OF I-BEAM & DIAGONAL CONNECTORS, ATTACH SCREWS AS SHOWN IN DETAIL D: PLAN (8).
(5) ROTATE I-BEAM & PLY BASE SO THAT BASE IS ON FLOOR
(6) ATTACH SCREW TO 2x6, AS SHOWN IN PLAN (2).
(7) ATTACH 2x6 TO TOP OF I-BEAM, AS SHOWN IN DETAIL D: PLAN(
(8) ATTACH ROPE TO 2x6 THROUGH Ø = 1/2" HOLE WITH BOWLINE KNOT
(9) ATTACH ROPE TO I-BEAM THROUGH Ø = 1/2" HOLES WITH HITCH KNOT.

NOTE (1) WE ADDED THE 2x4 DIAGONAL BASE CONNECTORS TO (1) INCREASE THE STABILITY OF OUR I-BEAM AND (2) TO DECREASE THE MOMENT CREATED BY THE X-DEFLECTION OF THE I-BEAM ACTING ON THE BASE. WE INTEND TO PLACE WEIGHTS ON TOP OF THE PLYWOOD BASE DURING TESTING TO "ATTACH" THE CRANE TO THE FLOOR.

(2) IN case the top member does not appear stiff enough under load to carry 210# without breaking during our tests, we have included


CEE-1 LAB 5
DESIGN. CRANE
PAGE 4/5
SCALE: 1/4" = 1'
8'
WHAT LOAD ARE YOU USING?
5'
6'
Geometry & Loads
Deflected Shape
10.08 kip·in?
Scale: 1/2" = 1'
(-)
THESE TWO NUMBERS SHOULD BE EQUAL
(-)
50.52 kip·in?
Moment Diagram
Scale: 1/2" = 1'
(-)
(+)
(+)
*HORIZONTAL EQUILIBRIUM?
(WILL HAVE IT IN CABLE, BUT NEED TO SHOW THAT)
Shear Diagram

FREE-BODY DIAGRAM




$\tan^{-1}\left(\frac{5}{4}\right) = \theta = 51.3°$

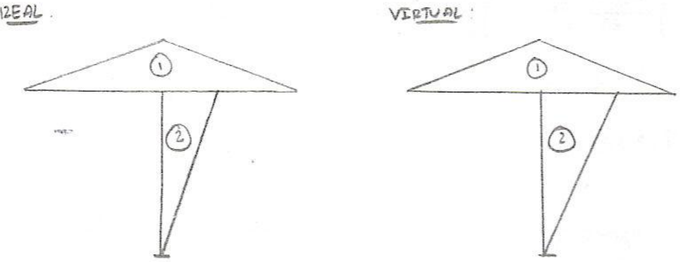
$\Sigma M_O = 0 \Rightarrow (210 lb)(4 ft) + P\cos\theta\,(5 ft.) = P\sin\theta\,(4$

$\Rightarrow P = 1517$ lb

$P_x = P\cos\theta = 842$ lb

DEFLECTION IN z-DIRECTION:

REAL.  VIRTUAL:



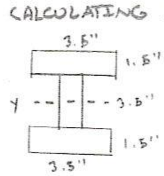

$$F\Delta = \int \frac{M_{1R} M_{1V}}{EI}dx + \int \frac{M_{2R} M_{2V}}{EI}dx = 2\int_0^{48} \frac{(210x)(210x)}{EI}dx + \int_0^{60} \frac{(F_x \cdot x)(F_x \cdot x)}{EI}dx$$

$$= \frac{2(210^2)}{EI}\left[\frac{1}{3}x^3\right]_0^{48} + \frac{(842^2)}{EI}\left[\frac{1}{3}x^3\right]_0^{60} = ?$$

ASSUME:

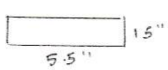
$E = 50\times10^6$ psi

CALCULATING I FOR COLUMN:




$$I = 2\left[\frac{1}{12}(3.5)(1.5^3) + (3.5)(1.5)(2.5^2)\right] + \frac{1}{12}(1.5)(3.5^3)$$
$$= 72.9 \text{ in.}^4$$

CALCULATING I FOR BEAM:

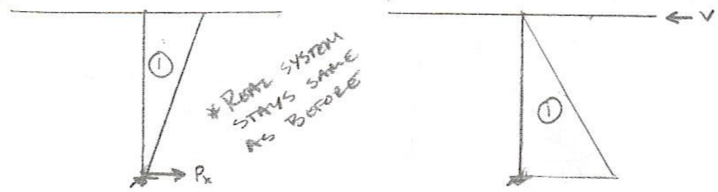



$I = \frac{1}{12}(5.5)(1.5^3) = 1.54 \text{ in}^4$

$$\Delta = \frac{2(210)}{(5\times10^6)(1.54)}\left(\frac{1}{3}\right)(48^3) + \frac{842}{(5\times10^6)(72.9)}\left(\frac{1}{3}\right)(60^3) = \underline{2.18 \text{ in. in } z\text{-direction}}$$

DEFLECTION IN X-DIRECTION:

