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Use of Case Histories in the Classroom

Carsten H. Floess
Earth Tech, Latham, NY

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Carsten H. Floess, P.E., Ph.D.
Earth Tech
40 British American Boulevard
Latham, New York 12110
USA

ABSTRACT

Use of case histories provides an important role in Civil Engineering education, presenting an opportunity for students to extend the principles found in textbooks to real world, practical problems. Case histories provide students with a sense of judgment and a sampling of the "art" in geotechnics.

The author, an Adjunct Professor of Civil Engineering at Rensselaer Polytechnic Institute, has used contemporary case history examples related to foundation and geotechnical engineering to supplement and invigorate classroom instruction and prepare students for the workforce. Typical examples related to foundation engineering include:

- Design of subsurface investigation programs for structures, wastewater treatment plants, etc., considering the use of conventional test borings, Cone Penetration Tests (CPT), in-situ testing, and laboratory testing.
- Evaluation of bearing capacity for shallow foundations based on boring and CPT logs
- Estimates of static pile capacities based on boring and CPT logs, including subsequent comparison with load test results.
- Settlement predictions based on available boring, CPT, in-situ, and laboratory test data, and subsequent comparison with field measurements, if available. Evaluation of whether predicted settlement is acceptable.
- Analysis and design of sheet pile and gravity retaining structures based on boring and/or CPT logs.

Example case histories are reviewed, including their role in supplementing textbook instruction. A key component of these problems is that they do not offer a unique solution, but rather a range of solutions depending on selection of suitable design parameters and method(s) of analysis. Feedback from students is also presented.

INTRODUCTION

Case histories proffer an important role in Civil Engineering education. As noted by Dr. Ralph Peck, the textbook should be supplemented with examples of projects and applications met in practice. This allows the nascent engineer to learn how to assess details, how to judge the relevance of data, and to develop a sense of judgment regarding quality and acceptable practice (Peck, 2004; Dunnicliff and Young, 2006).

In this spirit, the author, an Adjunct Professor of Civil Engineering at Rensselaer Polytechnic Institute, Troy, NY, has routinely supplemented coursework with contemporary case histories. These are typically local design and construction projects pertinent to the coursework. Many of the case history projects are routine, but serve to allow students to review typical subsurface and laboratory test data and to make judgments regarding appropriate design parameters and assumptions necessary to formulate a solution and to develop suitable conclusions and recommendations.

The legacy of Ralph Peck, Class of 1934, looms large at Rensselaer. He is a distinguished member of the Rensselaer Alumni Hall of Fame, celebrated for his expertise in subsurface engineering, combining the science of soil mechanics and geology with the practical art of foundation design. It is hoped that the case history projects used in the coursework embody and exemplify this "art" of the practice.

A key component of these real-life projects is that they do not offer a unique solution, but rather a range of possible solutions depending on the student's design assumptions and method(s) of analysis. At completion, the actual design is reviewed to provide a basis of comparison and discussion. This provides students with a sense of judgment and a sampling of the "art" in geotechnics.

Feedback from students has consistently been positive. The case history projects are generally indicated to be the highlight of the class.

CASE HISTORIES

To enhance learning and to foster practical thinking, the author has used actual Civil Engineering projects in the classroom, providing opportunity for students to extend principles covered in textbooks to real-world problems. These projects mostly relate to foundation engineering, but also encompass soil mechanics and geoenvironmental (landfill) engineering. The undergraduate course in Foundation Engineering at Rensselaer will be used to illustrate the approach.

The Foundation Engineering course begins with a review and discussion of subsurface investigations, with focus on reviewing local geology and obtaining adequate field and laboratory test data for a given project. Shallow foundations are covered next, with emphasis on estimating settlement and evaluating allowable settlement. This leads into ground improvement methods applicable to reducing settlement, followed by analysis of deep foundations. The course concludes with analysis and design of retaining structures and sheet pile walls. Miscellaneous topics are also covered; for example, underpinning, gravity dam structures, wave equation analysis of piles, and foundations subjected to overturning moments.

Five projects are typically assigned, encompassing these general topics. Ideally, new projects are assigned each year, but there is usually some repetition from previous years. Project turnaround is generally two weeks, with deliverables comprising a written report and a verbal presentation of assumptions, results, conclusions, and recommendations. Students work in small groups of three or four.

