Session 2793

Theoretical and Experimental Aspects in Engineering Design Experience

Ashraf M. Ghaly
Union College, Schenectady, New York

Abstract

Engineering design is a required component in many engineering courses. The design experience gained in such courses can be significantly enhanced through the use of student projects. Several projects have been introduced in some of the civil engineering courses offered at Union College. The competition-like format used in these projects resulted in a healthy strive on the part of the students to achieve the best possible results. The way the projects were structured required complete command of the theoretical principles before a design could be made. The implementation of the design required comprehensive research into various types of construction materials. In each of the assigned projects, students were given a handout detailing the goal of the project, methodology, procedure, and grading criteria. Students were given complete freedom to use the theoretical approach which they believed would yield the desired results. They were also allowed to experiment with different materials and different construction techniques. Students who wished to perform some testing on preliminary designs before finalizing their projects were encouraged to do so. This approach made it possible for students to refine and improve their initial designs and gave them appreciation of the effect of individual design parameters on the final product. They also enjoyed the experimental aspect of material testing and project construction and "destruction" when loaded to failure. The projects were very well received as indicated by student comments in course evaluation. The feedback commended the practical aspect of the projects, their relevance to real-world problems, the opportunity to make links between theory and practice, and the contribution the projects made in enhancing engineering judgment and appreciation. The projects are continuously reviewed to incorporate new advances in design procedures.

I. Introduction

ABET Criteria 2000, Criterion 3 (Program Outcomes and Assessment) outlines the desired attributes for graduating students of engineering programs. It states that engineering programs must demonstrate that their graduates have certain attributes. These specific attributes are numbered "a" through "k" and they cover many facets in engineering education. Attributes a, b, c, and e which are shown below place special emphasis on engineering design and the ability to formulate a solution to an engineering problem.

a) An ability to apply knowledge of mathematics, science, and engineering
b) An ability to design and conduct experiments, as well as to analyze and interpret data
c) An ability to design a system, component, or process to meet desired needs

e) An ability to identify, formulate and solve engineering problems

At Union College, the author has developed several design projects and incorporated them as required components in the courses he teaches. The projects are offered in a competition-like format and are structured to give the students hands-on experience in the implementation of theories learned in the classroom. The competition-like format sparked students' interest in the outcome of different designs and motivated them to use innovative techniques and procedures to achieve the desired goal.

The requirements of a given project were detailed in a handout describing the goal of the project, methodology, procedure, and grading criteria. The projects assigned, the courses in which these projects were incorporated, course number in college catalogue, and the level of course offering are listed in the following:

1. Project CubiCrete (Civil Engineering Materials, CER-022, Sophomore level).
2. Project Liquefaction (Soil Mechanics, CER-142, Junior level).
3. Project GeoSlam (Soil Mechanics, CER-142, Junior level).
4. Project GeoChallenge (Foundations and Construction, CER-143, Senior level).
5. Project BeamBang (Reinforced Concrete Design, CER-132, Junior and Senior levels).

All projects listed above require not only design and application of theoretical principles but also in-depth research into material properties and behavior. To comply with attributes g and k (shown below), students were required to document the results of their projects in a report using the engineering tools available at their disposal. This includes word processing, spreadsheets, graphics and CAD software, and presentation software. In addition to written reports, students were required to make an oral presentation to detail their process of thought to accomplish their projects, the procedure used in achieving different stages, actual versus predicted outcomes, lessons learned, and recommendations for improvement. Presentations were always followed by a question period where the students and the instructor had the opportunity to ask questions and learn more about the project. In addition to the instructor's evaluation, two randomly selected students were required to evaluate each presenter in terms of effectiveness, clarity, accuracy, technical content, adequacy of procedure, correctness of analysis, efficiency in using time, and efficiency in using presentation materials.

g) An ability to communicate effectively
k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

The following is a brief description of the assigned projects, requirements, and criteria.

