STRUCTURES
LEARNING PORTFOLIO

A testament to what I knew, what I know now, and what I may never understand about structures.
Reflective Essay

Structures 331 has a bit of a reputation among A&M architecture undergraduates. When you ask a senior about structures their eyes widen in fear, and then an attitude of pity and condolence follows. “It’ll be okay, just get through it” is the phrase most often heard, which is fairly intimidating when you are at the beginning of your structures journey. It certainly is no joke, but as I have found, it has certainly been worthwhile.

I had the great fortune of coming from a strong STEM background. The high school I attended prided itself on its science and mathematics offerings, with some of the strongest test scores in Austin. I had two wonderful Physics teachers and a dedicated set of math teachers that pushed me and also provided the opportunity to complete BC Calculus by graduation, not to mention for those who simply excelled, there was a Multivariable Calculus offering. When I graduated and began community college, I wanted to solidify the skills I had attained, having not been able to take AP exams which would allow me to place out of many requirements. I took Engineering Calculus I and II as well as Physics 201. My mathematics and physics backgrounds only got me so far in structures. My physics courses focused primarily in Newtonian mechanics, thermodynamics, waves and sound, and introduced topics of electricity, magnetism, and optics. From this experience I did learn how to employ free body diagrams, associate my trigonometry knowledge with vector resolution and equilibrium. Calculus gave me further insight into all things area related like integration and derivation which was very useful in understanding the relationship between shear, moments, and deflection. This was where my knowledge ended. Much of the theory and application to come in structures had never been seen before and would present a challenge.

Despite the difficulties of the material, I can now say I am able to choose economical steel and timber members as well as determine the thickness of a slab and the size and spacing of the steel needed to fulfill flexural requirements. Beyond just understanding the concepts, though, structures has also led me to take the long way home in my neighborhood just to see the foundations being poured, and timber framing being constructed on the townhouses behind mine. It is a great opportunity to see a building from foundation to finish outside of the classroom and has helped me to solidify concepts of load tracing, foundation reinforcement, and timber design. While structures is a whirlwind of material during the semester, stepping back to evaluate the methodology and concepts covered has allowed me to appreciate the vast knowledge of building systems and statics I have accrued.

Concepts

The only way I can really describe my introduction to the course is by relating it to a large cohesive picture, which when observed through a magnifying glass produces hundreds of little marks and scratches that work together to produce a unit or in the case of structures, units. We began the course by first looking at structural systems and the design process associated with
them and the parties involved (the architect and engineer being the primary). The design process made it very clear the needs for systems to be stable, stay together, have strength and stiffness and resist forces. This was also the first time we were introduced to charts which we would later analyze in homework one. The charts specific to the design process documented the different framing systems possible, the design criteria which would lead to their use and the reasons for their use. These charts promise to be useful in Integrated for their ability to point you towards the system you need based on the criteria you must fulfill. We also saw systems broken down by material and displayed graphically so that when we were given terms like ‘two-way waffle slab’ or ‘plate girder’ we would be able to visualize the system. This proved extremely helpful when entering the concrete chapters. During this first week we also discussed structural planning which detailed different types of resisting systems and the forces (Lateral, Vertical and Horizontal) which they resisted most effectively. Though it may have been inherent knowledge, the chapter also hit home the importance of balance in these systems to help resist lateral forces in all directions. The planning process was also demonstrated graphically showing structural plans for each of the different material types and the way it would be used in a building configuration- concrete foundation and footing, steel columns and framing, reinforced masonry walls, and timber in roof framing. The first homework would also reference the span length charts at the end of the planning chapter and would be used to help us construct our own structural frame, helping us to become acquainted with the direct relationship between span and beam depth and the variations in span based on material. We also brushed up on our basic math skills-determining significant figures and conversions, because for some of us, math and physics did not take place in the semester previous.

