The DORC* Factor: Engaging Students in Reinforced Concrete Design

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Abstract

To better engage upper-level undergraduate students, a beam design and testing class project and case studies are used in the reinforced concrete design course at the University of Wisconsin–Platteville (UWP). Details are furnished on how the project and case studies are used including time and resource constraints, variations of the project to meet different instructional goals, assessment of student motivation for the project, and bibliographical information for the case studies. The project and case studies engage students through creativity, competition, and real-world application of engineering principles while meeting instructional goals such as increasing student communication skills and awareness of current engineering issues, discussing engineering ethics, and accentuating the need for life-long learning.

Introduction

The properties of reinforced concrete can make the study of its behavior complex and overwhelming even for upper-level undergraduate students. Most of the emphasis in a first course of reinforced concrete design is on mechanical theory and calculation techniques. Many aspects of the field can be lost when the focus of the class plays so heavily on the analytical aspects of the topic and students can lose their motivation under the onslaught of applied theory and math. Overcoming these difficulties is particularly important at UWP because reinforced concrete design is required of *all* civil engineering students, not just those with an emphasis in structural engineering. Students who are not planning an emphasis in structures may not grasp the worth of the class to their future careers.

To better engage the students at UWP, the reinforced concrete design course includes a design competition in conjunction with the construction of a sample beam that is tested in the structures lab. Additionally, lectures on case studies are used to show students applications and issues of actual concrete structures. These exercises satisfy key educational goals. The beam design competition with subsequent fabrication and testing allows the students to see how the subjects they learn in class translate to practice in a hands-on approach. The case studies build a broader awareness of their field and introduce ethical issues into the class discussion.

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* Designer of reinforced concrete.

Overview of the Beam Design Competition and Testing Project

Over the course of the semester, students design and test a concrete beam. To accomplish the project, the class is divided into teams of three or four students. Each team accomplishes different aspects of the project: design of the beam or concrete mix, construction, instrumentation, or testing of the beam. Some aspects of the project (explained in more detail below) are set up as a competition between teams. A copy of the project assignment is provided in the Appendix.

The project targets several goals. Students in the competitive design and concrete groups must deal with aspects of economy, practicality, material availability, and constructability. For students in the construction, instrumentation, and testing groups, it provides hands on experience for many of the students. All students must make presentations to the class and complete a written report, tasks targeted at building communication skills.

Project Details

For the beam design competition, several student design teams produce a design for the beam based on given loading and a few geometric considerations. The design teams are allowed a wide range of options in their design: they select the concrete strength and can specify a rectangular or non-rectangular section of any dimensions so long as those dimensions fit within a given set of limits (the maximum size of the lab's set of forms). The students must be creative because their goal is to sell their design in a presentation to the class. The class picks a winning design. The instructor may choose to reward the winning design team with additional grade points as an incentive to be innovative.

Once the winning beam design has been chosen, attention shifts to the design of the concrete mix to attain the 28-day compressive strength, f_c', specified by the beam design team. Student concrete teams design concrete mixes to meet the design strength. The concrete teams prepare cylinders using their mix design and test the strength at 28 days. The groups present the results to the class. Again, the concrete design groups are involved in a competitive process to sell the engineering work they have completed. The class chooses the best mix design based on adequate design strength and cost.

The construction team uses the winning concrete mix to fabricate the beam (Figure 1). When the beam is ready for testing, the instrumentation team applies strain gages and works with the testing team to apply loads to the beam while measuring the strain and deflection (Figure 2). The construction, instrumentation, and testing teams then present the results of their work to the class. The final presentations from these groups seek to match practice with theory. In particular they compare predicted deflection and "cracking" load to the actual results from the beam.