Project CubiCrete: In many construction applications, concrete is desired to be light and strong. A light weight and strong concrete can reduce the weight of the structure, thus reducing the size and depth of foundation which makes the project more economical. The goal in this project is to design and construct the lightest and strongest concrete cube with given dimensions. Student teams learn the procedure of concrete mix design in class. The effect of different ingredients in the mix on the behavior and strength of concrete is covered in detail. The methods and techniques of mixing, pouring, and finishing of concrete specimens are discussed in full. In this project students can compete effectively by searching for light weight materials to use in the mix, or to use chemical additives to increase concrete strength. The students' real pleasure can be seen in the lab on the day of testing their specimens. With the crushing of concrete cubes, one can see the excitement and anticipation in the students' faces. This excitement reaches its peak as the applied load increases to the point where failure occurs. Student teams are allowed multiple entries up to three specimens if they so wish, however, the average of all entries will be used to determine the grade of a given team. Grades of teams are calculated based on the performance of the entire class. Teams achieving at or above the class average get full credit, whereas teams performing below average get a partial credit based on the ratio of their results and the average result of all teams in the class. Figure 1 shows a schematic of a concrete cube subjected to axial compression.

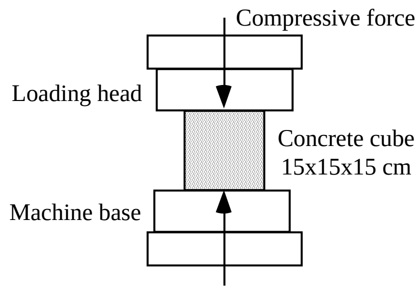


Figure 1. A concrete cube subjected to axial compression in Project CubiCrete.

Project Liquefaction: Liquefaction is a dangerous phenomenon which results in catastrophic failures of structures. Soil liquefies when the ground water rapidly rises due to some external factors such as floods or earthquakes. When the soil liquefies, it becomes a fluid-like and loses its ability to support loads from constructions. The theoretical concepts behind soil liquefaction and methods to reduce liquefaction potential are covered in the Soil Mechanics course. Project Liquefaction is structured to make the students think of innovative techniques and materials to reduce liquefaction potential. Students are divided into teams, two students each. Each team is given a Plexiglas cylinder (called permeameter) similar to the one shown in Figure 2. The permeameter is almost filled with soil and a steel ball is placed on top of the soil surface. Water flow is allowed to seep slowly from the bottom of the permeameter until the soil is saturated, and the head of applied water is increased slowly until the soil liquefies and the ball sinks. Students are required to design a soil column which will be as light as possible and can support the highest possible head of water before the ball sinks. This design involves application of principles related to soil compaction, material properties, liquefaction potential of soils with different properties, effect of soil stratification, and natural characteristics of soils. The project involves rules related to allowable size of soil particles where certain size can not be exceeded. It also involves rules banning the use of cohesive materials such as clays. The design and placement of the soil column inside the permeameter requires that students understand the fundamentals of soil behavior under the effect of upward seepage flow, and the project reinforces the theoretical concepts learned in the classroom. The grading criteria is based on the average ratio of (water head/unit weight of soil) for the entire class. All projects with a ratio higher than or equal to the class average receive full credit. All project achieving below class average get a partial credit calculated as a ratio of that project's performance relative to class average.

