

Concrete Training Aids in the Classroom

MAJ Cullen A. Jones, P.E.¹

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. The teacher and students 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 their instructors are teaching to facilitate their understanding of these new concepts. Instructors always try to represent these concepts in 2-D drawings on their blackboards but supplementing those with physical models is essential to bring these principles into the reality of practice.

KEYWORDS: ENGINEERING EDUCATION, REINFORCED CONCRETE, TRAINING AIDS, CLASSROOM DEMONSTRATIONS

INTRODUCTION

Standing at the border where principle meets practice, teaching a senior level design course can be a daunting task. But it is also an exciting and challenging time for the instructor and the students as they take the knowledge gained from previous courses and start to create realistic solutions. To be effective, instructors need to present their concepts across a broad front so students can receive the information through many different avenues. Because of this, students in some programs take a learning style inventory, a system originally presented by R.M. Felder and L.K. Silverman [2]. From these evaluations, the vast majority of engineering students are visual learners—they learn best when they can see with their mind's eye what is being described in a lecture.

Instructors should always try to represent concepts in 2-D drawings during their lectures, but experience has shown that supplementing drawings with physical models is essential. Because students can see and touch three dimensional representations of what the class has been discussing, they can more readily wrap their minds around new ideas.

For a long time, many schools have included foam “bendy” beams in their instructional programs. Although the bendy beam is simply a foam block marked with a neutral axis and a series of transverse planes, it is an invaluable tool for conveying design assumptions because it allows students to see that plane sections remain plane as the compressive zone shortens and the tension zone lengthens. This is a great start, but following it up with physical demonstrations of the behaviors of unreinforced and reinforced mortar beams drives it home for the students as they observe the increase in performance gained by simply adding reinforcing steel to the tensile region. A bit of showmanship (Fig. 1) helps bring other important training aids into the classroom: fun and excitement.

Keeping these aids in mind, a series of new training aids have been integrated into lessons at the United States Military Academy, focusing on some of the more tricky concepts and principles. The following is an overview of these teaching tools implemented over the past two semesters, focusing on reinforced concrete and masonry design.

¹ Instructor, Department of Civil & Mechanical Engineering, United States Military Academy, 752 Thayer Road, Mahan Hall, RM330, West Point, NY 10996-1792, cullen.jones@usma.edu

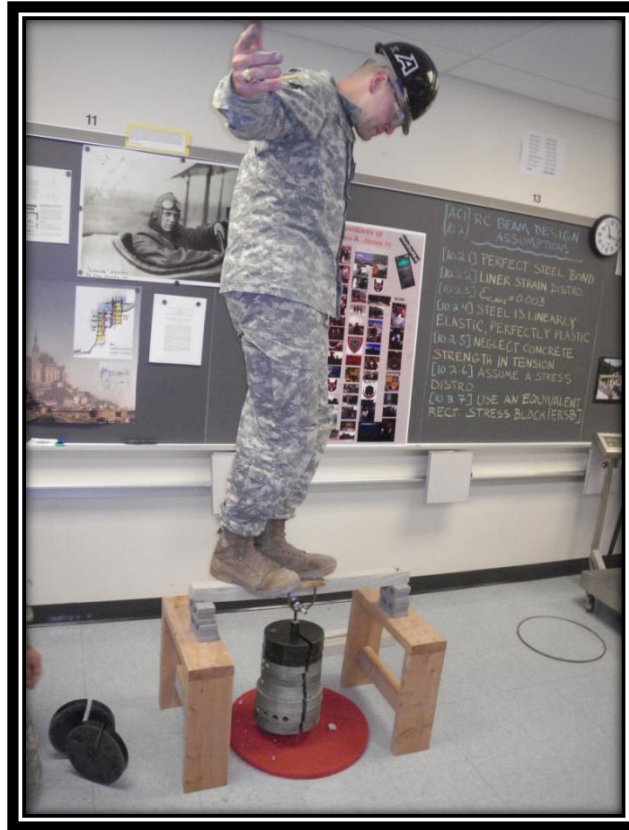


Fig. 1: The instructor provides a real live load on a reinforced mortar beam, adding excitement to the lecture