REAL: VIRTUAL:




$$V\Delta = \int \frac{M_{iR} M_{iV}}{EI} dx = \int_0^{60} \frac{(P_x)(x)(Vx)}{EI} dx = \frac{P_x \cdot V}{EI} \int_0^{60} x^2 dx$$

$$V\Delta = \frac{P_x V}{EI} \left[ \frac{1}{3} x^3 \right]_0^{60}$$

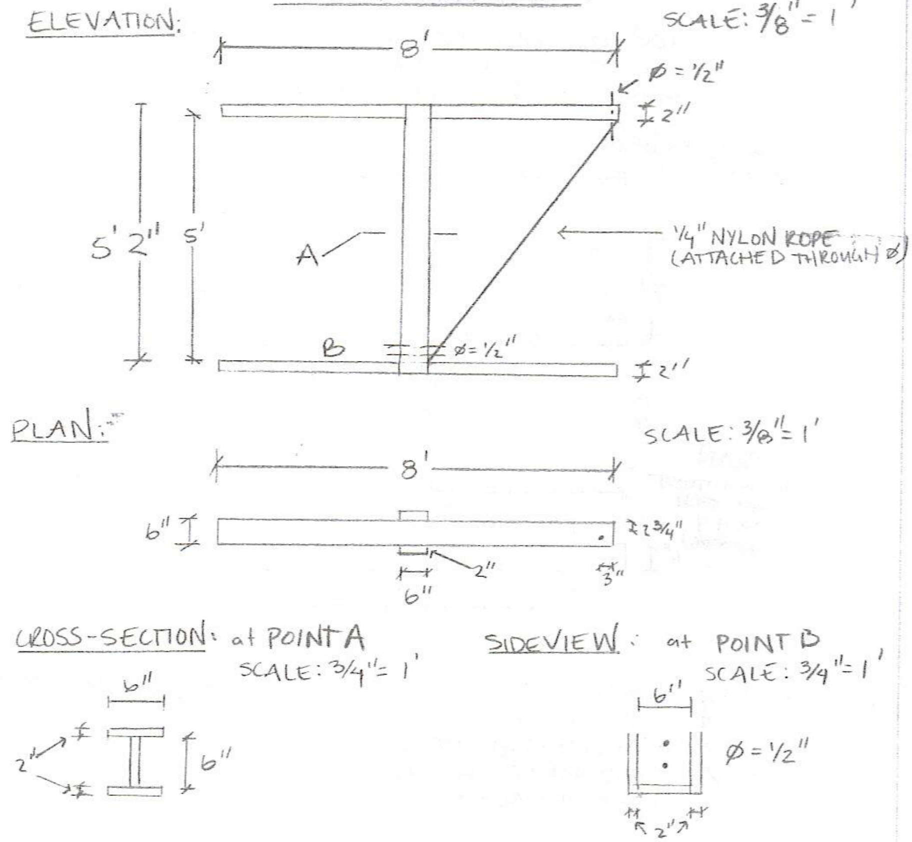
$$\Delta = \frac{P_x}{EI} \left( \frac{1}{3}(60^3) \right)$$

$$= \frac{(842)}{(5.0\times10^6)(72.9)} \left( \frac{1}{3} \right)(60^3)$$

$\Delta$ = 0.166 in. IN x - DIRECTION

CEE 1 - LAB 5 CRANE | 02/28/10 APPENDIX A

## CRANE DESIGN - NOT USED




**BILL OF MATERIALS**

(2) 2x6 - 8' LONG
(1) 2x6 - 5' LONG
(2) 2x6 - 5'4" LONG
(1) ø = 1/4" NYLON ROPE - 8' LONG

**BUDGET**

(5) 2x6 @ $5.00 = $25.00
(1) ø = 1/4" ROPE @ $0.40/(1) = $8.00

TOTAL = $32.00

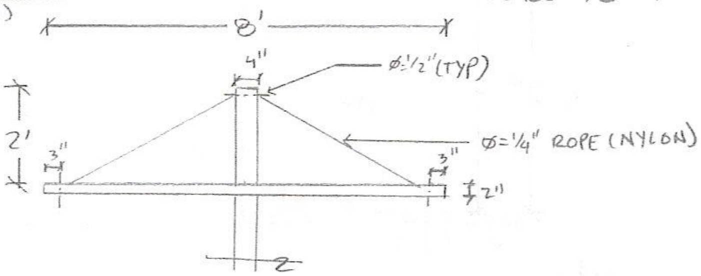
# CRANE DESIGN

## TOP MEMBER STIFFNESS CORRECTION

(to be used in case the top member cannot hold the load without breaking)

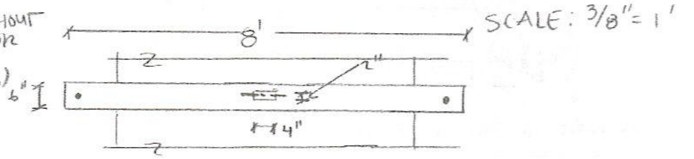
ELEVATION
(WITH ROPE)

SCALE: 3/8" = 1'




PLAN
(SHOWN WITHOUT ROPE FOR CLARITY OF DRAWING)

SCALE: 3/8" = 1'




BILL OF MATERIALS

(1) 2x4 2" LONG
(FROM LAB 4 MATERIALS)
(1) Ø=1/4" NYLON ROPE 10' LONG
(ALREADY HAVE)

BUDGET (FOR STIFFNESS CORRECTION ONLY)

TOTAL = $0.

