Concrete Training Aids in the Classroom
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Abstract – This article provides an overview of recently developed training aids and classroom demonstrations used in design of reinforced concrete and masonry structures organized by overarching concepts of flexural and shear design and general masonry design. Teaching a senior level design course to young engineers can be a daunting task at times. You stand at the border where principle meets practice. It is an exciting and challenging time for the students as they take the knowledge they have gained from previous courses and your current instruction and start to create solutions that can be made into reality. Engineering students need three dimensional representations so they can see and touch what we are teaching to facilitate their understanding of these new concepts. We always try to represent these concepts in 2-D drawings on our blackboards but supplementing those with physical models is essential to bring these principles into the reality of practice.

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INTRODUCTION
Teaching a senior level design course to young engineers can be a daunting task at times. As their instructor, you stand at the border where principle meets practice. It is an exciting and challenging time for the students as they take the knowledge they have gained from previous courses and your current instruction and start to create solutions that can be made into reality. I almost get giddy when I tell them during one class on flexural design that by the end they will have designed a reinforced concrete beam that could be actually made and perform as designed. I announce how they will be joining the long line of engineers that have come before them that have taken their knowledge of engineering and material mechanics and created a physical solution to a real world problem.

Together we develop a Reinforced Concrete (RC) beam based on American Concrete Institute (ACI) strength design during which we determine everything from gross cross sectional area, rebar sizing and spacing and effective depth. In the end, there lies their first reinforced concrete design in calligraphic splendor across a series of chalk boards with design details and sketches in color coordinated two dimensions. This is wonderful but we cannot stop there because engineers create physical solutions to real world problems; therefore, engineering students need physical models of their design principles and solutions.

To be effective instructors, we need to present our concepts across a broad front to our students so they can receive the information through many different avenues but at the same time capitalize on those avenues which have the highest traffic capacity. I regularly have my students take a learning style inventory originally presented by R.M. Felder and L.K. Silverman1. From these surveys, I find the vast majority of my students are visual learners. They learn best when they can see what is being described with their mind’s eye. We always try to represent these concepts in 2-D drawings on our blackboards but supplementing those with physical models is essential to bringing these principles into the reality of practice. Suddenly the students have a three dimensional representation of what we have been discussing to see and touch which helps them wrap their mind around these new concepts.
A great example of this is a set of training aids which have been used for a long time in our and many other programs; the foam bendy beam and reinforced and unreinforced mortar beams. The foam bendy beam is simply a foam block marked with a neutral axis and a series of transverse planes but the power it holds to help convey the ACI design assumptions is invaluable. The students can see planes sections remaining plane, the compressive and tensile region as delineated by the decreasing or increasing distance between the transverse planes.

Pictured 1 - Reinforced Mortar Beam Being Loaded to Tensile Failure

This is a great start but following it up with a demonstration on the behavior of unreinforced and reinforced mortar beams drives it home for the students as they observe the deflection and increase in performance just by adding reinforcing steel to the tensile region. This is normally demonstrated by the instructor adding themselves to the point load on the reinforced beam to (hopefully) induce a nice plastic tensile failure.

This last bit of showmanship brings up the other important attribute of training aids in the classroom: they are fun! If you always try to integrate a physical model into class (where appropriate) in a fun way, when your students walk into the room and see something sitting on the front desk, they will already be wondering how you are going to use it. You have already got them engaged and the class has not even started! This also helps to remind them how fun engineering actually is despite the workload they are currently enduring in an effort to join our ranks. It a running joke in my course that engineers are people that never wanted to stop playing in the sandbox with their blocks; therefore, they just found bigger sandboxes and blocks.