The second homework was the beginning of equilibrium in relation to points as we began discussing vectors and forces and introducing rigid bodies which are ideal and do not deform. This was also the time at which we dusted the cobwebs off of the trigonometry we once knew and employed it to resolve vectors with the tip to tail method and parallelogram method and solve for unknown forces using our three equations of equilibrium for the sum of forces in the y and x directions, and the sum of moments about a point. These equations and this understanding is what allowed us to move into solving for member forces in trusses by method of joints which made use of the conditions of equilibrium at each joint. It was also interesting to find that the connections in trusses were pin connections because this connection type is more realistic to how trusses are constructed in real life- you will very rarely see a truss fixed or attached to a wall. This portion I was very comfortable with, because it all sat well within my pre-existing knowledge and also presented new cases using old methods, which was exciting for me because they were cases that related the physics I had learned before to the architecture I was being exposed to now. It also was a topic that we were simultaneously covering (in less technical depth) in the History of Building Technology which Shelley teaches. My architectural world was coming full circle. The second homework was also the time at which we had our first Multiframe task, which was a little nerve-racking at first, because I sometimes experience a large learning curve with software, however constructing the truss was straight forward and gave me the ability
to check the values I calculated against the software's values. I have since learned that Revit also has a function that evaluates loads and stresses and I am interested to test it and compare it with my experience in Multiframe.

We did not abandon equilibrium at this point, but instead delved further into the topic as it pertained to rigid bodies. We started to discuss the different types of connections and the reactions they caused. This topic was integral to determining the number of unknown forces in a body and whether the body was determinate, capable of being solved, or indeterminate. The other factor that affected the determinacy of a body was whether or not it was completely constrained. If it was not completely constrained, than the body could not be in equilibrium and our equations would be useless. It was also at this point at which we defined the different types of loading that could be seen from concentrated or point loads to distributed loads that could present themselves as uniform or non-uniform, the latter of which presented in a triangular configuration or trapezoidal loading. We also learned to determine the forces in a truss by method of sections, which involved cutting a section through the members to be solved and fulfilling the equilibrium equations, the moment equation being the star player in this method. This material was covered in homework 3 along with mechanics and materials which introduced the different types of stress in conjunction with equilibrium and geometry we had seen before. Within this material we learned about the normal stresses of tension and compression, shear stress or ripping stress that acts parallel to the cross-section of a member, bearing stress which is a compressive normal stress between two bodies, and torsional stress or twisting stress which is a subcategory of shear caused by a moment around the axis. Stress and Strain were the penultimate topics covered in this homework. Since we covered stresses, this section focused on the different types of strain – normal strain which translates to a change in length, and shear strain which translates to a deformation of shape measured by the deformation angle of the sheared side. The relationship of stress to strain varies based on the materials, and when plotted describes the behaviors of these materials as elastic or plastic. Within the elastic range the slope of the stress-strain diagram is constant and is defined as E, the modulus of elasticity, and the materials in this range do not experience permanent deformation. In the plastic range the slope is not constant and materials experience permanent deformation which can lead to failure. The thing we like about steel as opposed to concrete is that even in its plastic range, steel gives warning before failure, while concrete simply fails catastrophically without warning. Thermal effects and indeterminacy conclude the topics covered in this homework by relating the fact that materials can be strained thermally as well causing them to contract with a decrease in temperature or expand in increased temperatures. It was interesting to learn here that there are no stresses related to this phenomenon when movement is free, but should there be a restraint on the material internal forces and stresses can be caused. This makes sense when we think about a piece of metal all by its lonesome out in the hot sun, it can expand and contract and there is nothing to stop it, but if that piece of metal is between two walls, it can expand outward, but not along its length. It tries to expand lengthwise anyways and because it is constrained, the walls now exert a force on the metal and an internal stress is caused.
Onward we marched from the concepts of stress and strain and into the more specific case of beam shear and bending moments. These topics would be translated into diagrams that were informed by the free body diagram and loading diagram whose only difference from the free body was that the loads had to be portrayed accurately. Shear and bending moments we would later find to be integral to the design process as limiting factors. It would also be seen through these diagrams that shear and bending were related—shear is the derivative of the bending moment, which meant that the zeroes of the shear diagram would correspond to the minimum and maximum values on the bending moment diagram. This relationship would also be shown in the geometry of the diagrams—if the shear diagram presented a sloped line, the integrated form would be a parabolic curve which could be seen in the moment diagram. We constructed these diagrams first by the equilibrium method which involved cutting the beam into sections in a seemingly endless process of determining the moments and forces at each succeeding portion of the beam. At this point the class looked glassy eyed towards you hoping and praying that there was an easier method with which to complete these diagrams, and you the delivered the holy grail unto us in the form of the semi-graphical method, which took no less room on the page, but was infinitely faster as we had simply to go length by length adding forces and loaded areas. Once this was completed we had only to determine the areas on the shear chart and plot them on the moment diagram, all the while earnestly hoping that the moment diagram would close at the end. Then (because I forgot this step more often than not) it was imperative to go back and determine the shear and moment maximums for the purposes of design. This seemed to be enough torture as it was the entirety of the fourth homework. All kidding aside, this might have proven the most important homework for what was to come in the design portion later, because of all of the important processes of analysis needed to finish the problem, and because just as we would find with design, these problems relied on everything done in the last step really emphasizing the need for an organized process of resolution. This homework utilized Multiframe in a new way, having us construct beams with a pinned and fixed connection and topped with a distributed load. I have to admit it was very exciting see the shear and moment data on my beam and have it match the diagrams I had worked so hard on. It made me feel like I might be okay at structures.