## APPENDIX C – *Interviews*

**Interviewee: Senior 1 (S1)**
**Interviewer: Rachael Hogan (R)**
**Date: 02/03/10**

****Not Recorded****

**Questions:**

1.) What does motivation in an academic setting mean to you?
2.) What do you have a motivation to do with regards to your studies?
3.) Who motivates you? What teaching methods motivate you?
4.) Are your professors responsible for creating motivation?
5.) How do you know that you truly understand something? How do you test it?
6.) Describe an instance where something motivated you to truly understand a concept. Why did it work?

**Responses:**

1.) - Understand a principle, apply it correctly
- End result is ultimate motivation, but going through the process is also very important.
- For example, unsatisfying not knowing every piece of the steel bridge project like welds and cross-bracing
- With steel bridge, they did things they knew they were supposed to do but didn't know why

2.) - Get his P.E.
- He thinks he likes Civil Engineering

3.) - Does not appreciate personal expectations e.g. "You should be working harder."
- He chose to do it, so he should already be motivated. He would probably be happy doing something else, but chose this related to his end goal.
- Ultimately, himself

4.) - Should be responsible for not letting motivation diminish
- Modern life has infiltrated the university, we have run out of time to go further
- Shouldn't get teachers off the hook, it should be interesting for them, not here just for research
- Professor is in a position to know what is important and what can be approximated. More often than not, real-life does not mirror repetitive book problems.
- Motivate us to understand what is correct and what is important in the field
- If a professor glosses over a topic that leads to frustration
- If we're motivating ourselves, why don't we pick all our own classes?
- On Capstone Design class: Why do we have it? Expectations placed on us and we don't know what they are. Not our own time, not our own game.

- What if we got to choose it? We could have some feeling that we want to do this. Attitudes are important and professors affect them.

5.) - When he can see where everything comes from and how everything goes together. Not say "I guess this works," but knows it is right. No question, just know.

6.) - For example, Israeli dancing: You don't want to look bad in front of a lot of people. Much like wanting "pretty" problem sets, or in other words, problem sets that achieve good grades.
- Classes where it is clear the professor knows everything so we should too versus classes where it seems like the professor doesn't understand everything he is teaching, so why should we?
- Professors should be role models, be an example

**--End--**

**Interviewee: Senior 2 (S2)**
**Interviewer: Rachael Hogan (R)**
**Date: 02/22/10**

**R:** So, where do you derive your motivation to learn?
**S2:** Umm, probably from my interest in the field of engineering. Societal pressure, pressure from my parents, just the expectation of my parents. My internal wanting to sort of learn as much as I can because I want to succeed in my profession. So I guess that's sort of for an engineering learning, which I'm assuming this is what you're asking about?
**R:** Yes, your structural engineering education in general.
**S2:** Yeah I mean, I'm motivated by wanting to be the best and wanting to be a successful practicing engineer where I don't have to worry about my designs falling down. I mean, every engineer worries about that, but where I can be comfortable submitting my designs and calculations that I've done and knowing that they're safe structures.
**R:** How influential would you say are teachers or professors on that motivation?
**S2:** I think they're very influential. I think that it's sort of a "one-ups-manship" almost. Not in a bad way, though, but a professor motivates you. You get excited, interested in that topic, you show that to them and they get even more excited about it, and it just keeps raising the bar. I mean some of the best experiences and relationships I've had with professors here are where you take the time to get to know them, they get to know you, and you work with them outside of class. Or within the confines of class, but you're taking things further. It's an amazing feeling when someone invests their time like that in you and I think that's a big motivation as well.
**R:** For sure. So, what specifically do you think is a professor's responsibility in the classroom in terms of teaching. How much are they responsible for your learning, etc? Does that make sense?
**S2:** Yeah, I mean I know that it's on every student to want to learn. They have to, each side has to bring something to the table I guess. The student has to bring the ability, and the desire, and the motivation. Not all of the motivation though. Professors have to be, a word that's

thrown around a lot is dynamic. They have to be engaging, they have to be excited. And, so, in terms of motivation I think both sides have to bring that to the table. The student has to bring the willingness to learn though. And then the professor has to bring the investment in the pupil. They have to bring the understanding, the, they have to want to teach and they have to have an interest in what the student does I think.

**R:** So, kind of in follow-up to that, at what point does it stop being the professor's responsibility to try to be engaging? When can they tell that a student just isn't there?

**S2:** I don't think there's ever that point. A professor, at least in our interaction with them, I mean yes they're here for research as well, but when they're teaching they are being paid to teach. It is their job to teach. I mean obviously sometimes you cut your losses and forget about it, but to just give up, like if you're a practicing engineer and you say this structure, I can't figure it out but it needs to get done, you can't just say I'm giving up on these calculations and let the design move forward. I mean you can scratch the design and start again, but you can't just give up on a design and push it to the next step, and I think that's the same with professors. I mean obviously some kids, the kids have to bring to the table something and that's imperative. I'm not saying it's all professors, and the students they definitely have to bring something to the table, but neither side can ever quit. I mean people do, and that's unfortunate, but I think that's outside the scope of your question.

