Case Histories in Geotechnical Engineering Education

James Mahar
Idaho State University, Pocatello, ID

Commemorate the Legacy of Ralph B. Peck
April 29 - May 4, 2013 CHICAGO
Seventh International Conference on
Case Histories in Geotechnical Engineering
and Symposium in Honor of Clyde Baker

CASE HISTORIES IN GEOTECHNICAL ENGINEERING EDUCATION

James Mahar, PhD
Senior Lecturer - School of Engineering
Idaho State University
Colonial Hall #9
921 S 8th Ave. Stop 8060
Pocatello, ID 83209, USA
mahajame@isu.edu
tel: (208) 282 5287, fax: (208) 282-4538

ABSTRACT

Case histories can be taught as an individual course or as part of a specific engineering class. These studies are very important when the teaching methodology incorporates the observational approach in design and construction. Several resources for case histories are available. However the most insightful are those in which the instructor has personal knowledge or the student participates in a case history-type project.

One of the most important elements in engineering education is the sequential design approach in civil works projects. Case histories provide a very effective means of illustrating the complete design process which is the framework of professional practice. In February 2012, the State of Idaho declared one of the historic buildings (vintage 1924-1925) at Idaho State University “unsafe” until a complete geotechnical/structural investigation could be conducted to determine the integrity of the building. This action provided an excellent opportunity for foundation engineering students to participate in a case history study and to provide data used in an ongoing engineering analysis. The students under the supervision of the instructor collected the available geotechnical data, performed subsurface investigations, made damage observations, carried out laboratory tests, analyzed the building settlement/structural deformation and prepared a geotechnical report outline. Strategies for mitigating further settlement/damage were developed in the course. The students were required to sign the documents which were submitted to the structural engineer responsible for the building assessment.

INTRODUCTION

When I attended the University of Illinois as a graduate student, I was fortunate to take a course dedicated entirely to engineering case history studies. The course was taught by Dr. Ralph Peck who focused on projects in which he had consulted and/or researched such as the stability of the RTF Ore Yard along the Cuyhoga River near Cleveland, Ohio. Dr. Peck would grade a one page/one sided summary of the pertinent facts, design assumptions/requirements and recommendations for each of the 10 projects presented in class. Dr. Peck not only required a thorough knowledge of soil mechanics but also demanded that students research construction means and methods. In addition, case histories were used as teaching tools in engineering geology, rock mechanics and rock engineering courses taught by Professors Don Deere, Ed Cording, Skip Hendron and Frank Patton. All of these courses had one common theme: instruction on the methodology and approach in engineering design and construction. Since 2003, I have attempted to teach the design process and integrate construction considerations using case histories in my foundation engineering and engineering geology courses at Idaho State University.

THE DESIGN PROCESS

In my opinion, geotechnical design is a process that progresses through a series of consecutive steps to successful completion of the project (see Fig. 1). Each phase relies on and checks the previous information/assumptions from which a workable set of plans and specifications are fully developed and implemented. Geotechnical design is not simply a set of calculations or risk assessments, although some form of analysis must be performed to proportion the final product. The process starts with a thorough understanding of the area wide and site specific geology. The geology and in particular the geologic history of the soils and rocks at the site make up the geotechnical framework for the design. An understanding of geology is so important in prediction of subsurface conditions across the site because of the limited subsurface data available on nearly all earthworks projects. Further, the geologic setting provides valuable information on the expected behavior of the soil and/or rock during construction and the throughout useful life of the project. For example, most practitioners would recognize and investigate potential swelling problems in foundation soils developed from weathering of Pierre Shale. Subsurface exploration programs must be formulated on the basis of the geologic model and tailored to address anticipated ground behavior and potential construction difficulties.

