Engaging Students in an Undergraduate Civil Engineering Course

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Abstract

The components of the undergraduate course in Design of Foundations in the Civil and Environmental Engineering Department (CEE) at Christian Brothers University (CBU) are discussed. The course consists of the following: classroom lectures, project case studies, failure case studies, ethical case studies and open-ended design problems. Examples of case studies with discussion questions are provided in this paper.

Undergraduate CEE Program at CBU

Christian Brothers University is a small Catholic university. The School of Engineering offers degrees in electrical, mechanical, chemical and civil and environmental engineering. The CEE program requires studies in structural, soil, traffic and transportation, hydraulics and water resources in addition to other courses in physics, chemistry, mathematics and the liberal arts. Only the courses in the geotechnical sequence are described here. Three required courses are offered in geotechnical engineering (geotechnical engineering, geotechnical engineering laboratory and design of foundations) along with elective courses. In the first two courses, students learn the fundamentals and in the third course, they are required to design various types of shallow and deep foundations.

Required Courses in Geotechnical Engineering

Most of the fundamental concepts in geotechnical engineering are discussed in the basic course in geotechnical engineering. The students in the geotechnical laboratory course do the basic laboratory soil testing and geotechnical report writing. Detailed soil investigation programs with field-testing of soils, additional ideas in geotechnical report writing, analysis and design of shallow and deep foundations are discussed in the design of foundations course. Students are required to complete six open ended projects in design: the design of a soil investigation program, a shallow spread footing, a pile foundation system, a pier foundation system, dimensions of a retaining wall and design of a slope. The designs are strictly geotechnical designs. Reinforced concrete design of foundations is taught in another course by the structural engineering faculty. Items covered in one portion of the design of foundations course are outlined in Appendix A. It should be noted, that in addition to assigning some theoretical problems from the textbook, an actual case study is discussed and evaluated by the students. This “practical solution” to a real world problem is a genuine benefit for the students. Thus in this course, an effort is made to expose the students to practical problems. Working on the open-ended project will help the students when they begin to practice geotechnical engineering.

Project Case Study, Failure Case Study, and Ethical Case Study

Project and failure case studies are helpful in understanding and reinforcing the concepts of foundation engineering analysis and design [1]. Ethical case studies help to delineate and recognize the professional and ethical responsibilities of an engineer [2]. Ideas and concepts in geotechnical engineering are reinforced again and again using case studies to familiarize the students to the engineering approach in solving foundation-engineering problems.

A case study of a two-story structure built on a residential waste site [3] is discussed below. Topics discussed in this study include soil investigation programs, analysis and design of foundations, construction problems, possible reasons for failure, and remediation of the damaged structures. Details for a geotechnical investigation, the design of an asphalt pavement, and problems encountered in the construction of a Parking Lot[4], and its performance are also discussed here.

Case Study of Construction of One and Two Storey Buildings at a Solid Waste Site

Project Description

The project site was an old residential solid waste dumpsite in west Tennessee. Four (one and two-story) buildings were constructed at the site. The buildings were, in general, steel-frame structures with exterior metal sheathing. The floor system consisted of beams and one-way structural slabs; the beams were supported on concrete monotube pile foundations. A methane gas collection system, consisting of a sand layer with a network of pipes, was placed on the waste site. All utilities were grade supported.

Geotechnical Investigation Details and Results

The soil investigation was done in 1977. The geotechnical investigation consisted of drilling and field sampling in two phases. More than 44 soil borings were done. Hollow core auger and hydraulic rotary methods were used in advancing the boreholes. The maximum depth of the investigation was 110 ft. Several obstructions were encountered while drilling because of the presence of concrete and asphalt blocks or car bodies. The geotechnical report indicated the presence of residential waste; the depth of sanitary landfill varied across the site with a maximum depth of landfill of about 60 feet. Below the sanitary landfill layer, loose layers of sand, clay, and clayey sand were found. Underlain the loose layers were dense layers of sand and clay.

The geotechnical engineer advised the Owner to abandon this project site and find another suitable site; the Owner decided to continue the project at this site.

Analysis and Design of Foundation System

Shallow foundations systems such as a spread footing will cause excessive total and differential settlements if they are located within the residential waste layer and a deep foundation system consisting of group of piles was considered for this project [5]. The piles were to transmit the loads from the columns to the underlying dense sand and clay layers by tip capacity.

Construction problems

During the construction, after the gas collection system was in place, the water main broke, washing away part of the gas collection system.

Performance of the buildings

After the construction was completed, the buildings were used as envisioned until the settlement of the foundations caused the walls to crack and methane gas from the solid waste came through the floor cracks. The differential settlements of the buildings were as much as 18 inches. The pavement settled as much as three feet in some places. The buildings were evacuated for health reasons. A failure investigation was carried out with more than 100 boreholes. Litigation ensued and the Owner sued all the parties involved in the project. Pretrial depositions were taken. The case was settled out of court. Remediation was carried out to retrofit the foundations. The cost of remediation was reported to be a lot more than the original construction cost.