Students within the class can choose the groups they would like to work on. This past semester, the group responsible for construction of the beam filled up most quickly. Students who joined the construction team generally had a construction emphasis and were interested in the hands-on experience aspect of the project. Second most popular were the design groups (because they finished most quickly in the semester). Students planning on continuing to graduate school generally favor the instrumentation and testing teams. The experimental aspects of the work these teams perform gives students some valuable experience for experimental work in the future.

Figure 1 Casting the beam.

Figure 2 Testing the beam.

Variations on a Theme

The beam design competition and testing project lends itself easily to many variations emphasizing different aspects of the design process. In recent semesters we have emphasized the growing international competition facing design engineers and the need to design structures with a mind to locally-available supplies and material.

"Off-shoring" of technical work has become a hot political topic in the United States. Competing with foreign design companies, often staffed by people with excellent technical abilities in countries where the cost of living is a fraction of the U.S., will become increasingly important for graduating U.S. engineering students. In a recent semester, the beam design competition and testing project was modified to illustrate this issue and help the students think about how to sell themselves in an increasingly global market for engineering services. To highlight the off-shoring issue in the project, the design teams were given the following directions:

> "It has come to your attention that the owner is considering hiring a foreign design firm because the firm can perform the work for a much lower fee. In your presentation/report discuss why the owner should choose your design firm over the foreign firm."

The design teams identified the fact that they are a local company with easier access to the client and communication issues as reasons to choose their company over the foreign competition.

In another recent semester, project supplies and material availability were emphasized. The instructions to the design teams specified that the availability of local materials should be investigated. Platteville is a small town with limited suppliers of construction materials. The students were encouraged to research the names of suppliers in neighboring cities and determine their stock of reinforcing bars and ability to deliver to the UWP campus. This work could also be assigned to a "materials availability team" that would research the cost and availability of local materials and report back to the class. Such a team would need to report in time for the design teams to utilize the information in the beam design.

Another variation would be to construct and test more than one beam, perhaps from the first and second place design teams. This variation has not been attempted because of limited enrollment.

Instructor Time and Resources

Significant resources and time requirements are needed to accomplish this project:

- Lecture time must be allocated for group presentations and testing of the beam. During this last semester at UWP, about two lectures worth of total time were used for these purposes. This should be accounted for when creating a semester schedule of lesson plans.

  Time must also be considered in assigning the project and formulating completion dates for specific tasks. Design teams can begin their task only after basic rectangular beam design has been covered. Preparing the design teams is often the most critical component of the timeline—they must finish their designs early in the semester to ensure enough time for the remaining tasks. During the next task, concrete design teams need a reasonable time for their cylinders to cure so that their results can be presented and used for the third task, construction of the beam. The beam will also need a reasonable time to cure. Curing time can be reduced from 28 days if fast strength gain cement is used. As the beam reaches testing strength, the instrumentation team may require several days to place strain gages. Each task of the project should be thoroughly thought through so that the critical path to beam testing flows smoothly. The instructor should also allocate time to supervise students performing lab tasks such as concrete casting. Optimally, the beam should be finished and tested with some time remaining in the semester so that the instructor can reiterate the important "lessons learned" from the project and illustrate how the principles learned in class relate to the hands-on work completed.

- In order to cast and test a beam, formwork and a load frame must be available as well as sufficient lab space for the entire class to view the beam test. Material properties such as dry-rotted unit weight, absorption content, and moisture content should be know (or equipment should be available to determine these properties) in order to allow accurate concrete mix design. Equipment should be available for fabricating and testing many concrete cylinders. A concrete mixer is desirable if the beam size is large. Additionally, it is a good idea to test a sample of the reinforcing bars in tension to determine exact yield stress (f_y). It should be kept in mind from the outset that the project requirements will be dictated by the lab space and equipment capacity available. Because of finite bar selections (which often lead to a greater than necessary amount of reinforcement), the tendency to over-design concrete in order to ensure compressive strength, and the tendency of reinforcement to have a higher than specified yield stress, the actual capacity of the beam may be substantially higher than the design capacity. Thus, the load requirements in the problem statement should be a fraction (say 60%) of the capacity of the testing equipment.
- Affixing strain gage instrumentation to a concrete beam can be tricky and requires some planning ahead to allow enough time for surface preparation and drying. The students on the instrumentation team are required to meet with the lab technician well in advance to schedule a time when they can affix the gages with the technician's help. We also distribute to the group a student report detailing the many steps required to affix strain gages to concrete. A copy of this report is available from the authors.