After evaluating the internal forces and moment, we took out our magnifying glasses to study centers of gravity, or centroids, and moments of inertia, the cross-sectional properties which would help us later to determine beam bending stresses and shear stresses. The cross section shape and how it resists bending and twisting are what allow us to understand beam and column behavior. The centroid is considered the center of mass of the shape. The moment of inertia is described as the capacity of an object to resist bending or buckling, defined as the summation of all the parts of the object times the squared distance from the centroid. When this information is synthesized into a problem it is mind-boggling. The process and organization aspects of beam shear and moment diagrams come back into play here with different equations and formatting. The important thing I learned about these problems is that when you know what you are looking for, the first step is to set up a table, define the shapes you will be assessing, determine your
reference origin, and create a column for each value you need to document or calculate. When computing the first moment area (Q), you need to be able to define your areas, your \( \bar{x} \) which is the distance along the x-axis from your reference origin to the centroid of the shape, and your \( \bar{y} \) which is the distance in the y direction. When looking for this area it is possible to have negative areas, which is something I had a hard time with when working the problems, mainly because I would forget the shape I was working with was a hole rather than a solid- a testament to a need to stay organized in your thought process, too! The moment of inertia is dependent on the shape of the cross section, and its equation can be found in the charts for geometric properties of areas. When determining the total moment of inertia, you need all of the previously discussed data used to fine Q as well as the moment of inertia of each of the separate shapes, \( \bar{x} \) which represents the distance in the x direction from the reference origin to the centroid of the composite shape and \( \bar{y} \). With these additional values you can get the difference of \( \bar{y} \) and \( \bar{y} \) which will be used to determine the overall moment of inertia in the y direction.

From cross-sectional properties we moved into beam stresses, which affect an area rather than a point which is why our cross sectional properties, specifically our moment of inertia is needed. The reason we need to understand stresses is because they are a primary limiting factor on our design members. Bending stress is a combination of normal stresses (compression and tension) caused by bending. Shear stress is a stress that acts parallel to the cross section it acts upon much like the shear force. The limit for shear stress is not the same as that of bending stress. Bending stress often has a greater capacity than shear; steel is the only material we have studied in which the two stress limits are similar. Assignment 5 would prove to be our first foray into the realm of design when we were asked to choose the lightest sections to fulfill the stress related problems. It proved easy enough as long as you had your charts on hand, if you didn’t have them there was really no way to complete the problem, thus carrying the book around became a fairly common occurrence.

Once we had covered beam stresses we continued on to pinned frames and arches which explored different frame configurations and how they performed when forces were applied at connection points. Instead of creating separate beam and shear diagrams, we combined them into one and it was demonstrated on the frame. These diagrams also informed the deflection of the structure. Pinned frames are considered fully constrained in most cases, and thus can be solved through the equilibrium equations. This is because those pins allow for the introduction of a new set of equilibrium equations. This concept rolls over into compound beams which are introduced at this time as well. Rigid frames are usually statically indeterminate and so must have deflection values in order to be solved, though simplified methods can be used to solve them, we used the stiffness in class to determine such a case. Assignment 6 covered these materials as well as introducing columns and buckling. Columns have an additional failure mechanism known as buckling which is determined by its slenderness ratio \((kL/r)\), modulus of elasticity \((E)\), and moment of inertia \((I)\). In short, stubby columns, a reasonably subjective identification, crushing of the column may occur before buckling. In long slender columns, it
takes much less load to incur buckling. The ‘k’ in the slenderness ratio takes into account the end conditions or connections of the column. Lateral bracing can decrease the slenderness ratio, shortening the unbraced length, and allows for increased buckling loads within a column. With most column problems the goal was to evaluate the column rather than design it at this stage in order to understand the forces.