Possible Reasons for Failure

Pile foundation systems: It was not clear whether the piles were installed within the loose sandy layer or within the dense sand layer underneath the layer of solid waste. The project geotechnical engineer had no role in the installation of the pile foundation system[6]. It was possible that the piles were not long enough [3]. Also, the pipe piles used may not have been the correct size as recommended: the wall thickness may have been smaller[6]. It was also not clear whether the piling contractor used any criteria in installing the piles.

The methane gas collection system: Perhaps the placing of the unsupported gas collection system may not have been the right choice. As the solid waste settled down, the differential settlement of the solid waste layer may not have helped the stability of the gas collection system. Partial collapse of the gas collection system due to the breaking of the water main did not help the overall integrity of the system.

The skin friction capacity of the pipe piles: Pile foundations derive their load carrying capacity from the friction between the walls and the soil surrounding them and the tip capacity at the bottom of the piles. If the piles located within a solid waste layer experience a downward pull because of the settling of the organic solid waste layer surrounding them (negative skin friction), the piles are pulled into the soil, thereby causing a settlement of the pile foundation system. Predicting the negative skin friction of the pile system at a landfill site is not possible because of the presence of extraneous materials, such as concrete, bricks, and organic waste material. An alternate design would have been not to allow the negative skin friction to act on the piles by providing some mechanism to break the contact between the piles and the surrounding solid waste.

Remediation of the foundation systems: One of the internationally well-known remediation companies was awarded the contract. This company installed minipiles bearing on the dense sand around or below 110 ft and the existing pipe piles were cut off just below the floor beams. It is understood that the total remediation cost was more than the original construction cost.

From an educational point of view, this case study will give students a better understanding of the concepts of pile foundation systems at a landfill site.

Conclusions

Several geotechnical principles have been discussed using this case study:
(a) Performance of constructed facilities at any landfill or fill site is unpredictable since there is no sure way of estimating the total and differential settlements, especially when using shallow foundations or poorly designed and constructed deep foundations.
(b) It is not possible to estimate the negative skin friction on the pile foundations; ways of minimizing the expected negative skin friction should be explored. (c) Any gas collection system needs to be anchored to some stable supports or such systems need to be designed to be able to withstand large differential settlements. (d) Design-build awards may bring down the costs and may allow some technical innovations in the remediation process.
(e) Performance related specifications will also enable the contractors to come with unique solutions for the problems at hand. (f) Students may benefit from the failure case study approach of teaching the foundation courses.

Discussion Questions:

a) How do you estimate the negative skin friction capacity of a pile?
b) What are the typical allowable total and differential settlements of a steel-framed structure?
c) Discuss how the remediation was conducted in this project?

Failure Case Study of Design and Performance of a Parking Lot

Need for Failure Case Studies

Discussing the failures of projects, related principles and applications are brought together and thus reinforce the students understanding of the subject matter. Discussion of a specific failed project gives the opportunity for the instructor to discuss professional and ethical issues related to the project with the students.

Description of the Project

The development of the shopping mall (20 acres) was carried out in eastern Pennsylvania in the fall of 1989 and spring of 1990. About 1,000 parking stalls were designed for the mall. During the summer of 1990, major repair work was needed for the parking lot. Potholes and water seepage from cracks in the pavement were some of the problems.

Soil Investigation and Testing

The initial geotechnical investigation consisted of ten boreholes with a maximum depth of investigation of about 17 feet. Soil testing included six Atterberg limit tests, one CBR test, one standard Proctor test, and one mechanical sieve analysis test. The soil was essentially silty sand (SP) and silt with clay and shale, silt (ML) with rock fragments. Bedrock was encountered at the bottom of the boreholes. The Standard Penetration Test results indicated the N-values to range from 4 to 160 indicating that the soils varied from very loose to very dense. The Atterberg limits varied from 21 to 29, and the plasticity index ranged from 2 to 5 indicating that the soils were of low plasticity. No groundwater table was encountered during drilling.

Traffic data and Design of the Pavement Cross Section

No traffic data was supplied to the geotechnical engineer. It was assumed that the traffic on the parking lot was mostly passenger car traffic with occasional delivery truck traffic. Asphalt Institute’s minimum thickness standard was used in designing the asphalt pavement. Therefore, a minimum asphalt thickness of three inches with a crushed limestone base of nine inches was recommended.

Drainage Control Plan

The project design engineer for the shopping mall had a drainage control drawing sheet as part of the set of construction drawings. The drainage control drawing sheet indicated two detention ponds at the site and also a swale across the site to drain the surface runoff into the detention ponds. The construction work was monitored by a geotechnical firm, a retired registered engineer, and a professional photographer. The project manager had a record of the weather conditions on a daily basis and photographs of the progress of work during the construction period. During the construction period, the drinking water main broke, and several thousand gallons of water was dumped into the subgrade.