Student Motivation

To determine how engaged the students were in this project, a modified version of the Student Opinion Scale was used[1]. The Student Opinion Scale is an instrument designed to measure the motivation of students after taking an examination. It is not specifically designed to measure motivation of students for a project. We have modified the questions slightly to help us to understand how the project motivates and engages the students. The statements from our modified Student Opinion Scale along with average response data from the most recent semester are given in Figure 3. The students respond to the statements using a five-point Likert scale from 1 (Strongly Disagree) to 5 (Strongly Agree). Several of the statements are reverse scored (lower values correspond to higher motivation). The reverse scoring has been accomplished for the data shown in the figure.

As can be seen from Figure 3, overall motivation for the project is high, ranging from "Agree" (4) to "Strongly Agree" (5) on six of the nine questions. The remaining three statements had neutral or lower motivation scores. The lowest "motivation" score (2.33) was received for the statement, "While working on this assignment, I could have worked harder on it." This highlights one difference between measuring motivation on an exam (as the Student Opinion Scale is designed to do) and motivation for a project. On a timed exam, students are focused and can work diligently to finish the exam. On a project, however, where the time spent is open-ended, most students would likely agree that they could have worked harder on the assignment. The same rationale might also explain the relatively low score (3.09) for the statement, "I did not give this assignment my full attention." The low scores on these statements are an indication that further revision and verification is required to more accurately use the Student Opinion Scale for project assignments.