**R:** Yeah, so ideally.

**S2:** Right, ideally I don't think a professor, if a student's highly motivated they have to bring it up even to the next step because student's, if they're not being challenged they get bored even if they're extremely bright. And the most smart kid, the brightest kid in the class will shut down if they're not being challenged.

**R:** So it's playing with your competition almost, in a sense.

**S2:** Exactly, it's always "one-ups-manship," it goes back to that.

**R:** So, in terms of teaching methods which do you respond best to, what do you learn best from? Just kind of in general.

**S2:** I that's, that's really hard to say.

**R:** It's a hard question.

**S2:** It varies by professor, I mean every professor has their own personality, every student has their own learning style. But, there are different combination of those that work, and some things work for certain subject matter, other things don't work. So I think it really, I mean you need a professor who's highly motivated in that field who can bring things outside the scope of that class into the class to excite the students. I think you need someone who's willing to change the schedule around, I think you need someone who will work with different media for teaching and adapt based on the students in the class and based on the content and what type of thing; I mean for an English class you're not going to use the projector and display the notes on it. But, by the same token, you need something. You can't just have a free discussion and you need to find, each professor finds their own teaching style and what works best for their personality.

**R:** What works best for structural analysis, say? Or anything like that, mechanics of materials, that type of thing.

**S2:** For structural analysis I think it's getting some sort of physical interaction. Also, drilling problems and drilling different things in, different possibilities in. Because structural analysis, a lot of it is, as we learned, having an inate, I mean a lot of engineering is, having an innate sense of how things will work before you do the calculations. And so, I think that's very important, but I think there are different ways to go about it. Having a textbook and saying do this problem, this problem, and this problem, that doesn't work. I think having it build to something.

**R:** But it's a combination it sounds like you're saying, too?

**S2:** Yeah, definitely. You need some source material for the students to refer back to. I mean like I know we didn't have a textbook in 24, that was great because a lot of the notes were very relevant to what we were doing. By the same token, I know I was constantly referring to old textbooks for certain types of things.

**R:** So you need both?

**S2:** Yeah.

**R:** Ok, so lastly I'm going to ask you to try to remember a defining moment in your academic career in which you remember developing a true understanding of a concept. Or that moment where it kind of clicked in your brain. Do you remember how it was presented to you?

**S2:** Does it have to be my first?

**R:** No, no, anytime.

**S2:** I mean one that comes to mind immediately is a couple weeks ago, I mean I had taken soil mechanics, intro to soil mechanics, I've taken all kinds of geotech classes here, and I've been doing research on suction caissons. I guess at the beginning of the semester for my foundations class we were doing a refresher of soil mechanics and what not and we were talking about the tri-axial test. I sort of understood what it meant, and all that stuff, and I kind of understood what my research was about. But then I was sitting with my advisor one day, and it just clicked. And it was like, wait, what I'm researching is an example of a confined, drained, triaxial cell. And that was pretty cool.

**R:** Did it just come to you? Or was it something he said? Or something you just thought of in a different way?

**S2:** It was just that I was thinking of it in a different way and I guess meshing ideas that we were throwing around together and it just clicked. And I was like, wait, I understand what's going on now.

**R:** So do you think that, I don't want to lead your bias or anything, but is it because you've seen it that many times before? Or do you think it's because it's just a different way? I don't know if it's possible to answer, but…

**S2:** I don't know, it's probably a combination of having seen it in different lights and also just having done it so many times. And also having people ask me, trying to figure out, I mean I think a lot of people were asking me what it meant trying to do that homework.

**R:** So trying to teach it to others helped you to better understand?

**S2:** Yeah, definitely. And trying to explain my problems with my model to my advisor, it just came to me randomly. It was weird, we were talking about, something about meshes and computer stuff and it just came to me.

**R:** Well, that's always a good feeling! Good, well any other thoughts on the subject?

**S2:** No.

**R:** Well, thank you very much.

**--End--**

**Interviewee: Graduate Student 1 (GS1)**
**Interviewer: Rachael Hogan (R)**
**Date: 03/05/10**

**R:** Can you first just generally describe your educational background? Overall, where you come from?

**GS1:** Both my parents are teachers, so education was always really big and my dad was a science teacher so I was the preschooler who was yelling at other kids for calling "rolly-pollies" "rolly-pollies" instead of isopods and talking about exo-skeletons of insects. And then I went to private high school that did not offer any engineering classes so when I was looking at colleges I found out that engineering schools did not have as many English or history requirements so I applied to those. You had to write essays to get into engineering schools about why you wanted to be an engineer and what you wanted to do, and I actually had to research what engineering was online to find out how I could possibly write these essays. But, I feel like education, especially math and science, was always emphasized in my family and I always had fun with it, but I was never the kid who knew what I wanted to do.

**R:** So, where do you derive your motivation to learn? Especially if you didn't really know what engineering was, how did you get into it and why are you still here?

**GS1:** Well, I've always thought that math was really fun, calculus was my favorite class I ever took in high school followed by physics, and I don't really know where my motivation to learn comes from, I just know that I've never been someone who wanted to get a good grade to get a good grade. I never really cared what my grades were, I was more interested in learning the concepts. It would always really upset me when other people would cheat. In my biology class in high school one of my really close friends cheated on one of the tests and I was so upset and hurt by it because to me why would you cheat on something, you didn't actually get anything out of it, you're just cheating yourself. That's just kind of how I've always looked at learning and I don't know, I just like to learn. It's obvious that I only learn because I like to because in the classes that I don't enjoy and they're not fun, I really don't do that well.