Failure Investigations

After a severe winter season, water was coming out of the cracks in the asphalt pavement. Rutting, large potholes, and alligator cracking of the pavement at several locations were observed.

The project manager hired another geotechnical testing laboratory to investigate the causes of the problems so that the liable party would be required to repair the pavement. A series of 24 auger cores were taken from the pavement for analysis to determine the actual thickness of the asphalt pavement and base course in addition to finding out the quality of the materials used in the base.

The investigation results are summarized as follows: groundwater was present; large boulders two to three feet in diameter were found within the base course; thickness of the pavement varied from 2 inches to 3 inches. The limestone base course was mixed with clay soils along with big boulders. The following recommendations were made to remediate the problems: install a subsurface drainage system to drain the subsoil; properly repair the problem areas; place an asphalt overlay.

Lessons Learned

No amount of record keeping will do any good unless the data is reviewed and acted upon! Even though the work was monitored by a soil testing company and a retired civil engineer and the paper work was transmitted to the management, the seriousness of the problem was not understood by anyone at the time of construction. The management failed to review the daily pictures of the progress of work and did not take any action until after the pavement problems were encountered.

Murphy's Law is true! The breaking of the water main at the project site was unforeseen. It was not clear whether the drainage plans were followed at the time of construction. Even though there were two detention basins, at least one of the drainage outlet pipes from the detention basin was clogged. Consequently, water was not draining out of the basin; instead the water was recharging the sandy silt layer and hence water was seeping out of the cracked pavement.

Construction specifications must be followed while earthwork is in progress. Even though the geotechnical report called for particle sizes not exceeding three inches are to be used in the subgrade, large boulders two to three feet in diameter were found buried in the subgrade. The base course materials were mixed with clay soils; whereas the specifications called for crushed limestone base.

Discussion Questions:

a) List factors affecting the design and performance of an asphalt pavement parking lot?
b) List possible reasons for the failure of the asphalt pavement in this project?

c) How would you remediate the failed asphalt paving in this project?

Ethical Case Study

Ethical considerations in engineering analysis, report writing, design, and construction are very important. One ethical dilemma in writing the engineering report for the Parking Lot project is discussed briefly in the following example.

One method of exposing the students to their ethical responsibilities is by discussing case studies where decisions involving ethics are made. One of the recommendations made by the geotechnical engineer was the thickness of the pavement cross section. More often, the project manager does not provide a traffic count for the design of the thickness of the parking Lot[7]. So the geotechnical engineer assumes a traffic count and based on the soil test results recommends a thickness. Since the thickness needed in this case was smaller than the minimum thickness required by the Asphalt Institute, the geotechnical engineer recommended an asphalt layer of three inches[4].

After the geotechnical engineer issued the report, the manager of the project contacted another registered geotechnical engineer who recommended a different thickness for the pavement cross section. Then the manager contacted the project geotechnical engineer to reissue the report with the changes in the thickness requirements for the asphalt layer.

Discussion questions:

a) How should the geotechnical engineer respond to the project manager’s request?
b) What are the requirements of your State Engineering Registration Board for registrants?

Discussion and Conclusions

Students’ written comments in the faculty evaluations vary. “The only teacher that taught us about ethics; other faculty members should follow him,” wrote one student recently. Some like it very much; some don’t seem to appreciate it. They do get involved in these discussions, which in the long run will help them when they begin to practice engineering.

APPENDIX A

CE 340 Design of Foundations - Course Outline

Chapter 1.0 Subsurface Investigations

1.0 What will you learn in this chapter?
1.1 Terminology
1.2 Reasons for subsurface investigations
1.3 Planning for soil investigation
1.4 Soil exploration methods

1.5 Field sampling
1.6 Other field tests
1.7 Ground water table (GWT)
1.8 Designing a soil investigation program for a typical project
1.9 Discussion of a typical boring log
1.10 Laboratory testing of soil
1.11 Foundation investigation report
1.12 Numeric example problems and homework problems
1.13 Student design project
1.14 Case study of a typical project
1.15 Review questions
1.16 References

References

1) Class notes, "Workshop: Using Failure Case Studies in Civil Engineering Courses," University of Alabama, Birmingham, AL, summer 2003.
2) K. Madhavan and R. Eugene McGinnis, "Integrating Case Studies and Ethics in Civil and Environmental Engineering," Proceedings of the MAESC 2003, May 2003, Christian Brothers University, Memphis, Tennessee.
3) Loren D. Flick, et al., "Minipile Milestone in Memphis," Civil Engineering, September 1992, pp 46-49.
4) K. Madhavan and R. Janardhanam, "Distress – Cause and Effect: A diagnostic Study," Proceedings of the Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, MO, June 1-6, 1993.
5) Author's personal files.
6) Personal communication with the project geotechnical engineer.
7) K. Madhavan, "Advice to Structural and Project Engineers from a Geotechnical Engineer," Proceedings of the MAESC 2003 Conference, May 2003, Christian Brothers University, Memphis, Tennessee.

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