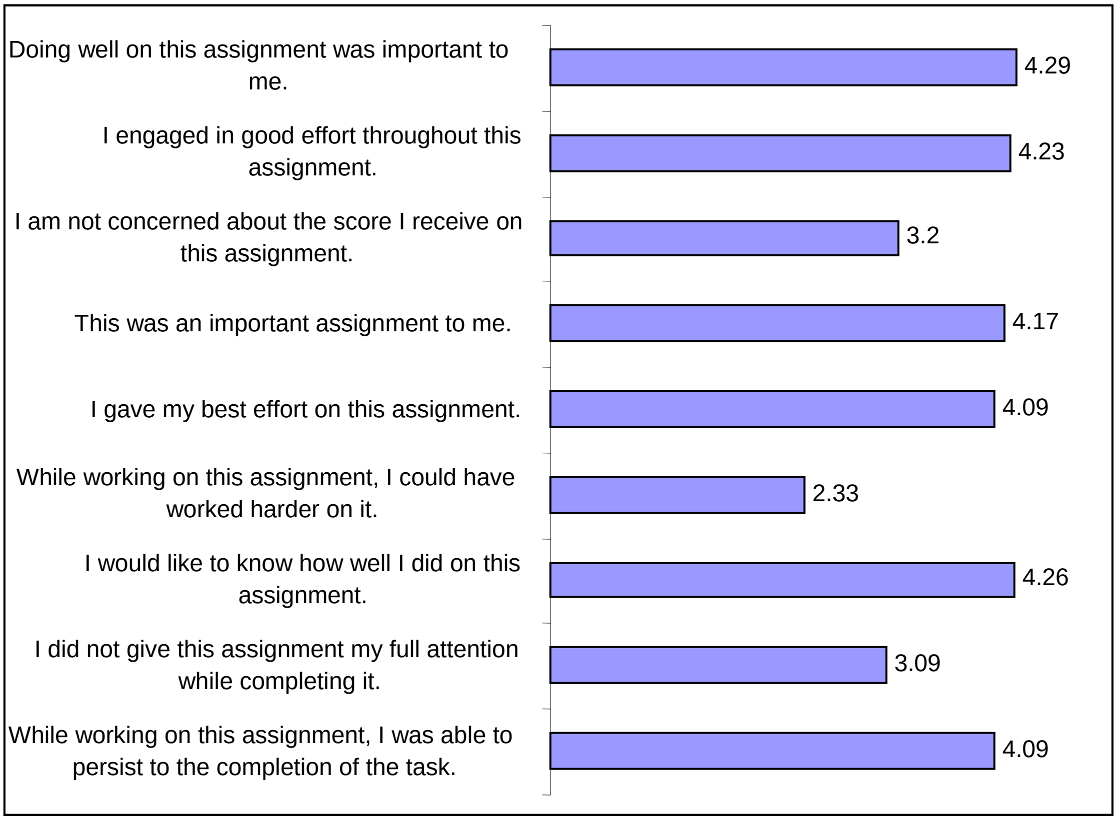

Figure 3 Motivation as measured by the Student Opinion Scale. The results presented are reverse scored as required so that shown scores reflect motivation on a scale of 1 (lowest motivation) to 5 (highest).

Case Studies

Case studies are also used in class to explore design, construction, and ethical issues. Two specific case studies that have been used in past classes are the 1981 collapse of the Harbour Cay Condominiums and a comparative case study of the performance of the Murrah Building during the 1995 Oklahoma City bombing versus the performance of the Pentagon during the 2001 September 11 attacks.

The Harbour Cay collapse resulted from punching failure of a flat plate slab. Punching shear is not a major course topic, but this case study also includes issues regarding quality of engineering work, quality of construction practice, quality of oversight by building authorities, and the consequences when all three of these key aspects lapse on one project. The case study is presented over about 35 minutes of one 50 minute lecture and the remaining time is used to initiate discussion of the issues. No assignments are given with the case study, but some may be tried in the future.

A typical first course in reinforced concrete focuses heavily on structural issues (analysis, design, and mechanics of behavior) and has less appeal to civil students with a non-structural emphasis who may have to take the course due to the requirements of their field of study. Because the Harbour Cay case study also addresses issues of construction practice (the collapse occurred during construction of the condominium complex and resulted partially from construction flaws), this lecture helps to bridge the course material to the construction management students. The parable of the collapse justifies the importance of understanding the theory of reinforced concrete behavior for those students who may never design reinforced concrete buildings but may be involved with their construction.

A similar presentation on column failures is presented after the students learn about column design. The performance of columns during the 2001 Pentagon attack is compared to the performance of columns in the 1995 Oklahoma City bombing and issues of terrorism and progressive building collapse are discussed. This case study is socially relevant and current. The issues of this case study can be directly linked to issues of security and how they impact trends in building design philosophy. On a technical basis, the relative performances of the structures under extreme load situations highlights the influence of column confinement (tied columns in the Murrah Building versus spiral columns in the Pentagon) and detailing on overall structural integrity (the Pentagon is generally considered to have performed well under its attack while the Murrah Building is considered a lesson in the dangers of progressive collapse).

Students' comments from end of the semester evaluations underscore the merit of the case study lectures:

> "The presentations … were a great way to reinforce what we learn in class."
>
> "Enjoyed the real world examples."
>
> "I loved the presentations."

How often do students "love" something about a concrete class?

Material for the case studies was gathered from the existing literature. For Harbour Cay, the National Bureau of Standards Report by Lew, Carino, and Fattal is the best source[2]. If this is not available, a good summary of this report can be found in the August 1982 issue of *Concrete International*[3]. For the Oklahoma City bombing and the Pentagon attack, the best sources are the ASCE Building Performance Reports for both of these events[4,5]. The ASCE Building Performance Reports are still in print and can be purchased from ASCE's online bookstore. Much more additional material on the Oklahoma City bombing can be found in the August 1998 issue of *The ASCE Journal of the Performance of Constructed Facilities*[6,7,8].