**R:** That's a good segue into my next question, which is how influential would you say are teachers or professors on that motivation? You've said that if a class isn't as fun you don't necessarily learn as much…

**GS1:** I think fun for me is partially related to what the teacher or professor expects out of me. If a professor is teaching 70 to 200 students, they don't know who you are, they give out blanket assignments to everyone that are really just basic because it's an intro class where the professor doesn't have anything invested in the student, or really in the people in particular, I can't be motivated in that type of situation. I need the professor to be, I need it to connect to what they do. Because what professors do is generally what is interesting to them so they're able to present it in an interesting way.

**R:** So what is a professor's overall responsibility in the classroom? In terms of creating motivation or deriving it?

**GS1:** I think it varies. I think in the intro classes where you have 200 students in a class and there's really no room for a professor to get involved one-on-one with the students, I think there their responsibility is to try to encourage self-motivation, because you can't be good at or excel in your field unless you have some self-motivation. Which I think is why in a lot of these intro classes the professors can't motivate a lot because there's no way a professor can motivate all 200 students personally. But I think that as you get deeper into the subject they need to find a balance between nurturing and letting people go on their own and make mistakes. I think that the most successful professors find a balance in between, where the students that can handle it they let them fall flat on their face and do poorly. But students that can't handle it or who need a little bit of help or encouragement along the way they help out. But I think that at different steps in your education you need different things.

**R:** What teaching methods do you respond best to? You yourself? Or learn best from in general?

**GS1:** Not memorization. Anything but memorization pretty much. I respond well when I am not put on the spot, when I can come out of my shell in a class on my own. When I'm allowed to do that I become a very vocal, active participant in class, but when I'm put on the spot and feel really uncomfortable I tend not to get involved and not learn in the class. I don't really know…

**R:** Visual? Or blackboard?

**GS1:** I need to write things by hand. If I'm given powerpoints I don't read them and I don't listen in class because I've already got it written down. But if professor's are writing on the board and I'm also writing while they are saying it. I think Masoud's style is what I learn best from.

**R:** My last question is to describe a defining moment in your academic career, that you can think of, where you remember developing a true understanding of a concept. Any point, how was it presented to you, what made it click?

**GS1:** That's a really hard question. I think most of ES 9, actually I don't really remember what was taught in ES 9, but the founding principles of ES 9 clicked for me when Professor Hines wrote the virtual work equation on the board and derived it from stress and strain. I feel like the concept of what stress was and what strain was clicked. The connection between stress and force and strain and displacement hadn't been clear to me before. I feel like his presentation of virtual work explained a lot of concepts of strength of materials that I did not get.

**R:** Do you think it was the way he explained it?

**GS1:** I think it was a second exposure to it. As well as the fact that he was able to see how far we had gotten, we being my class, had gotten in our understanding of strength of materials, stresses and strains and relation to forces and displacements. To go from where we had, where our learning had stopped, which was fairly early, and present it in a way that started there and just quickly brought us to where we should be.

**--End--**

**Interviewee: Senior 3 (S3)**
**Interviewer: Rachael Hogan (R)**
**Date: 03/08/10**

**R:** So, first can you generally describe your educational background? Where you come from? Just a quick overview of what you did and why did you get into engineering.

**S3:** I went to public high school in Farmington, CT. It's a really good school system, it's pretty high up there in the state and in the country. So I got a good basis in math and science, and I always like math and science more than I liked liberal arts. Not that I didn't like them, but I just felt more strong about it. My dad's an engineer, so I had thought about it. I wasn't sure right after high school, but I applied to the engineering school just on a hunch, and I kind of switched my thinking about which major specifically within engineering, but I was pretty sure I wanted to be an engineer when I got to college.

**R:** When did you switch?

**S3:** Well I originally thought I was going to do environmental because I kind of like the earth sciences, like biology. I really liked environmental science when I took it in high school, but I took chemistry the first semester I got here and I hated it, so I changed my mind. I felt like architecture, that program that's like the minor in architecture. I talked to Dean Knox and she was like "that's not accredited, so why don't you just be a civil engineer?" And I'm glad it worked out this way.

**R:** From that, where do you think you derive your motivation to learn? Generally speaking?

**S3:** I don't know, I guess I just never really minded doing math homework. So, like the first year when we took all that foundation stuff, it wasn't like I was really loving it, and I don't think it was really engineering at that point, but I didn't mind getting through that. So I guess I started feeling motivated maybe sophomore year, maybe junior year. Definitely felt the motivation when we took Steel, for sure. It finally was like real to me, what an engineer does. But, yeah, I don't think it happened until the second year of college really.

**R:** So, how influential would you say your teachers or professors are on that motivation? You said it didn't come for a little while.

**S3:** Um, very I would say. You can definitely feel the difference when you have a teacher that, not that you don't like or they're a terrible person, but if they're lackadaisical about the subject there is very little chance of me being motivated. I've enjoyed having professors who also practice their profession. I think they can provide a more real view of what we do.