With this in mind, I have attempted to integrate a series of new training aids over the last two semesters to help with some of the more tricky concepts and principles. The following is an overview of each organized by overarching concepts of flexural and shears design for reinforced concrete and general masonry design.
TRAINING AID EXAMPLES
FLEXURAL DESIGN

RC Beam Cake

How do we relate the importance of cover and spacing around the reinforcing steel we are teaching our students to design when they have had minimal experience with interacting and observing the performance of RC structural elements? I found the best way has been to develop an analogy with materials with which that have had experience and enjoy namely cake and cookies. Quite simply you make a cake with longitudinal reinforcement made of out of cookie straws and sugar wafer high chairs. Depending on the height of your cake pans you may have to create the cake in two layers which gives an excellent opportunity to incorporate an easily identifiable neutral axis which the students can relate to the strain diagrams they have been developing in their notes. This semester we actually made the cakes using standard (and clean) Modulus of Rupture beam molds.

There is an enormous number of teaching opportunities with this training aid! The class starts out with an impromptu celebration of the birthday of reinforced concrete (Joseph Moniers’ 1849 patent) relating the history of the world’s most ubiquitous construction materials to the students. Next comes the fun of serving the first slice and denoting that it is in fact a reinforced cake! While the cake is being served, I relate an apocryphal tale of the failed iterations of the cake which came before the one they are currently consuming. I discuss how the first attempt had the cookie rebar too close together resulting in congestion of the cake batter above ruining the cakes bottom. We discuss how the next iteration had the bars spaced too far apart resulting in vertical cracking between the cookie straws. This brings us to the successful product which they enjoying in class.

During this discussion we cover subjects ranging from the protective qualities of required cover, the limitation of spacing due to the maximum size of aggregate, the tendency of beams with reinforcement spaced too far apart to act as independent beams and it’s a piece of cake really! The whole time the students are engaged, having fun, learning and getting fed.

Pictured 2 - RC Beam Cake Production & Use
One-Way Slab Model

When teaching the design of one-way slabs it is always critical to start with a description about how the slab loads travel perpendicular to the beams which support it; therefore, we design the flexural reinforcement in the slab perpendicular to the beams as well. In more engaged classes, a student may ask what about the loads traveling near the girders at the ends of the slab sections. Of course there is a small amount of load traveling in that direction but when compared to the magnitude of the forces flowing towards the beams it's negligible. I created a simple model of a one way slab ensuring the dimension met the critical criteria of the ratio of the long to short side being greater than or equal to two. For the beams and girders, I used a simple cross stitch frame available at any craft store covered with 1 inch polyfoam. After making the slab, I then drew a grid on the top so while in class I could apply a load anywhere on the slab and the students could observe the magnitude of the flexural deformation in both directions.

Pictured 3 - One Way Slab model

Slab on Grade Model

Slab on grade design hinges on determining an appropriate thickness of slab based on the modulus of sub-grade reaction of the soil, the loading conditions, and the modulus of rupture of the selected concrete mix. It can be difficult for students to put together how these three variables contribute to the performance of the slab. One of the best models I have found to work through this with my students is a large pad of memory foam. We start off with a review of the modulus of sub-grade reaction by applying a unit load to the pad and seeing the resulting depression in the “soil.” Next we discuss how by emplacing a slab on grade, we can distribute the load over a larger effective area and reduce the resulting depression while at the same time make a durable surface. So now we need to find something to act as a slab on grade with comparable compressive and tensile behavior qualities as concrete. At this point, I look up at the ceiling tiles as if having an epiphany and proceed to pull one down to use as our adhoc slab on grade and loading it to subsequent flexural failure. We then proceed to pull more panels down to test failure conditions under rack and post loading and bulk loading. This sudden display of wanton destruction keeps the students happily engaged as we explore the combined effects of material properties and load effects (note all ceiling panels used in this demonstration were already scheduled for replacement).
Post-Tensioning Bungee Model

Trying to provide an overview of pre-stressed concretes benefits and behavior to individuals that are just getting comfortable with the mechanics of regular reinforced beams can sometime be tricky. Multiple new concepts are thrown into the mix such as the effects of a different grade of steel used for pre-stressing tendon, the stages of pre-stressing during construction and decompression when placed under service loads. To help with this, I took a foam beam with alternating cuts along the top and bottom. Typically this model has been developed and used at multiple institutions to describe flexural similar to the foam bendy beam discussed in the introduction. By routing a channel along the tension face, this enables you to install a bungee cord to act as a post-tensioning tendon. The beam assumes a pre-stressed camber and you can then load the beam to service conditions to reach the decompression state and even possibly overload (just watch out for the bungee cord!).