Many other case studies of structural collapses are available for presentation and discussion, but case studies of innovative and successful structures would also provide good lecture topics. Some notable examples of such structures are the Confederation Bridge across the Northumberland Strait, the Petronis Towers in Kuala Lumpur, the Troll Offshore Oil Platform in the North Sea, and the Three Gorges Dam in China. Only a little literature on these structures exists in publication, but videos showcasing innovative structures are available from the Discovery and History Channels.

Conclusion

A beam design and testing project as well as case studies have both been used successfully to instill motivation and interest in reinforced concrete design students. The beam design and testing project is structured not only to motivate the students in learning difficult (and for some students seemingly irrelevant) material, but to engage a number of important goals:

- *Competition* – Students who become professional designers will have to compete against rival companies. The beam design and concrete design teams are introduced to this reality by competing against each other to have their designs chosen for the final beam. Students in other teams are also reminded of the competitive nature of the profession by attending presentations and picking a winning team.
- *Creativity* – The minimal restrictions contained in the beam design problem statement encourage many options to be considered. Creative solutions are generally rewarded by being selected as the winning design. Creativity is also important in the class presentations—those teams that creatively sell themselves stand a much better chance of winning.
- *Awareness* – By having the students consider how they must show themselves to be competitive against off-shore engineering firms, the students are asked to consider an important issue confronting today's engineers.
- *Communication Skills* – Oral presentations (required of all teams, see Figure 4) and written reports improve the communication skills of the students. Significantly, the oral presentations of some of the teams are required to be persuasive speech in order to sell their work. This is new for many students who may have only experienced informational technical presentations.

Figure 4 Student presentation by concrete design team.

- *Design Skills* – Being involved in a "construction" project from start to finish enhances the students' design skills. For example, requiring students to plan their designs based on locally-available materials instills awareness of some of the practical constraints in the design process. In general, the real-world application of this project helps the students to see the many factors (some non-technical) that contribute to successful design.

The case studies also meet several important instructional goals. The importance of continuing education is stressed by showing the students the lessons learned in past engineering projects. The studies also provide a way to discuss real-world engineering ethics issues.

References

1. Sundre, D. and Moore, D., "The Student Opinion Scale: A Measure of Examinee Motivation," Assessment Update, Vol. 14, No. 1 (January-February 2002), pp. 8-9.
2. Lew, H.S., Carino, N.J., Fattal, S.G., and Batts, M.E., "Investigation of Construction Failure of Harbour Cay Condominium in Cocoa Beach, Florida," National Bureau of Standards, Washington, D.C., Publication No. NBSIR 81-2374, September 1981, 130 pages.
3. Lew, H.S., Carino, N.J., and Fattal, S.G., "Cause of the Condominium Collapse in Cocoa Beach, Fla.," ACI Concrete International, Vol. 4, No. 8 (August 1982), pp. 64-73.
4. Hinman, E. E. and Hammond, D. J., "Lessons from the Oklahoma City Bombing," ASCE, Special Publication, 1997, 60 pages.
5. Mlakar, P.F., et al., "The Pentagon Building Performance Report," ASCE, Special Publication, January 2003, 61 pages.
6. Corley, W. G., Mlakar Sr., P. F., Sozen, M. A., and Thornton, C. H., "The Oklahoma City Bombing: Summary and Recommendations for Multihazard Mitigation," ASCE Journal of Performance of Constructed Facilities, Vol. 12, No. 3 (August 1998), pp. 100-112.
7. Mlakar Sr., P. F., Corley, W. G., Sozen, M. A., and Thornton, C. H., "The Oklahoma City Bombing: Analysis of Blast Damage to the Murrah Building," ASCE Journal of Performance of Constructed Facilities, Vol. 12, No. 3 (August 1998), pp. 113-119.
8. Sozen, M. A., Thornton, C. H., Corley, W. G., and Mlakar Sr., P. F., "The Oklahoma City Bombing: Structure and Mechanics of the Murrah Building," ASCE Journal of Performance of Constructed Facilities, Vol. 12, No. 3 (August 1998), pp. 120-136.