Reinforced “Concrete” Beam Model

When teaching students with minimal familiarity of the performance of reinforced concrete structural elements, what’s a good way to relate the importance of cover and spacing around the reinforcing bars? Experience has shown, the best way is using a structural analog constructed of materials the students know well and love—cake and cookies. The cake represents the concrete, and the cookies (cookie straws) represent the longitudinal reinforcing bars. To complete the tasty construction, the “bars” are supported on sugar wafer high chairs (Fig. 2). Depending on the height of the pan, the cake may need to be baked in two layers, but that’s a bonus—it provides an excellent opportunity to incorporate an easily identifiable neutral axis and, depending on the quality of the frosting between the layers, it can show the importance of shear transfer between layers.

But there are even more teaching opportunities with this training aid! This semester, cakes were baked using standard (and clean) molds for modulus of rupture test beams, giving the students a look at a real form. The day the cakes are served starts out with an impromptu celebration of the birthdays of reinforced concrete by Joseph Lambot who invented reinforced concrete in 1848 to build a boat used on the Lac du Bourget, and Joseph Monier who rediscovered the technique to build the plant tubs in the Orangery of Versailles in 1869 along with an overview of the history of the world’s most ubiquitous construction material.

While the cake is being served, an apocryphal tale is related of the failed cakes that came before the one the students are currently consuming. It is discussed how the first attempts had the cookie bars too close together, resulting in congestion of the cake batter above the reinforcement and leaving unsightly voids in the cake bottom. It is then pointed out that later iterations had the bars spaced too far apart, resulting in vertical cracking between the cookie straws. That tale ends with the successful and enjoyable end product. The discussions range from the protective qualities of required cover, the limitation on spacing imposed by the size of aggregate (What if the cake batter include nuts?), and the tendency of beams with widely spaced bars to act as independent beams [1]. The whole time the students are engaged, having fun, getting fed, and learning.



Fig. 2: The production of (and a look inside) a reinforced cake beam

One-way slab Model

When teaching design of one-way slabs, it's critical to start with a discussion of load paths. The students need to understand that load travels perpendicular to the support beams, so the slab's flexural reinforcement also runs normal to the beams [5]. In more engaged classes, a student may ask what about the load paths near the girders at the ends of the slab sections. Of course, there is a small amount of load traveling in that direction, but it's nice to have a model that demonstrates that most of the load goes to the beams.

A simple model can be created of a one-way slab panel with an aspect ratio of at least two. The beams and girders are represented by a simple cross stitch frame (available at any craft store) covered with a 1 in. layer of soft polyurethane foam. A grid is drawn on the top of the slab, so the students can observe the flexural deformation (and curvatures in each direction) caused by a load applied anywhere on the slab (Fig. 3).



Fig. 3: A model of a one-way slab. The grid helps students visualize the large difference in the transverse and longitudinal curvatures

Slab-on-Ground Model

Slab-on-ground design hinges on determining an appropriate thickness of a slab, based on the modulus of subgrade reaction of the soil, the loading conditions, and the modulus of rupture of the selected concrete mixture [4]. It can be difficult for students to put together how these three variables contribute to the performance of the slab, but success can be found in using a large pad of memory foam as a model. The lecture starts with a review of the modulus of subgrade reaction from soil mechanics. The application of a unit load (bricks) to the pad allows the students to see the resulting local depression in the “soil.” The discussion can then move to the effect of a slab between the load and the soil. The “slab” can be a piece of acoustic ceiling tile. Because the tile distributes the load over a larger effective area of the memory foam soil, the depression is demonstrably reduced. But the tile also demonstrates what can happen if the concrete is overloaded. After the load is increased sufficiently to induce flexural failure (Fig. 4), other panels can be used to compare failure behaviors under point loads (for example, at the posts of warehouse storage racks) and under bulk or distributed loading on pallets. This display of wanton destruction keeps the students happily engaged as the class explores the combined effects of material properties and load effects. Just one note: The destruction should not be indiscriminate—all ceiling panels used in previous demonstrations had been scheduled for replacement.