The intent is to make the projects as realistic as practicable. Accordingly, students are typically provided only with representative boring and/or CPT logs, plus typical laboratory test data, as well as key project information such as site plans, design loads, and geologic background. Projects typically entail several components:

1. Preparation of a geotechnical model, including appropriate soil stratification, geotechnical design parameters (strength, compressibility, unit weight), depth of water table, frost depth, and other pertinent considerations.
2. Technical analysis, typically using at least two alternative analysis methods, thereby allowing students to develop a sense of the range of "correct" answers.
3. Cost analysis, particularly when more than one option is being considered.
4. Presentation of conclusions and recommendations in written and verbal format.

At completion, the actual case history project is reviewed, allowing students to compare their work with reality. Field measurements, such as pile load tests and settlement data, also serve as a basis of comparison, if available.

Example projects are described in the following sections:

Example 1 - Subsurface Investigation

The goal is to allow students to plan a realistic subsurface investigation program, whether for a building, wastewater treatment plant, or other structure. The typical project includes a desk top study, whereby students are provided access to readily available geologic and topographic maps, geologic reports, and other pertinent information. They are also encouraged to find information on the Internet.

Based on the desktop study and information regarding the type and size of the structure and preliminary loads, students are asked to detail the number and depths of subsurface explorations, type(s) and frequency of sampling, and types and quantities of laboratory testing. Students are encouraged to include Cone Penetration Tests (CPTs) and other in-situ test methods to supplement conventional test borings.

Students are also asked to develop cost estimates for the investigation, using typical unit prices in the upstate New York area. Costs for associated engineering services are also developed.

A typical example is a planned airport parking garage addition. The garage addition has a footprint of about 100,000 sf (9,500 m^2) with column loads up to about 1,900 kips (8,500 kN). It was emphasized to the students that it is unknown whether shallow or deep foundations would be required and that they should plan the investigation to accommodate both options.

Most students were able to determine from the desk top study that the site is underlain by surficial sand deposits with underling lacustrine clays and silts of glacial origin, followed by glacial till and bedrock. Based on geologic reports, the students were also able to determine that depth to rock was on the order of 50 to 100 feet. This information allowed them to define boring depths and plan laboratory testing (with focus on compressibility of the clay soils). Results are summarized in Table 1.

Table 1. Student Project - Subsurface Investigation

Team No.	*Exploration Type*	*Number of Explorations*	*Cost US$*
1	borings	40	$48,000
2	borings & CPT	25	$39,150
3	borings & CPT	19	$40,750
4	borings & CPT	28	$53,700
5	borings & CPT	35	$83,815
6	borings & CPT	15	$43,500
7	borings & CPT	24	$42,400
8	borings	28	$65,000
9	borings & CPT	28	$90,000
10	borings	28	$57,500
11	borings	27	$60,500
12	borings & CPT	24	$130,000
13	borings	12	$26,000
Median		27	$53,700
Actual	borings & CPT	13	unknown

The project results were useful for discussing some business aspects of the engineering profession. For example, the students were asked to select the best project team; i.e., who would you hire if you were responsible to select a consultant? Team No. 6 was chosen, even though they did not have the lowest cost. This led to a discussion of qualifications based selection, and that low cost may not always be in the best interest of the project owner.

Costs associated with engineering services; i.e., project planning, field inspection, analysis, report preparation, etc., were also discussed. Students commonly underestimate the time and effort required for these activities, often by a wide margin. Another area of related discussion deals with labor multipliers and overhead costs.

In summary, the importance of developing and implementing an adequate and practical subsurface investigation is emphasized. It represents the starting point of all projects. It is important for students to understand the basics of planning such investigations, and the importance of collecting appropriate and sufficient data necessary for efficient design of foundations.

Example 2 - Bearing Capacity and Settlement

The goal is to allow students to evaluate and study the performance of shallow foundations, considering ultimate limit states (bearing capacity) and serviceability limit states (settlement). It is emphasized that both bearing capacity and settlement must be evaluated to determine the feasibility of spread foundations and to develop appropriate design parameters.

The students are typically provided with information regarding the type and size of the structure and anticipated loads, plus representative boring and/or CPT logs and pertinent laboratory test data. They are asked to analyze bearing capacity and settlement and to provide recommendations for an allowable bearing capacity meeting both ultimate and serviceability limit states.