Biographical Information

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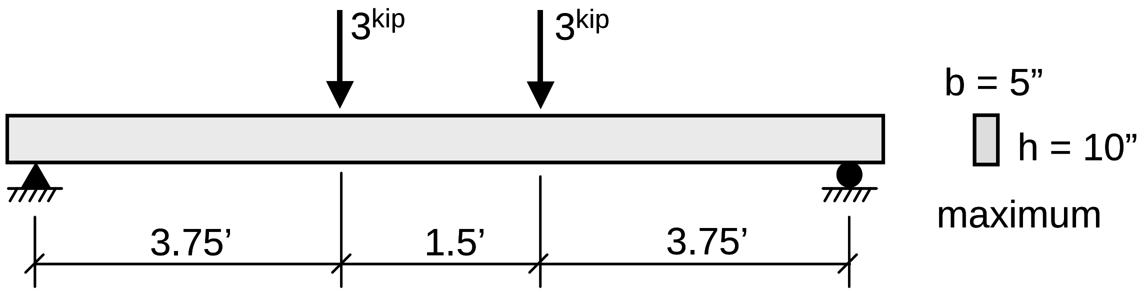
KEITH THOMPSON is an Assistant Professor in the Department of Civil and Environmental Engineering. Dr. Thompson earned his B.S. in Civil Engineering from North Carolina State University in 1994. He worked for one year as a bridge engineer with Figg Engineering Inc. in Tallahassee, FL. Afterwards he earned M.S. and PhD degrees from the University of Texas in Austin (in 1998 and 2002 respectively). He instructed structural engineering classes at Penn State University and Auburn University before joining the faculty at University of Wisconsin–Platteville in 2004.

Appendix: Project Assignment for Fall 2004

CE 3150 – Reinforced Concrete Design – Fall 2004

Design and Construction of a Reinforced Concrete Beam

As a class, we will design, build, and test a reinforced concrete beam to withstand the loads shown below. The formwork available to fabricate the beam limits us to maximum cross-section dimensions of 5” x 10”. The class will be split into several teams with different responsibilities. A sign up sheet for each team will be made available outside of my office (137 OTT). There is limited space for each team. You can sign up for only one team. Anyone not signed up for a team by Friday, October 1 will be assigned a place by the instructor. Written reports will be required from each team. Additionally, every group will make a brief presentation to the class on the work they have done.



Design Teams

There will be four design teams of no more than three people each. Design the beam to resist the given loading in flexure. Do not use load or resistance factors for this design.

Materials: Select a concrete strength that you feel is feasible (remember that the facilities of our lab are limited, so do not specify exotic concrete properties). Reinforcing bars can be obtained locally from Heiser’s but their selection is limited (you may want to visit Heiser’s to see what is available). A greater selection of reinforcing bars may also be delivered from Dubuque, but there may be some shipping delay. As a first step, you should investigate the accessibility of materials and find out what is feasible.

Detailing of Reinforcement: The clear spacing requirement for bars may be reduced to 0.75”. A 0.75” clear cover may also be used. Stirrups will not be used in this beam.

The designs from each of the four teams will presented to the class and a decision will be made on which design to use. Included in the presentations should be a summary of the material quantities required and a synopsis of your design calculations. The selected design must be shown to satisfy the required loading. Judgment of the winning design will be based on consideration of the material quantities required and accessibility of the required materials. These will be your biggest selling points when making a presentation.