**R:** That makes sense. Next, what is a professor's responsibility in the classroom?

**S3:** Well, I think they should be as honest about what we're actually responsible for once we get to the real world. I definitely think they should try to motivate you to do well, to be honest about your work. I think they should encourage you to come to them to ask questions. It shouldn't be the only time you interact with them is in the classroom. I understand a lot of them are really into their research, but they should also be into us coming to ask for help. It's better when you have a close relationship with your professor than just seeing them for, you know, two hours a week.

**R:** In general, what teaching methods do you respond best to or learn best from? You yourself.

**S3:** I guess, I don't really mind when professors do PowerPoint provided that they don't have slides with a million words and are just reading from it. I like it better when there's board work, like they're actually doing problems on the board. I don't know, it helps me with homework actually seeing something being done.

**R:** So more visual kind of stuff?

**S3:** Yeah, definitely a more visual learner.

**R:** Ok, last question. Try to describe a defining moment in your academic career in which you remember developing a true understanding of a concept. If you can remember how it was presented to you, or kind of what made it click for you. I'll give you a second to think about it.

**S3:** I'm trying to first think of a concept I think I definitely understand. I guess, I don't know if I can reexplain the concept to you…

**R:** No, you don't have to, just how you learned it.

**S3:** It was virtual work. When Hines explained it to us and he drew that diagram with the triangle for why the ½ is in the equation. I think understanding came from, you know, visual presentation rather that just philosophical talking about it or just throwing an equation on the board. It's making it physical. First, I think we started out in a lot of our basic classes just giving us the equations, but that doesn't mean you understand it. You can get the right answer that way, but I think that's how I spent probably sophomore year. But I think junior year for me was more about trying to understand the physicality of some of the things. Not that I'm completely there yet probably, but definitely more so on my way.

**R:** But it reinforces the concepts a whole lot better?

**S3:** Yeah, definitely. He was the first professor that made that seem important to me. I wouldn't say the only professor, but only a few.

**R:** And so have you now taken that to your other classes senior year do you notice?

**S3:** Well, this semester I'm really not taking anything structural. But yeah, when I took 123, that was actually Advanced Structural Analysis, we worked with these huge matrices and you could totally just get bogged down in being off by one entry in like a 12x12. But it was more so understanding physically where the numbers come from. It's not like how it all works out, but ok this is how this number is oriented and interacting with others.

**R:** So that helped get through that?

**S3:** Yeah, it helped.

**--End--**

**Interviewee: Senior 4 (S4)**
**Interviewer: Rachael Hogan (R)**
**Date: 03/08/10**

**R:** So, first can you generally describe your educational background? Where you come from and why you got into what you got into.

**S4:** I went to a public school in New Jersey. I had a really good physics teacher, who I took for two years. Dr. Chen, she was wonderful. I just found the physics very interesting and I was very good at moving things and diagrams. Also, I did theater so I built a lot. I didn't actually get to design what I built, but just in physically making things it was cool. So, I kind of learned to do engineering, but I wasn't so sure. So I came to Tufts. I actually applied Liberal Arts and I transferred into engineering the summer before freshmen year.

**R:** Before you got to school?

**S4:** Before I got to school, and I picked Tufts because you can do that pretty easily. I was deciding between Mech E and Civil for a while, and I picked Civil because I hate Mech E.

**R:** And how'd you find that out?

**S4:** I just didn't like rotation. Which is in Civil, but I just didn't like it. I figured I wouldn't really like engines and things. Plus, I like bridges, like Brenner.

**R:** You had Brenner freshmen year right?

**S4:** Yeah I liked him.

**R:** So, where do you derive your motivation to learn? Kind of a broad question, but in general.

**S4:** I just really like getting to the answer. I just really like the beauty of finding an answer in things. I really liked that physics had a system, it was a self-contained system that did things. To be honest, the thing that really freaked me out was when that system was translated into the real world, and I hadn't really seen that translation before. For direct citation, that moment where Professor Hines suggested we divide by 2. It was just weird. Realizing that something I had associated as a science, a very specific, direct, self-enclosed science was not was a very difficult realization.

**R:** So that there was a gray area in science was difficult?

**S4:** And I think if I had been building things the whole time up to that it would have been a lot easier. But because I had only learned the system and I hadn't learned the…Like if you're making something in mathematics you can set up something in axioms, you can set up an entire world that just exists on paper. Which is, I feel like, what we do for two years. And I had nothing to compare that to once I removed myself from the building process.

**R:** Interesting. So, how influential would you say your teachers or professors are on that motivation?

**S4:** To a certain extent, I could have a bad teacher and still do well. But having, I mean teachers are a very important part.

**R:** So, do well in terms of grades? Or in terms of understanding the material?

**S4:** Yeah, I'm trying to think of a bad teacher I had. I've had a few bad teachers that I have the book and I've learned from the book a little bit. But most of the time I need the teacher to explain and also to get me excited about what it is I'm trying to do. And care about what it is I'm trying to do. Because it's also the stories they tell between the lessons. Putting things in perspective of an actual project. But that's not entirely from the Civil department, that's from things in general.