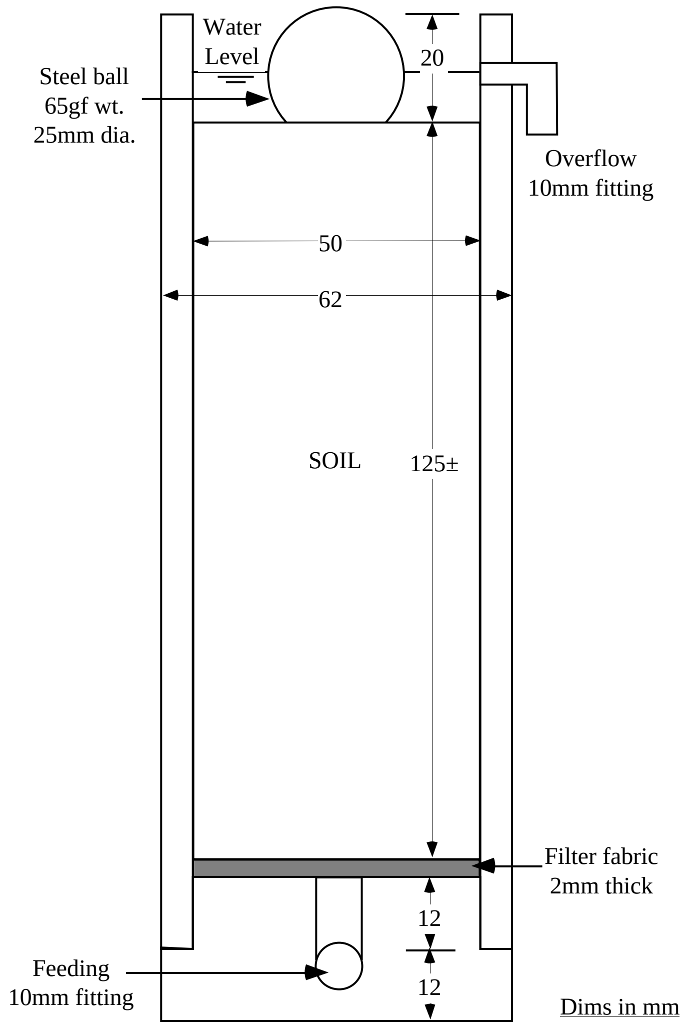


Figure 2. Permeameter of Project Liquefaction.

Project GeoSlam: Construction of buildings or roads requires strong foundation soil. If the soil is loose or contain high percentage of voids, excessive settlement could result in an unacceptable structural deformation. To overcome this problem, soil can be densified where its properties can be improved to resist external loads within admissible range of settlement. Modification of soil properties can be achieved using compaction. The compaction technique is a simple way of reducing the volume of void in the soil by packing more solid matter in a given volume. This technique can be achieved by imparting energy, by hammering, for example, into the soil layer. It results in better interlocking between soil particles, thus increasing the layer's compressive resistance. The principles of soil compaction and ground improvement are theoretically covered in the classroom. Furthermore, a standard specification on soil compaction is conducted in the lab using standard mold and compaction hammers (Figure 3). After this lab, students gain appreciation of the effect of compaction on improving the compressive resistance of the soil by increasing its unit weight. Project GeoSlam is given to the students at that time and they are asked to design the lightest and strongest soil cylinder. The standard mold is required to be used, and the students can select the standard compaction hammer they wish to use. Students can use any type of soil, degree of compaction, level of energy input (represented by the number of compacted layers, number of blows from the hammer per layer, and height of fall of hammer), and compaction technique. Teams prepare their specimens which are extracted from the mold, weighed, and tested in compression. Students appreciate the effect of compaction when they realize that it can greatly improve the properties of the soil, however, they also realize that the type of soil, level of imparted energy, and degree wetness and moisture content of the used soil are also factors which play an integral role in the outcome of the project. For each student team, a ratio of (compressive force at failure/weight of soil in mold) is calculated. The average of all ratios from all entries is calculated. Teams with ratios above class average receive full credit in the project. Teams with ratios below the class average receive partial credit calculated relative based on their performance relative to the class average.