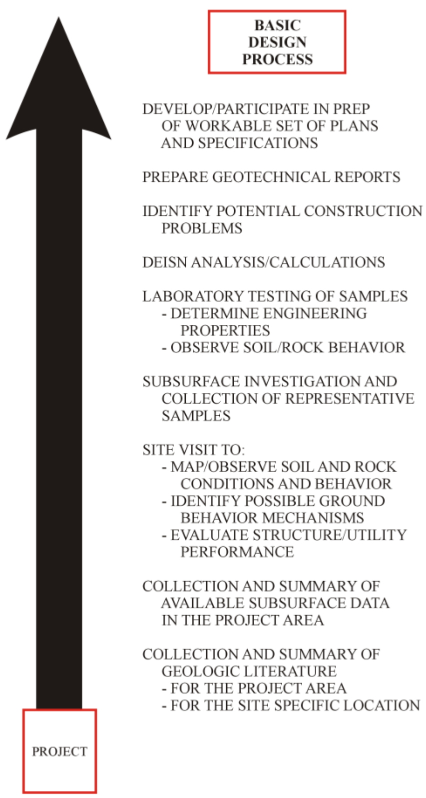

Fig. 1 Geotechnical Design Process

The basic steps in the design process are summarized as follows:

- collection and summary of geologic literature
    - project area
    - site specific location

- collection and summary of available subsurface data in the project area

- site visit to
    - map/observe soil and rock conditions
    - classify soil and rock types
    - identify possible ground behavior mechanisms
    - evaluate existing structure/utility performance

- carry out subsurface investigation and collect representative soil and/or rock samples

- perform laboratory tests on samples
    - determine engineering properties
    - observe soil/rock behavior during preparation and performance of laboratory tests

- design analysis/calculations

- identify potential construction problems

- prepare geotechnical report(s)

- develop/participate in preparation of workable set of plans and specifications.

In geotechnical engineering education, the key is to set up the course to demonstrate the design process and inform the students that this approach is part of the teaching methodology. The methodology can be further illustrated by setting up a sequence of projects to mirror the design process for grading and course evaluation. Case histories provide an excellent means of teaching the design process, provided they are orchestrated in a time-line sequence. In my opinion, assignment of projects that incorporate the design methodology are much more effective and informative than timed hourly exams in evaluating student performance and in educating the geotechnical engineering student for professional practice.

COLONIAL HALL CASE HISTORY

Background

In February 2012, the State of Idaho closed Colonial Hall on the campus of Idaho State University. The justification was a potential life safety issue based on an engineering report in which the investigators postulated that the existing damage in the building may cause collapse during a strong but non specified earthquake. This decision by the State provided an excellent opportunity to teach the geotechnical design process using a case history on campus as part of an advanced course in Foundation Engineering. In addition, it provided an excellent means for the students to obtain actual experience in performing a foundation engineering investigation and to be accountable for providing data to the design professional responsible for evaluating the structural integrity of the building.

Colonial Hall - The Building

Colonial Hall is a two-story, masonry structure built on shallow foundations. The footings are reinforced concrete, 30 in. wide and founded 4.2 ft (crawl space) and 7.0 ft (basement) below the ground surface. An 18-in. thick poured concrete stub wall supports the first floor concrete deck. The exterior walls are triple width, unreinforced brick load bearing walls. Two expansion joints are present in the east and west exterior walls near the north-south center of the building (see Fig. 2). Two interior concrete load bearing walls along a central corridor support the floor/ceiling panels. The first and second floors as well as the roof deck are one-way, cast-in-place joist/slab systems. The downspouts that collect precipitation on the overbuilt roof discharge at the sides of the building. There is no gutter system along the canopy above the main entrance on the west side of the building.

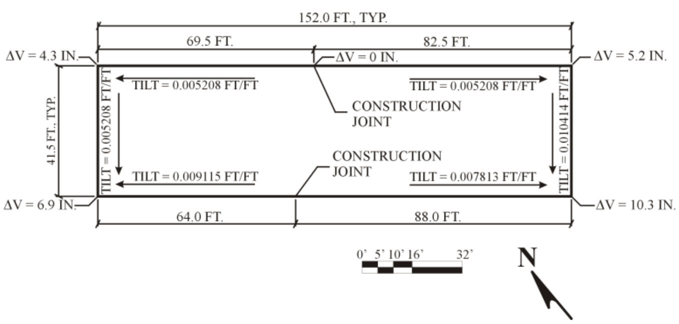

Fig. 2 Colonial Hall Dimensions, Settlement and Tilt Vectors on Campus of Idaho State University.