This is the point in the semester at which if you weren’t sure you were in an architecture class quite yet, you will have surely figured it out. Assignment 7 was the point at which we began discussing building codes and standards for design. The concepts of allowable stress design (ASD) and Load and Resistance Factor Design (LRFD) were introduced as well as the combination load factors that would come to be used as a built in safety factor for design. The code not only specified types of loads (live, wind, dead, snow, etc.), it also specified durations of load (c.). Beyond the load factors, we received a plethora of charts detailing the different factors to be used for wind and snow in different parts of the U.S. It is also important to mention that the load factors are statistical expressions and the different cases should not be added together. After the introduction to building codes and standards for design, we began to assess systems rather than components, because beams and columns do not exist in isolation (unless of course it’s Trajan’s column which is thought to be purely decorative but is still structurally significant). When an architect builds, they often build foundation to roof, however when an engineer assesses the design, they begin with the roof, and this is exactly where load tracing begins. Load tracing is how loads on and end the structure are transferred through the members to the ground. This section involved a lot of technical vocabulary and getting to know the differences between girders, joists, and beams. I learned that when you are load tracing, your horizontal members experience a distributed load along their tributary area, and columns experience a point load. Another type of structure studied at this time was the retaining wall which had to resist both sliding and overturning, and experienced a distributed load that non-uniform along on of its vertical faces. It was the first and one of the only times we would solve for forces due to pressure.

Moving into assignment 8 we began the design process starting with timber. Timber is an anisotropic material which means that it behaves differently when stressed from different directions. When designing for timber there are several limit states that must be assessed, including deflections, shear stress, and bending stress, all of which are meant to account for the realities of the material. This was the first time we dealt directly with deflection which is proportional to the double integral of the bending moment, for simplification purposes common loading types have been tabulated and can be combined through the principle of superpositioning. The process of design requires one to determine the maximum shear and bending, and deflection stress to ensure that these are within allowable limits, and these values are used to find a timber section within tabulated charts. When designing timber columns similar principles apply, but a variety of load factors must be taken into account depending on the environment and type of load. At this point we had not incorporated ASD or LRFD; we were
simply working to determine the stresses and the section that would economically overcome them.

Assignment 9 continued along the grain of timber by incorporating the topic of connections which deals primarily with bearing stress and shear within the connection. The limit states for nails and bolts in relation to timber have been tabulated and are used in equations to determine the number of nails needed. In the same assignment we move into steel design which incorporates both LRFD and ASD in order to build in safety factors to the component being designed. The limit states for steel are similar to those for timber. Steel comes in different flange configurations unlike timber, and steel can clearly carry greater loads than timber. In both steel and timber it was important to choose the most economical section which is typically determined by the self-weight of the section. Once a section is chosen it is important to reevaluate the stresses with the self-weight included in order to ensure that the beam remains adequate, if it does not, than a new section must be chosen until an adequate beam is found.

After designing for steel beams, we designed for steel columns which again share many similarities with timber. Steel is more resistant to environmental conditions and there are different methods of connections such as welds and bolts which will be discussed later. If loads are applied to a column off-center the load is considered eccentric, which makes buckling more likely and additional calculations must be done to get the buckling force. This was our first homework dealing with loads that were not centered on a column. For steel web joist design we made use of standard tables detailing allowable loads based on span and flange type, we returned to our method of sections to determine member forces, using tributary width to determine the loads for load tracing.

Assignment 11 dealt with steel connections which have many limiting states: shear yielding, shear rupture, block shear rupture-the failure of a block at a beam due to shear and tension, tension yielding, tension rupture, local web buckling, and lateral torsional buckling. This is because the material and connection are of the same material and can both deform when overstressed. The strength of a weld is determined by length, type of weld, and the weld size. The available strength has been tabulated according to these specifications. Design of concrete beams is different from timber and steel because it is poor in tension and so must be reinforced with steel. Not only must the reinforced concrete be able to sustain the load, but the amount of steel reinforcement must be within certain reinforcement ration limits to prevent cracking of the beam. Since steel reinforcement is typically done using multiple bars, one must not only calculate the area of steel reinforcement required, but also number of bars, spacing and type of bar to be used.