A typical example is a college library. The 5-story concrete structure has a single basement and column loads ranging from about 100 to 600 kips (450 to 2,700 kN). Borings indicate the site is underlain by granular fill overlying medium compact sand of lacustrine origin.

Most students were able to determine from the study that settlement is the controlling factor for the heavier column loads, and that bearing pressures needed to be less than the allowable bearing capacity to control settlement. Settlement estimates were highly variable, depending on student assumptions and method of analysis, illustrating the “art” in foundation engineering.

The project provided means to review and discuss several interesting aspects. For example, there were numerous questions regarding the appropriate depth of embedment to use for analysis of bearing capacity and settlement. Should the embedment depth refer to the depth of footing below the basement floor level, or to depth below ground surface? The project also led to discussion on the concept of floating foundations and whether the soils should be considered to be preloaded because of the basement excavation.

One year, the class participated in a settlement prediction contest for footings supported on sand sponsored by the University of Western Australia. CPT and flat plate dilatometer data were provided along with some geologic background. Four footings were evaluated, varying in size and depth of embedment. Settlement was predicted for loads varying from 100 to 180 kN.

Results of the contest are summarized in Figure 1. The class, identified as Participant Number 15, ranked in 12th place overall out of 28 participants. Respectable, for a group of undergraduates!

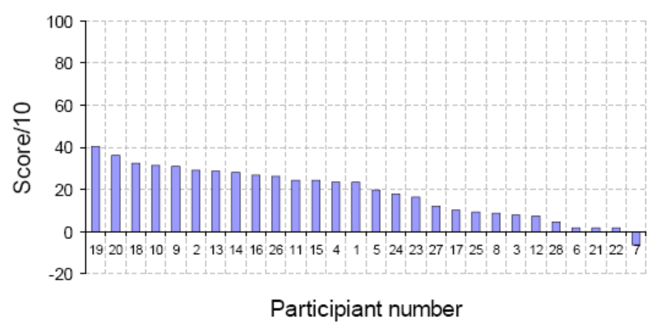

Figure 1. Rankings of Settlement Prediction Contest (Participant No. 15).

Example 3, Ground Improvement

The goal is to allow students to study various ground improvement methods. Although the primary focus is on methods used to densify soil and reduce settlement, students are allowed to select any reasonable topic, such as:

- Deep Dynamic Compaction
- Vibroflotation/Vibroreplacement
- Blasting (for densification)
- Surcharging
- Compaction Grouting
- Chemical Grouting
- Cement Grouting
- Jet Grouting
- Deep Soil Mixing
- Ground Freezing
- Geosynthetics (for ground improvement)
- Lime Stabilization
- Biostabilization

The students are required to research a selected topic, and are encouraged to contact specialty contractors for information. The research includes but is not limited to:

1. History and development, country of origin, key engineers or firms, etc.
2. Typical applications and usage; potential applications
3. Design principles
4. Interesting case histories
5. Advantages/Disadvantages
6. Costs

Example 4 - Pile Foundations

The goal is to allow students to evaluate and study the performance of pile foundations, considering static axial capacity and load testing. It is emphasized that static analyses must be supplemented with field analyses and data, including driving resistance, wave equation analyses, static load tests, and dynamic load tests.

The students are typically provided with information regarding the type and size of the structure and anticipated loads, plus representative boring and/or CPT logs and pertinent laboratory test data. They are asked to analyze static capacity using several analysis methods, allowing a comparison of methods and providing a sense of the range of computed capacities and the inherent uncertainty in selecting a discrete value for the ultimate or allowable axial pile capacity.

A typical example is a municipal parking garage. The multi-story concrete structure will be supported on steel H-piles or pipe piles with allowable axial loads ranging from about 150 to 220 kips (680 to 980 kN). Borings indicate the site is underlain by granular fill overlying lacustrine silt and clay, followed by thick deposits of glacial till over shale bedrock.