Fig. 4: A foam model provides demonstrations of the benefits (and failure modes) for a slab-on-ground

Post-tensioning Model

Working with students that are just getting comfortable with the mechanics of regular reinforced beams, it can be a bit tricky to provide an overview of the benefits and behaviors of pre-stressed concrete. But a simple model can help. New concepts, including the effects of the prestressing steel grade, stressing stages during construction, and decompression under service loads, can be demonstrated using a small beam model. As many other instructors in the world, this model starts with the use of a rigid extruded polystyrene foam beam with alternating cuts along the top and bottom (Fig. 5). By routing a channel along the tension face, it is possible to install a bungee cord along the length of the beam to act as a post-tensioning tendon. The bungee can be clamped at different levels of tension, demonstrating the need for high strain in the tendons (and showing why high strength steel is needed). The bungee cord forces the beam to camber. Service loading forces the beam into the decompression state. It is also possible to overload the beam, so watch out for the bungee cord and falling weight.

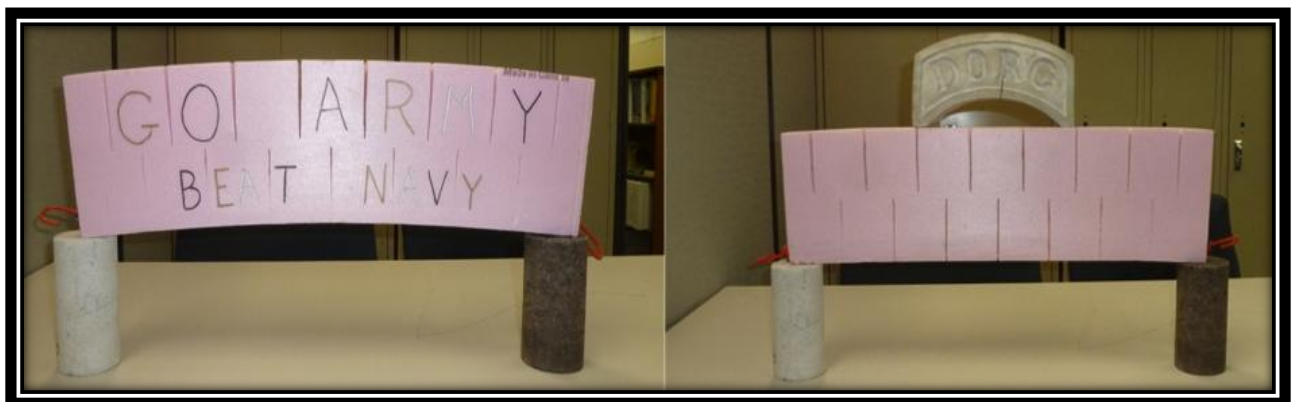


Fig. 5: A foam beam with a bungee cord tendon demonstrates camber and decompression under service loads

Truss analogy model

Shear cracking behavior and the necessity for stirrup reinforcement tend to be difficult topics for undergraduate students to grasp. A typical lecture begins with a review of Mohr's circle and an examination of stress blocks above and below the neutral axis, near to and distant from the support. As the investigation continues, the instructor and students can track the principal compressive stress trajectories on a drawing of a reinforced concrete beam, and soon the shear cracking pattern becomes apparent. The discussion can continue, again using drawings, on how a reinforced concrete beam can be modeled as a truss with compression struts and tension ties [1]. At this stage, a good student will start to see the concepts in his or her mind's eye, but many others will need more evidence. To help, a simple model of a beam made out of a 2x6 in. piece of lumber can be used.