Slabs were the next and antepenultimate topic of interest within the course. Similarly to concrete beams they require steel reinforcement in order to bear tension and to prevent cracking simply on a larger scale. Additionally certain tabulated minimum thicknesses must be followed to prevent cracking as well. Slabs and concrete beams are particularly vulnerable to shear and thus require
stirrups even when the applied shear is slightly less than the shear limit state. When slabs are supported by regularly spaced beams or columns, the greatest applied bending moment and shear must be found before proceeding with design calculations. Additionally slabs require a certain minimum area of steel to cope with temperature expansion effects which were studied with elasticity earlier.

Columns and footings were the penultimate topics of the semester. Concrete columns are also typically reinforced with steel, most notably to prevent buckling, especially when the column is undergoing a bending moment in addition to a compressive load. When we design for columns we must determine the eccentricity based on the axial load and the design moment. The type of steel reinforcement used is found using charts of eccentricity and factored axial compression load. From this we can determine the number of bars needed and type in order to discern the area which will allow us to determine the axial capacity. Footings are important because they stabilize a structure and provide the final transfer of force from the structure to the ground. Along with the other concrete design considerations, they must also take into account the maximum pressure that the soil can support, otherwise shifting and sinking can occur similar to the issues of a retaining wall.

Masonry was the last of all the topics we covered in class in which we talked about its materiality, use of ASD, and the use of steel in resisting all tensile stresses since masonry has similar properties to concrete and ceramics. We also learned that like concrete, masonry also makes use of stirrups for reinforcement and has similar requirements for flexure design. In column design, masonry has a minimum dimension it must exceed, and they must also be reinforced and have ties.

**Skills**

Though I have touched on a few of the more difficult skills in considering the concepts that were learned this semester, I will try to clarify the main ones here. The ability to draw a free body diagram and manipulate the three equations of equilibrium was integral to a large percentage of the material we covered, whether it was resolving vectors and forces, determining member forces in trusses, constructing shear and moment diagrams or evaluating the moment and shear of pinned frames, all required you to identify the body the force(s) were acting upon, the type of supports being used, reactions and where they were occurring, as well as adding any known forces and their directions which identified whether they were tensile or compressive. Once all the known and unknown forces were pictured, the equilibrium equations had to be constructed summing the knowns and unknowns for the x and y direction and for the moments. All three of these equations had to balance or equal zero in order to maintain equilibrium. Free body diagrams had the added benefit of allowing you to consolidate distributed loads uniform or non-uniform into point loads by dividing them by the beam length, once we began load diagrams the loads had to remain in their original format to determine shear and bending. Shear could be found by taking the initial loads and going section by section across the beam adding area loads.
and point loads. These values were plotted graphically and the area under the curve determined
the values for the moment diagram with the zeroes of the shear diagram corresponding to the
maximums and minimums of the moment diagram. Trusses analysis was another important skill
which required use of the free body diagram and equilibrium equations, but instead of solving for
unknown forces along a beam, they were used to determine the member forces of individual
pieces of a truss and whether they were tensile or compressive. The truss would first be prepared
by cutting a section through the members to be resolved and then the equilibrium equations
employed. Cross sectional areas had to be analyzed graphically by first choosing a reference
origin and then measuring the x and y values as well as the values from the neutral axes. It also
involved being able to use charts and tables to determine the equations for the moment of inertia,
and understand the way in which the information was being presented, in some cases the I, x,
and y values had to be flipped because the geometry had been rotated. For shear and bending
stresses in beams, one had to be able to identify the equations dealing with shear and those
relating to the bending moment. With pinned frames it was a refresher once more of the
equations of equilibrium; however the aspect of being pinned allowed us to double our set of
equations in order to solve for the greater number of unknowns. We would use this again for
compound beams. Additionally pinned frames introduced a new method of constructing shear
and bending diagrams and also featured a deflection diagram that was informed by the other two.
When we began evaluating columns the slenderness ratio was critical to success, defined by the
effective length over the radius, the slenderness ratio is known more commonly as kL/r,
describing the end conditions, and unbraced length divided by the radius. Knowing this would
allow us later to determine the strong and weak axes of a column and figure out which direction
was more likely to buckle first and whether this direction could sustain specific loads in
comparison to its maximum buckling values. After columns, we enter into the territory of design
which requires that we define our shear and moment limits, and not exceed them based on our
section of choice. Once the section is chosen, the weight of the beam must be factored and added
per LRFD to determine whether the shear and moment are still adequate, and if it isn’t then the
process begins again. We see the same cycle repeat if the deflection is not within limits. For
cracking our main limiting factor could be seen in our area of reinforcing steel which could not
be too little or the concrete would be under reinforced, but could not be over reinforced or it
would lead to cracking. It was also important to make sure we reinforced against shear with
stirrup design, determining an adequate spacing as well.