Students were also challenged to predict the axial capacity of a 63-foot test pile bearing in the glacial till and installed in proximity of a test boring. The test pile was loaded to failure (during the design phase). Predictions were highly variable, depending on student assumptions and method of analysis; nevertheless, most predictions were within 50 percent of the load test result, as summarized in Table 2:

Table 2. Student Project - Pile Load Test Prediction

Team No.	**Prediction**	**Load Test Result**	**Difference**
	kips	kips	**%**
1	350	411	-15
2	706	411	+72
3	612	411	+49
4	396	411	-4
5	471.1	411	+15
6	260	411	-37
7	544	411	+32
Avg.	**477**		

The project provided a means to review and discuss the uncertainty in predicting axial pile capacities and the need for wave equation analyses and load tests to improve confidence in determining pile capacities.
Student pile capacity predictions were proffered as a contest, providing incentive and competition. Certificates and small prizes were awarded to project teams with the best predictions, Figure 2.

The photograph in Figure 2 shows the student field trip to the project site, hosted by the New York State Office of General Services and Gilbane Building Company, Providence RI. This photograph was also showcased in an article in Engineering News Record (ENR) regarding future engineers and contractors (December 12, 2005).

Figure 2. Pile Capacity Prediction Contest Award.

Example 5, Retaining Structures

The goal is to allow students to evaluate and design retaining structures, with focus on evaluating stability and sizing major wall components. Projects generally include steel sheet pile walls and other retaining structures, such as gravity dams

The students are typically provided with information regarding the type and geometry of the structure and anticipated loads, plus representative boring and/or CPT logs and pertinent laboratory test data. They are asked to develop design pressure diagrams and analyze stability, including bearing capacity for gravity structures.

An example is the Gilboa dam project, Prattsville, NY. This dam impounds water for New York City water supply system and was judged to be potentially unstable under extreme flood conditions. Various measures are being implemented to enhance stability, including installation of vertical and inclined tie-down anchors. Students first made a field trip to the site, hosted by Nicholson Construction Company, Cuddy, PA. They were able to witness the installation and testing of high capacity multistrand anchors. The group field trip is shown in Figure 3.

Figure 3. Student Field Trip, Gilboa Dam.

Back in the classroom, students were asked to evaluate the stability of the dam, considering normal pool conditions and extreme flood conditions. They were able to confirm that the dam was stable under normal conditions, but that safety factors were inadequate for extreme flood conditions. The stabilizing impact of the tiedown anchors could readily be appreciated after performing the stability analyses.

Miscellaneous Topics

Miscellaneous topics are also used on occasion, including underpinning, foundations with high lateral loads (towers and poles), liquefaction, etc.

PROBLEM BASED LEARNING

The approach to teaching foundation engineering described herein is in essence similar to Problem-Based Learning (PBL). According to Kumar and Hsiao (2007), PBL has been successfully used by other educators, particularly in the medical field, but is still in its infancy in engineering education. PBL challenges students to "think and learn" by solving real-world problems while working in groups.

The problem based approach as described herein is intended to supplement (but not supplant) conventional textbook learning. It extends solving well defined, idealized problems to more realistic situations requiring interpretation and judgment. For example, projects typically require interpretation of boring and/or CPT logs to develop appropriate soil stratification and geotechnical design parameters. Students are free to select the method of analysis, but are encouraged to use more than one approach to develop a feel for the range of potential outcomes and gain an appreciation of the "art" of foundation engineering.

STUDENT FEEDBACK

Feedback from students regarding the value of class projects has been universally positive. Representative student comments include:

- "His projects bring a higher level of understanding of the course material than any other teacher can accomplish."
- "The field trip to the dam was an excellent learning experience (especially applying the idea to a project)."
- "The projects were a good learning experience."

CONCLUDING REMARKS

To enhance learning and to foster practical thinking, the author has used actual Civil Engineering projects in the classroom, providing opportunity for students to extend principles covered in textbooks to real-world problems. Over the years, the author has assigned approximately 60 student projects, of which about half are unique (i.e., there is some repetition).

The problem based approach described herein is intended to supplement (but not supplant) conventional textbook learning. It extends solving well defined, idealized problems to more realistic situations requiring interpretation and judgment. It provides students with an appreciation of the "art" of foundation engineering, as expounded by Dr. Ralph Peck, a distinguished member of the Rensselaer Alumni Hall of Fame.

A difficulty with this approach is locating a pool of suitable projects and related geotechnical data. This is not easy to accomplish. However, student feedback has been positive, making the required effort worthwhile.

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