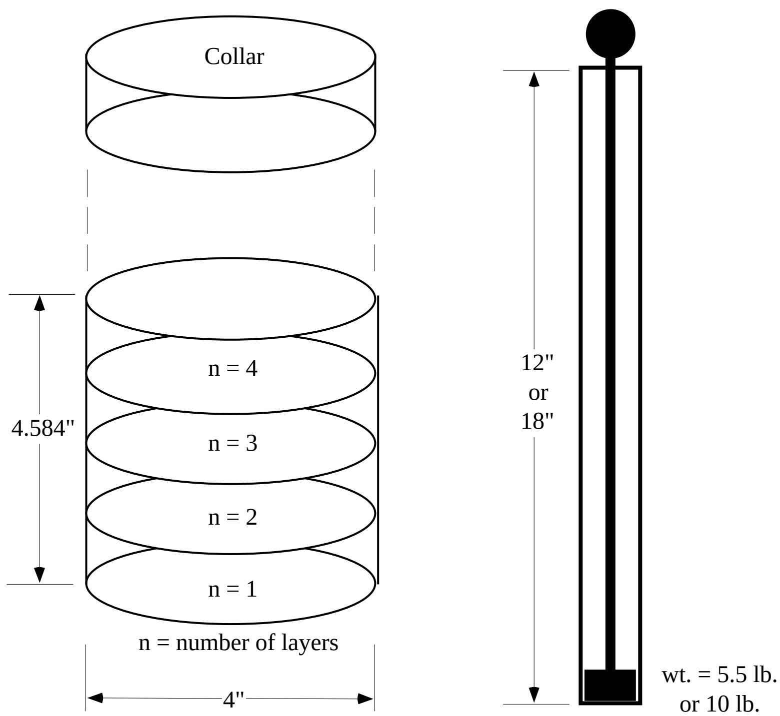
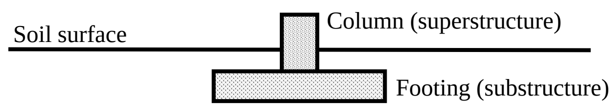
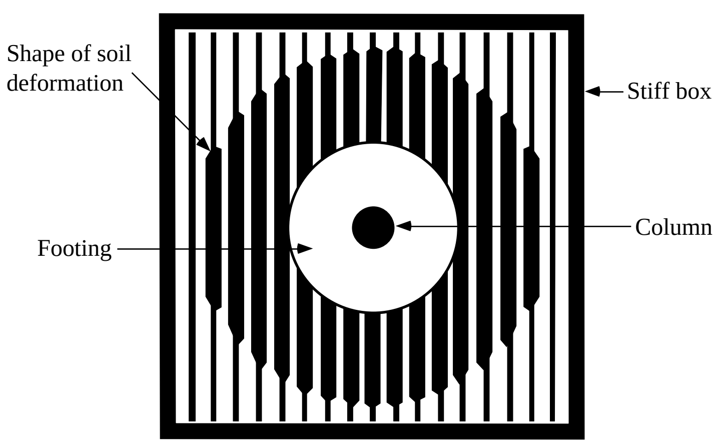


Figure 3. Mold and hammer of Project GeoSlam.

Project GeoChallenge: Structures in general comprise two major components, superstructure and substructure. The above-ground structural component is the superstructure and is supported by the below-ground component which is the substructure (Figure 4). If the load from the superstructures is not great, and the soil in the site of construction is highly resistive of compressive forces, a shallow foundation (footing) can be used to transmit the structural load to the supporting soil layer. The design of shallow foundations is covered in detail in the Foundations and Construction course. Students gain appreciation of the effect of many factors which influence the design outcome. As a practical application of the knowledge gained in foundation design, Project GeoChallenge challenges the students to use the theories learned in the classroom to design and construct a foundation on the soil of their choice. Using theoretical principles, student teams are required to predict the maximum load the foundation can resist before it fails. The foundation is then loaded and the actual failure load is recorded. The closer the predicted load to the actual one, the higher the grade of the student team. The goal of the project is to illustrate that foundation design is a procedure which requires understanding of soil behavior under the effect of compressive forces, the relationship between load on and settlement of the foundation, the relevance of soil strength in the sizing of the foundation, and importance of accurate determination of parameters of soil on which the foundation rests. Since foundation design is usually a difficult task which requires great factor of safety in real-world application, certain degree of tolerance is allowed in this project. The grading criteria permits some acceptable degree of discrepancy then compares the actual and predicted failure loads. If the actual failure load matches, or lies within the allowable discrepancy, the predicted failure load, the student team gets full credit in the project. Partial credits are awarded based on the degree of agreement between the actual and predicted failure loads.



Elevation of footing



Plan of footing and shape of soil deformation

Figure 4. Elevation and Plan of footing in Project GeoChallenge.