**R:** So relating things to the real world helps you want to learn them?

**S4:** Yeah.

**R:** More on this, what is a professor's responsibility in the classroom? In terms of creating motivation, keeping it there in students. Should they just teach for an hour and leave?

**S4:** Well, I'm not really one to stay after and talk to professors most of the time. Office hours, I mean one time I went to office hours for a math professor and I had a question because I didn't really understand a concept that was really important. I thought he was just going to talk to me for 15 minutes, but he talked to me for like an hour and a half. And he just went over it like three different ways and by the end of it I really understood it. He didn't really talk to me, he just taught for an entire lesson to me. And that was pretty much the most helpful and intimate teaching experience I've had, like someone teaching me something. Besides just a friend teaching me something over lunch, which is nice, too. I mean, I guess the only other professor I've stayed after to talk to was Hines. And that was because he would give very vague assignments that required you to stay after and ask him questions. So that was actually kind of, I don't think he mean to do that, but it was kind of smart on his part because it made you – in trying to clarify what the problem was you ended up doing a lot of thinking in front of the professor, which helped the professor guide you as opposed to just giving you a well-written explanation. Not that you shouldn't give well-written explanations, but you know what I mean. I guess that only works with assigned stuff. But I always felt like, even in math or Statics and Dynamics, if you said solve this equation and you didn't give a method that would be a very interesting way of doing it. For an entire semester you learn like 30 different methods and you're supposed to do this method for this and that method for that, but you don't know how to just given a problem, do it. You only know how to apply a method.

**R:** And they may be related…

**S4:** Exactly, and because of the way the system is set up you know it is going to be a specific method because of what number it is or something. This in number three and the fourth thing we learned or something around there. I think it would be really interesting if we were just given a problem and you had to talk to the professor to figure out how to solve it or something. Because those kind of things are hard to work with.

**R:** What teaching methods do you respond best to or learn best from? Visually? Reading on your own?

**S4:** I do really well writing, taking notes. But also, physical things, those were really helpful.

**R:** For example?

**S4:** Like the twisting thing, like a plastic thing and you twist it and you see the planes moving. But any kind of CAD work was always really nice. I don't know if that's the way it's taught, but those kind of things are really helpful to do on your own. I also really liked when you're put on the spot to do things. I didn't like it, I actually hated it, but it was very helpful learning. If the lab was to solve this problem, and then do it, and then see that it worked that would be nice. It could also be really annoying, but it can be helpful. Also, I remember I think Sanayei or Hines once made us go in front of the class and everybody had to do their own diagram. I feel like if that was done once at the beginning of class and once at the end of class of every single class that would be super helpful. Because once you break that awkward thing where you're afraid of being wrong it starts to become about just being confident. It's about gathering confidence, it's not about solving a problem. Because when you're working at your desk and talking to people behind closed doors you can just keep it in your head, but when you're doing it in front of everybody you have to be at least confident in what you don't know. So that was nice.

**R:** My last question is to describe a defining moment in your academic career in which you can remember developing a true understanding of a concept. If you can remember how it was presented to you or what exactly made it click for you. It can be anything, from any time, but try to think about why you felt like you really understood it.

**S4:** I can think of a couple. I can remember the first time I actually understood what beam theory was. I actually understood what plane sections remaining plane meant.

**R:** When was that?

**S4:** In Hines' class, spring of junior year. I had learned about plane sections remaining plane fall of sophomore year, and I had been using it but never knew what it meant, and that was really cool. I don't know if I could still tell you what it was. I could probably do it if I tried really hard, but I don't know. I remember just being amazed that I didn't previously know it, and learning it in that way was so helpful. How did he do that? He drew a picture, I think he also had a physical thing…

**R:** An eraser he drew lines on.

**S4:** Yeah, but it wasn't just that, I had seen that before. I think it was a mixture of very simple diagrams that built on themselves. That's always really helpful. No, you know what the most exciting moment was? Was when I learned that the shape mimicking the moment diagram, because the way I learned that was I had to teach it to these other kids and I didn't understand it myself. So I sat in my room for the hour I was supposed to be grading and just drew. I derived it three different times on three different shapes to prove it to myself. Because I did it once and was like that's weird. I knew it should work that way, it does work that way, but I'm going to do it again. Three different times, I had all these notes, it wasn't organized at all, it was just the process of me proving it to myself. And that I still remember, that I remember vividly. Because I am completely and 100% certain that that is true. So, I think it's the fact I had to teach someone else that made me learn it. Most things are like that.

**R:** Well that's all I really have, do you have any other thoughts on the topic? What you would like to see more of in undergraduate education?

**S4:** I guess just an inherent understanding of how forces work, which is something done by building. I think there should be a required, maybe not required, but an extremely, strongly recommended sort of Habitat for Humanity project or something like that. Where you have to go out and freshman year all you do is build, and sophomore year you help design things or something. Just being around a built environment is extremely helpful, and I feel like, I mean I had that more than most people did. But I wasn't around it that much. I can't really think of anything else.

**--End--**

**Interviewee: Professor 1 (P1)**
**Interviewer: Rachael Hogan (R)**
**Date: 03/09/10**

**R:** First, can you generally describe your educational background as an engineer?

**P1:** Degrees? Schools?

**R:** Yeah, I've only done seniors so far, so they've told me from high school. But for you maybe since undergrad.

**P1:** Ok, got a bachelor's of science in civil engineering at Tufts. An M.S. in civil engineering at M.I.T. And then, a PhD at M.I.T.