As seen in Fig. 6, the beam comprises multiple pieces. After routing a groove along one edge (for future installation of longitudinal reinforcement), a band saw can be used to cut the beam along the compressive stress trajectories (mimicking the drawing based on stress block analyses). The beam components are assembled with simple hinges as top compression fibers and a bungee cord as the longitudinal reinforcement. 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 of the beam. After displaying this phenomenon, the simple question can be asked: "How can we stop this from happening?" The truss analogy (discussed earlier in the lecture) now comes into play as the instructor overlays the beam with a truss model made using components from a popular construction toy kit. This also gives students a chance to discuss why shear stirrups are typically placed vertically rather than perpendicular to the shear cracking.

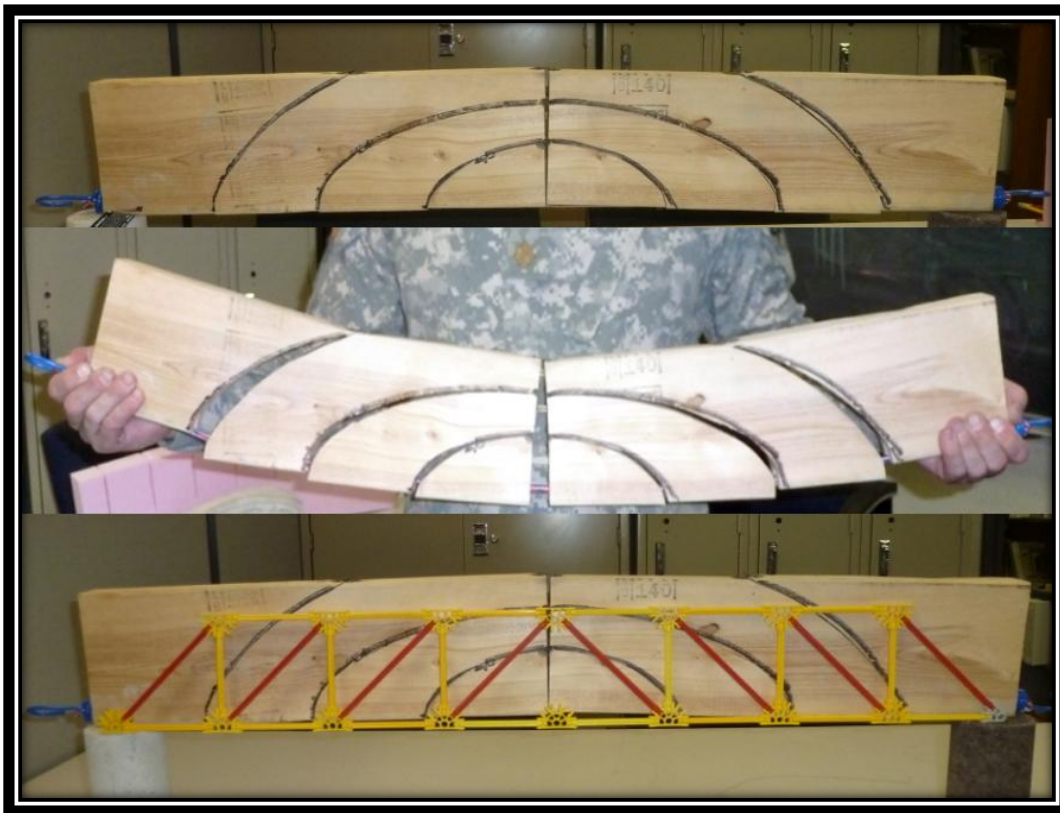


Fig. 6: A piece of dimension lumber can be used to demonstrate the truss analogy for shear design

Spread Footing Model

Spread footing design is always a fun topic because it links reinforced concrete design to the concepts students learned during their soil mechanics and foundation design courses. This is the point in their education where instructors should really want the students to recognize the importance of soil-structure interaction as both materials react to loads. It is easy to see the footing react, but what about the soil?