Project BeamBang: This project was a required component in the Reinforced Concrete Design course in which the design of reinforced concrete beams is covered in detail. The project is about the design and construction of a reinforced concrete beam with a given span and maximum given cross section. Students perform the structural design of the beam, design the concrete, mix the ingredient with the desired specifications, place the reinforcements in the mold, and pour the concrete in the mold. The beam is tested in pure bending by simply supporting the two ends and applying concentrated loads at 1/3 and 2/3 of the span (Figure 5). Grading formula is function of the ultimate load on the beam at failure, area of reinforcement in the section, and unit weight of the concrete. The higher the ratio [Load/(Steel area * Unit weight of concrete)], the higher the grade of the student team. Students competed in this project by adopting many innovative ideas related to type of reinforcements and unconventional materials used in making the concrete. In real-world, structural applications, concrete members are always desired to be as strong as possible with the lightest possible weight and percent of reinforcement. This can results in a considerable cost saving. The project as structured reinforced these principles. Projects of student teams were evaluated and graded using the class average as reference. Projects achieving above class average received full credit, and those achieving below the average received a partial credit depending on the their performance relative to the average.

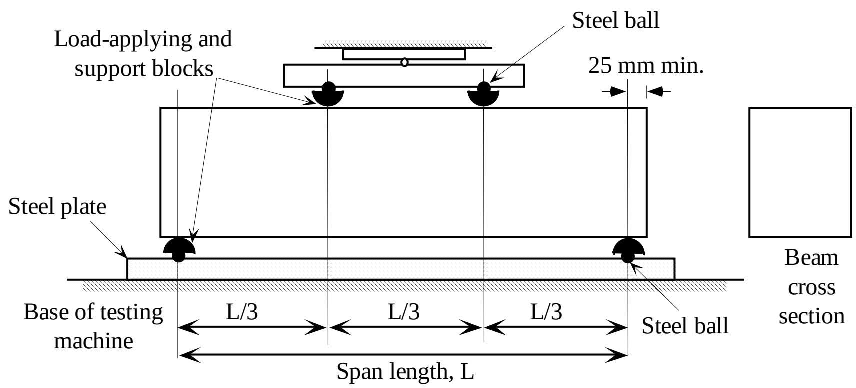


Figure 5. Schematic view for loading in Project BeamBang.

II. Conclusions

Five hands-on projects are developed and introduced in civil engineering courses at Union College. All the projects require understanding of theoretical fundamentals and application of these principles to achieve a desired goal. The projects simulate problems encountered in real-world applications in the civil engineering field. Design components in these projects satisfied attributes a, b, c, and e in Criterion 3 of ABET 2000. Written and oral components in the projects satisfied attributes g and k of the same. In end-of-term official course evaluation, students indicated that they enjoyed the projects and liked the practical application of the theories and concepts learned in the classroom. Many students thought that the projects reinforced ideas which are otherwise difficult to appreciate without a real design and testing in the lab. Excitement and anticipation could always be noticed on the day of testing. Loading projects to failure or crushing concrete specimens was always the highlight of any event. It drew the loudest cheer, and one could feel the emotional attachment between the teams and their projects. Almost all the students who did these projects in the past few years felt that the grading criteria was fair. These projects are regularly reviewed and upgraded to incorporate new rules related to the latest methods of design and testing.

Bibliography

1. "Engineering Criteria 2000, Third Edition," Engineering Accreditation Commission of The Accreditation Board for Engineering and Technology, December 1997

ASHRAF M. GHALY

Ashraf M. Ghaly is an Associate Professor of Civil Engineering at Union College, Schenectady, New York. He is the recipient of the 1997 Stillman Prize for Excellence in Teaching. Dr. Ghaly's major area of teaching and research is geotechnical engineering. He also teaches courses and conducts research related to mechanics of structural materials. Dr. Ghaly is a registered Professional Engineer in New York. He received his B.Sc. and M.Sc. degrees from Alexandria University, Egypt, and earned his Ph.D. from Concordia University, Montreal, Canada in 1990.