Truss Analogy Model

Relating the mechanisms that cause shear cracking and the necessity for stirrup reinforcement consistently seems to be a difficult subject for my students to grasp. We always begin going back to Mohr’s circle looking at stress blocks above and below the neutral axis and closer and far away from the support. As we investigate, we track the principal compressive stress trajectories on our RC beam and the shear cracking pattern becomes apparent. We begin to discuss how the RC beam is starting to act as a truss with compression struts and tension ties. Some students are starting to see it in their mind’s eye but most still need more convincing.

To help, we use a simple model of a beam made out of a 2” X 6” piece of lumber. First, the beam has a track routed along one end to allow installation of longitudinal reinforcement. Then principle compressive stress trajectories are marked and cut out with a band saw. The beam is then
reassembled with simple hinges and a bungee cord is used as the longitudinal reinforcement (see post tensioning model). Now when the beam is placed into flexure, the compressive struts produced due to shear cracking try to push the longitudinal reinforcement out of the bottom. After displaying this phenomenon the question is asked how we can stop this from happening. At this point, the truss analogy used early in the class becomes apparent and I then overlay a truss model using a popular construction toy. This also gives us a chance to discuss why we normally place shear stirrups vertically as opposed to perpendicular to the shear cracking. I rather enjoy the looks of enlightenment that occur at this point in the class.

Footing Model Sand Box

The design of spread footers is always a fun point during our course because of the linkages we can make with the concepts they learned during their soil mechanics and foundation design courses. This is a point where we really want them to see the ground – structure interaction as both materials react to the load they are trying to support. It is easy to see the footing react but what about the soil? To give both equal billing in this demonstration a sandbox with windows on two sides was constructed and then filled with layers of alternating colors of sand (we used our school colors of black, grey and gold). Scaled footing models were constructed with mortar and scaled flexural reinforcement and dowels. The entire set-up could then be placed in a large scale universal testing machine and an axial load applied to the column until the footing fails.

Depending on the construction of the scaled footing model, a flexural or shear failure can be induced during loading. The great part of this is while the loading is occurring the reaction of the soil can be observed through the shifting of the alternating sand layers behind the windows. There are numerous opportunities during these demonstrations for discovery and discussion especially at the point one-way or two-way shear failure occurs. With the sudden loss of bearing surface, the
students can observe the increase in rate of vertical depression as the load exceeds the bearing capacity of the layered sands. While inducing a two-shear failure the students get to see how the footing thickness, column size and concrete strength cause it to perform differently than during a one-way shear failure which they are familiar with from the classes on beam design and helps them see the reason behind establishing a two-way shear perimeter a pseudo critical distance of d/2 from the column faces.6

![Footage of the Footing Sandbox models](image)

**Pictured 7 - Footing Sandbox models**

**MASONRY DESIGN**

During our instruction on strength design of reinforced masonry, we begin with the analysis and design of lintels. This is always a great starting point because of the corollaries we can draw between reinforced masonry and reinforced concrete. In essence, a lintel is simply a reinforced concrete beam which the students have had numerous exposures analyzing and designing. The aspect they do not have much exposure to in a formal setting is the concept of arch action and how it can reduce the required distributed load we need to design the lintel to be able to sustain.7 To start, we talk about the structural concept of a corbelled arch, its historical examples and how most of them have built them as kids while playing with blocks. This brings us to our physical model which using the requirements for arch action we identify the outline of hidden corbelled arch and proceed to remove extraneous blocks while maintaining a stable arch. The model can be continued to be modified such as removing lateral support allowing the arch to fail due to thrust action.
SUMMARY & CONCLUSION

I hope those that find themselves in teaching roles in design and construction of reinforced concrete and masonry structures find these ideas for training aids and demonstrations helpful as they guide future engineers to create solutions in the most ubiquitous construction material of the last two centuries. Those interested in plans and specifications of any model presented can send request to me at cullen.jones@usma.edu.

REFERENCES

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