Colonial Hall was built in 1924-1925 and first served as a dorm and later as an office building. I have spent the last 10-years in Office #9 of Colonial Hall which is located in the area of greatest building damage. During this tenure, I have monitored the lack of crack development along the ceiling/south wall interface which is on line with the east side expansion joint.

Initial Tasks In Case History Study

In the first class period, the students were introduced to the design process concept and were informed that Colonial Hall would be the case history study for the course. The background of the building including the reasons for its closure was presented in the first lecture. The students were divided into teams: each team member was given responsibility for one or more of the various elements of the design process. All of the students participated in the field investigations. One of the goals of the case history study was to determine the cause of the building damage from which a realistic assessment could be made of its present condition, need for any repairs and expected future performance.

To initiate the case history study, student teams were assigned the task of collecting and summarizing the available geologic information on the project area. Data sources included the USDA Soil Conservation Survey of Bannock County, Idaho. Idaho State Geologic Survey reports and graduate student theses. Collection of data on the earthquake history in southeast Idaho and northern Utah was included in the literature search exercise.

Boring logs used in the design of the closest campus buildings were obtained from the archives of the Idaho State University Facilities Services staff. The near-surface soils consist of 6 to 45 ft of loess (wind-blown silt) on the east and west sides of the Colonial Hall, respectfully. The ground water table at the time of drilling was below the depths of the borings some 30 to 52 ft below the ground surface. Standard penetration test values range between 4 to 10 blows/ft and the dry unit weight of the split spoon samples varies between 88 to 100 lb/ft^3. The loess is highly susceptible to settlement/collapse when the degree of saturation reaches approximately 85% or more. Saturation of the wind-blown silt deposits has been responsible for damage to several structures in the Pocatello area.

The literature search of the recorded earthquake history in the southeast Idaho and northeast Utah area revealed that most of the earthquakes within 75 miles of Pocatello have magnitudes ranging between 2.4 and 3.4 on the Richter scale and occur along or adjacent to mapped fault lines 40 to 70 miles east and south of the city (USGS 2012). On 12 March 1934, an earthquake in Hansel Valley, Utah caused damage to at least three buildings on the campus (Salt Lake Tribune). The Hansel Valley seismic event with a 6.6 Richter magnitude is the largest historical earthquake in the state of Utah. The epicenter was located roughly 90 miles south-southwest of Pocatello on the northern end of Great Salt Lake. Aftershocks with magnitudes ranging between 5.1 and 6.1 continued between mid-March and early May 1934. Apparently Colonial Hall suffered some damage during the Hansel Valley earthquake, but the nature and location of the damage were not reported (JHS Architects 2012). The ground motion appears to have been in a north-south direction parallel with the long axis of the building. Review of the USGS National Seismic Hazard Maps show horizontal accelerations for the Pocatello area in the range of 0.16 to 0.32 g with a 2 percent probability of exceedance within 50 years (Peterson et. al. 2008).

Case History Field Investigation

The next step in the case history process was to carry out a field investigation in and around Colonial Hall. One on the most important parts of this study was to assess the cause of the damage in Colonial Hall. Measurements were made of the building footprint, construction joint locations, footing dimensions/depths, floor joist/slab characteristics, exterior wall thickness and gutter/drainage conditions (Fig. 2). As-built plan and cross-section views were prepared by the student teams.

Hand auger bore holes were drilled by the students in the areas of greatest damage. The soils were field-classified using the Unified Soil Classification System and auger samples were sealed in plastic bags for laboratory testing. Undisturbed consolidation test samples were carved in the foundation soil 4 to 5 in. below the footings in area of greatest damage and outside the influence zone of the foundation stress. Numerous calibrated pocket penetrometer readings were taken in the soil just below and outside the footings to estimate the unconfined compressive strength of the loess.

One of the most interesting parts of the case history investigation was the building damage survey. Students obtained hands-on experience measuring the building damage and interpreting the damage pattern. The teams mapped the cracks in the foundation walls and concrete slab/joist panels as well as the separations along the construction joints. Three-dimensional movement vectors were obtained in order to access the nature of the building displacement. A level line survey of the structure was carried out using a 4-ft level and a folding rule along a common mortar joint. Student-instructor discussions were conducted in the field to review the factual data, reconstruct the mechanisms of ground/structure movement and determine the nature/potential cause or causes of damage. The intent was to focus on the building behavior and not to simply collection of data.