Concrete Teams

There will be three concrete teams of three or four people each. The concrete teams will design a concrete mix to meet the specified strength for the selected beam design. Each team will prepare a sample mix to fill six small (3” diameter, 6” height) cylinders for compression testing. 14 and 28 day strengths will be measured. Cylinder testing will follow the general guidelines of ACI 5.6 (a copy of this section can be obtained from the instructor).

Mix designs will be provided to the construction team on the day cylinders are cast to allow the construction team to conduct an inventory of necessary supplies. 14 day strengths will be provided to the instructor as soon as they become available. Selection of the best concrete mix will be based on the 14 day strength in order to accelerate the start of beam fabrication.

Presentations of the mix designs and strength results will be made to the class one week after the 28 day strengths become available.

Construction Team

There will be one construction team with five or six members. The construction team will obtain the necessary supplies to fabricate the beam, setup the formwork to the correct dimensions, place the reinforcement in accordance with the selected design, cast the concrete (with guidance from the winning concrete team), and remove the formwork. The concrete team will also cast cylinders from the same concrete batch as the beam to be used for quality control.

The construction team must ensure that adequate supplies and tools are available (an inventory of fine and coarse aggregates and cement should be made as soon as mix designs are available; verify that each mix can be produced with the given materials; additionally the availability of a concrete mixer, trowels, shovels, etc. should be examined). Consideration should be given to the handling needs of the beam after fabrication.

The construction team will make a presentation on the fabrication of the beam focusing on any problems that arose and how they were overcome.

Instrumentation Team

There will be one instrumentation team of three or four members. The instrumentation team will apply strain gages to the beam and possibly the reinforcement before casting. The instrumentation team will help connect the gages to the data acquisition equipment and run a system check before testing. The instrumentation team will also be responsible for performing a tension test of a sample of the reinforcing bars used in the beam.

The instrumentation team will make a presentation of their instrumentation work and the general theory behind the working of the instrumentation (the instructor will provide some guidance on this).

Testing Team

There will be one testing team of three or four members. The testing team will set up the actuator and run it during the testing of the beam. The testing team will also record data and take photos during the test. The testing team will measure the strength of the concrete on the day of the test using the quality control cylinders.

The testing team will make a presentation on the test data focusing on the comparison of the experimental data to the theoretically expected performance.

All teams will produce written reports to accompany their presentations. The design and concrete teams must turn in their reports within two weeks of making presentations. All other teams must turn in their reports by the last day of class.

A tentative schedule of events for this project is presented below:

Date	**Activity**	**Group(s) Responsible**
Oct. 1	Deadline to Signup for Groups	Everyone
Oct. 11	Design Presentations	Design
Oct. 18	Cast Cylinders	Concrete
Oct. 18 – Oct. 22	Inventory of Materials & Equipment	Construction
Oct. 25	Beam Design Reports Due	Design
Nov. 1	14 Day Cylinder Tests – Select Mix	Concrete
Nov. 1 – Nov. 13	Assemble Formwork, Reinforcement, etc.	Construction
Nov. 14	28 Day Cylinder Tests - **Cast Beam**	Concrete - Construction
Nov. 22	Concrete Mix Presentations	Concrete
Nov. 22 – Dec. 5	Instrument Beam – Assemble Load Setup	Instrumentation - Testing
Dec. 6	**Test Beam** – Concrete Mix Reports Due	Testing - Concrete
Dec. 13	Presentations on Construction, Instrumentation, and Testing	Construction – Instrumentation - Testing
Dec. 17	Reports Due	Construction – Instrumentation - Testing

Notes:

- The beam will only be 21 days old at the time of testing.
- The significant dates listed above are all Mondays.

Grading

Group members will be asked to evaluate the effort from their teammates. The overall group grade will be distributed based on these evaluations. The group grade will be based upon completion of the tasks for each group. For example, there will not be a penalty for not having the winning beam or mix design, only for not meeting the requirements of the design. Bonus credit may be awarded on a subjective basis if exemplary work is noted.