**R:** All in civil engineering?

**P1:** Yeah, they're all in civil engineering.

**R:** So, thinking back to your educational experiences where did you derive your motivation to learn? Was it more of a self-motivation?

**P1:** Desire to learn? I, digging way back into the deep recesses of my mind, I think some of that comes from within. I mean there are certain things in my growing up, my childhood situation that encouraged me to learn to become educated. I certainly got that encouragement from family, from parents. They wanted me to have a better life than they had and education was one of the ways for that to happen. And then I had some inspirational teachers. Everybody goes, it's really sixth grade through high school, and everybody has lousy teachers. Have you ever had a lousy teacher?

**R:** Yeah, a few.

**P1:** But if you're blessed you get to run into three or four really special people, and they were really inspirational teachers. Mr. Gilbert my math teacher and Mr. Rosenthal my English teacher.

**R:** See, you still remember.

**P1:** Oh, absolutely.

**R:** And that leads into my next question is…

**P1:** I was also in a high school environment. I went to a competitive high school, so I was around, surrounded by people, you know the culture was to strive to learn, to be educated. To be smart was a good thing. Nobody was embarrassed to be the smart guy.

**R:** That leads right into my next question is how influential, I guess both from your perspective now as a professor and thinking back to your own education, how influential are teachers and professors on motivation for students?

**P1:** They can be very influential. I think also poor teachers can sometimes discourage students, not give them incentive.

**R:** In what ways do you think they do that?

**P1:** Good teachers or bad teachers?

**R:** Bad teachers.

**P1:** Well if you have a bad teacher, that doesn't show any excitement, it could be a bad teacher for a lot of reasons. You don't know the topic, that's pretty unusual. It's more a matter that they're not able to share the excitement of the topic, the relevance of the topic, so the students become disinterested in the topic.

**R:** So, what is a professor's responsibility in the classroom?

**P1:** To teach.

**R:** But are they responsible for making the students want to learn what they're teaching?

**P1:** They're responsible for having command of their subject. They're responsible for teaching, which also means to convey a certain attitude and excitement in the classroom that motivates students. They also are responsible for telling the students, for providing feedback to students, and that may not always be what the student wants to hear. So you have to know how to be honest, but to do it in a nice way.

**R:** Constructive.

**P1:** Yeah.

**R:** I could ask this questions two ways I guess. What teaching methods do you respond best to personally? First.

**P1:** Once I got to college and was going to be an engineer, I always responded very well to things that related theory to practice. I really like it when I can take, if you showed me a mathematical equation and it had no relevance I'd lost interest. On the other hand, building something without any background theory is not engineering. It's a craft, not that being a craftsperson is bad, but for me engineering is the integration of mathematics and theory with a practical problem.

**R:** And what teaching methods do you employ now?

**P1:** I try to do that. I try to describe background theory and then show its application. And in showing its application I try to point out some of the practical difficulties, practical issues in applying a theory.

**R:** So, my last question is to describe a defining moment in your academic career in which you can remember developing a true understanding of a concept. If you can remember how it was presented to you, or what made it click in your mind, from any point in time.

**P1:** College?

**R:** It doesn't matter, just any defining experience you can remember grasping.

**P1:** I can remember a number of experiences. I mean way back in high school, one of the things I got from one of those high school teachers was an ability to read, think, and write. And I worked very hard at that. And it was until I was well along in college that I began to have some confidence in my ability to write and to communicate. That was sort of an "aha" period. That's one example.

**R:** Do you think that was because you had that many years of practice of it?

**P1:** Yeah part of it. I also, another "aha" moment…there are a lot in between. But I can remember my first year in graduate school, studying for a master's degree. I went to M.I.T. and you're surrounded by a bunch of smart people. It turns out the professor, who became a very good friend of mine, he knew me so he would ask me questions in class and I thought that I must be the dumbest turnip in the class.

**R:** Put you on the spot?

**P1:** Put me on the spot. And I struggled and I also, eventually I realized I wasn't the only one that didn't understand. Almost everybody else didn't understand. And then it took a matter of time, maybe a semester or two, until the technical information really began to click. I mean the subject was soil behavior. You know I struggled for probably the better part of an academic year. You know he was asking me questions that I didn't know the answer to, no one else knew the answer to, I didn't know that. But eventually it began to come together.

**R:** So over time. That's all I have formally, do you have any other thoughts on teaching understanding or motivation?

**P1:** For engineers?

**R:** Yeah, or in general. But a lot of this is coming from the discussion in the ethics panel.

**P1:** The ethics panel, by the way, was very interesting. In general, the students and the faculty see it very differently.

**R:** Yeah, you always kind of know that, but I didn't realize how drastic the lines were. And I feel like we're all trying for the same thing, but it's just coming at it from such different perspectives was interesting to me.

**P1:** Yeah, you know everybody has responsibility in the relationship. And I think students have a certain responsibility.

**R:** I completely agree.

**P1:** You know if a professor says these are the rules of the course, then these are the rules of the course. So, I don't know.

**--End--**