To give both materials equal billing in the demonstration, the soil can be modeled using a sandbox with 1 in heavy glass windows (4 x 1/4" panes of hardened annealed glass) on two sides. The box is filled with alternating colors of sand (such as USMA's school colors of black, grey and gold). Footing-column models are also fabricated using mortar as the concrete and wires as the flexural reinforcement and vertical dowels. To demonstrate soil-structure interaction, the sandbox and a footing-column model are placed in a universal testing machine and an axial load is applied to the column until the footing fails (Fig. 7).

Depending on the construction of the footing model, a flexural, one-way shear, or two-way shear failure can be induced during loading. But the great part about this model is that it allows the students to observe the reaction of the soil through the shifting of the alternating sand layers behind the windows. There are numerous opportunities during these demonstrations for discovery and discussion, especially at failure of the footing. With the sudden loss of bearing surface, the students observe the rapid increase in the rate of vertical depression as the load exceeds the bearing capacity of the layered sands.

A two-way shear failure helps the students see how the failure is dependent on footing thickness, column size, and concrete strength, and it demonstrates that a two-way shear failure is different than the one-way shear failure that they are familiar with from their lectures on beam design. The demonstration even validates the concept of the critical perimeter distance of $d/2$ from the column faces [1].



Fig. 7: A sandbox and universal testing machine can be used to demonstrate soil-structure interaction and failure modes of reinforced concrete footings

Masonry Lintel Model

Instruction on strength design of reinforced masonry begins with lintels. Lintel analysis and design are great starting points because students can readily see the correlation between reinforced masonry and reinforced concrete. They soon realize that, in essence, a lintel is simply a reinforced concrete beam—something they have had numerous opportunities to analyze and design. There is one aspect, however, that they probably haven't seen in a formal setting: the concept of arch action and how it can be used to reduce the distributed load required in the design of the lintel [3].

That is where a model, a stack of dimension lumber blocks, comes into play. To start, the class can talk about the structural concept of a corbelled arch, its historical examples, and how most of the students have probably built them when they were toddlers. They can then identify the outline of a corbelled arch on the model, and then proceed to

remove extraneous blocks while maintaining a stable arch (see Fig. 8). The model can continued to be modify by removing lateral support (concrete blocks) and allowing the arch to fail due to thrust action.



Fig. 8: A simple wall constructed of wood blocks provides a model of a masonry lintel and arch action

Summary

Hopefully, readers engaged in teaching 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, it's important that instructors get the points across to the broadest audience possible. Those interested in plans and specifications of any model presented here can send requests to cullen.jones@usma.edu.

References

- [1] ACI Committee 318, "Building Code Requirements for Structural Concrete and Commentary (ACI 318M-11)," American Concrete Institute, Farmington Hills, MI, 2011, 503 pp.
- [2] Felder, R.M., and L.K Silverman, "Learning and Teaching Styles in Engineering Education," *Engineering Education*, V. 78, No. 7, Apr. 1988, pg. 674-681.
- [3] National Concrete Masonry Association, "Allowable Stress Design of Concrete Masonry Lintels," *TEK 17-1B*, Herndon, VA, 2001, 4 pp.
- [4] Tarr, S. M., and Farny, J. A., *Concrete Floors on Ground*, EB075, fourth edition, Portland Cement Association, Skokie, IL, 2008, pg. 47-90.
- [5] Wight, James K. & James G. MacGregor, *Reinforced Concrete: Mechanics & Design, fifth Edition*, Pearson Prentice Hall, 2009, pg. 218-221.

Cullen A. Jones

Cullen A. Jones is a Major in the U.S. Army and an Instructor of Civil Engineering at the United States Military Academy at West Point, NY. He is the director for Design of Reinforced Concrete & Masonry Structures and also teaches Protective Design, Engineering Mechanics and Design, and the Civil Engineering Capstone Course. He has a BS in Civil Engineering from the United States Military Academy, an SM in Civil and Environmental Engineering from the Massachusetts Institute of Technology and is a professional engineer in Delaware. He is the faculty advisor for United States Military Academy's ASCE & ACI Student Chapters.