**Problem Solving Abilities**

I have always felt capable mathematically in structures, but it changed the way in which I
approach problems significantly simply in the fact that when I approach a problem now I try to
be as physically organized with information as possible as well as mentally organized, working
to create a detailed story in my head about what is happening in the problem, what step comes
next and why it is that particular step that comes next. I had to learn to do this because structures
problems are extremely information dense and if I was not careful, I would quickly confuse
myself with concepts I had no problem with minutes before. The practice problems proved helpful in enforcing this methodology because I had a step-by-step system I could use for almost every type of problem. Another large obstacle which will be discussed in learning abilities and illustrative documentation was multiple choice. I had a very hard time wrapping my head around conceptual questions and so in order to work through this, I have learned to break down the questions and then the answers in order to make sure that I have given myself the best chance at the correct answer possible.

Learning Abilities

Though it was not a problem for me on the homework, I am horrendously slow when taking quizzes. When I sit down to do homework, I give myself several hours to prepare the problems, read through the notes, set up my steps and then complete the work. I do not have this luxury during quizzes and it was ultimately my downfall towards the end of the semester as the concepts became more complex and the processes became more involved. I have found myself doing trial runs with clean quizzes to try to help me prepare for the final because of this difficulty. I have also found that group work is extremely distracting for me when it comes to topics such as these. My preferred method of learning is to give myself time in isolation to complete what I can, bring questions to my tutor, and then bring completed homework to group study sessions so that if there is anything I have missed I am able to fix it or understand a concept that still is not clear. Both of these issues stem from one particular problem which has been diagnosed as mild attention deficit disorder, which means that group settings are essentially chaos for me and are almost always unproductive. This also made the cardboard couch project difficult. When I am by myself, though I may become distracted, there are far fewer distractions which allow me to focus on the task at hand. I also found that when I really didn’t understand something I was reading or doing, more often than not there was a YouTube video that explained the process or concept perfectly.

Illustrative Documentation

I chose to present a few items in this section that I think represent concepts I fell short on and the ways in which I sought to fix it. The first of which was my worst quiz- a quiz in which I rushed and made stupid concept errors, but somehow, despite rushing, still did not finish and wound up missing out on half the points on the quiz which also happened to be the easiest points.

At this point there is a detailed narrative (story) of what was done and what was thought about when the concepts were not applied properly, with absolutely NO mention of making "mistakes" by putting down the "wrong number".

The reasons for putting down "wrong numbers" (such as copying what was done on the practice quiz, instead of thinking about where the number should be obtained from) are stated.
POOR QUIZ AS GRADED
with annotations
and notes
highlighting issues
At this point there is a detailed narrative (story) of what to do, why it was done, and how they knew why to do it.

There are NO statements such as "I put a 5 here and a 2 here and left out a 6 here...." and then produce a correct answer. The reworking HAS to direct the reader through the process for credit; not just show them the work.

Any presentation of work without a narrative will not be read and will NOT get any credit.
REWORKED QUIZ
with annotations
and notes
highlighting the
understanding of
the issues
Conclusion

This class proved extremely challenging conceptually and I understand to a certain extent the seniors that try to console those who are just beginning, but I think that structures has strengthened me in many ways. I can now calmly look into the eyes of a design problem and work my way methodically through it. I am able to correctly identify different types of stresses. I understand the big picture, now, in a way I did not when I first began, and for these things I am a stronger student and hopefully a stronger designer.