Summary Of Student Field Observations

The structural damage in Colonial Hall is concentrated near the center of the building primarily along the east-west construction joints and intervening slab/joist panels (see Fig. 2). The vertical crack at base of the west side, crawl space foundation wall is 1/2-in. wide with an east-west offset of 3/8-in. (north side east). Further, the north side of the crack is 1/8-in. higher than the south side. The crack becomes progressively wider with increasing elevation in the stub wall above the foundation (1-1/2 in. at 6.1 ft above the base of the footing). The moment crack progresses up through the building and is open 5-1/4 in. in the concrete roof deck above the second floor rooms some 40 ft above the base of the foundation.

The north half of the building is tilted 0.0052 to 0.0091ft/ft north and the south side slopes 0.0052 to 0.0078 ft/ft south (Fig 2). Based on the level line surveys, the south end of the building has settled 5.2 in. (east side) to 10.3 in. (west side) and the north end has settled 4.3 in. (east side) to 6.9 in. (west side) with respect to the construction joints. In addition, the structure has an overall tilt of 0.0052 to 0.0104 ft/ft west. The total magnitude of settlement in Colonial Hall is not known and could not be determined because no reference point elevations were established at or shortly after the time of construction in 1924-1925. Other than the tilt and the interior cracks between the construction joints, the two halves of the building show essentially no angular distortion. Moreover, the two halves of the building have undergone rigid body rotation to the north and to the south away from the construction joints. The students concluded that the damage in Colonial Hall was caused by differential settlement of the foundation walls with tilt away from the center of the building some unknown time in the past 87 years.

Calibrated pocket penetrometer readings outside the footings yielded unconfined compressive strength values of the loess in the range of 3.6 to 4.4 tsf. The water content in area of the measurements varied between 2.7 and 6.9 percent. Near the outside edge of the footings where the water content was 8.9 to 14.4 percent, the pocket penetrometer values ranged between 1.3 and 1.7 tsf.

The downspouts discharging from the roof as well as rainfall/sprinkler water falling against the sides of the building have created 2 to 4 in. deep rills along west and north sides within 1 ft of the foundation. The water falling in the rills tends to pond in irregular depressions as it flows toward the north and south ends of the building. Concrete slabs and asphalt pavement along the east wall and much of the south side of the building help abate infiltration of surface water into the loess below the footings. In addition, the canopy over the front of the building has no gutter system and precipitation falls directly on the soils immediately adjacent to the entrance. Significant settlement and lateral movement have occurred in the brick bearing walls that support the front entrance slab and canopy.

The 2.6 to 5.1 in. of differential settlement along the west side of the building is consistent with ponding of water along the west wall and the greater thickness of the loess west of the structure.

Laboratory Test Results

The soil samples collected from the bore holes and test pits were taken directly to the laboratory to determine the water content and Atterberg Limits. The foundation soils are classified as silt (ML) with 15.6 to 22.2 % sand (see Table 1). The loess is strongly effervescent when tested with 0.1 normal HCl. Water contents varied between 2.7 and 14.4% with values dependent on the sample location below and near the outside edge of the exterior footings. The highest water contents were immediately north of the front entrance. Consolidation tests were carried out by the students on the undisturbed samples to estimate the compressibility of the loess at its natural water content and in response to water saturation. At the natural water content, the vertical strain ranged between 2.4 and 3.4% at vertical effective stress of 1 and 2.6 tsf. When immersed in water, the loess underwent a vertical strain of 4.9 and 6.7% at vertical effective stresses of 2.6 and 4.2 tsf, respectively.

Table 1. Laboratory Test Results on Foundation Soils Inside Colonial Hall Crawl Space

Sample	Depth[1] (FT)	Water Content	-#200 (%)	Liquid Limit (%)	Plasticity Index (%)	Dry Unit Weight (lb/ft^3)
B-1	0	6.9	82.3	21	NP	74
B-2	2	5.4	77.8	23	NP	82
B-3	4	4.5	84.4	22	2	88

[1] Depth Below West Wall Footing

Data Summary

All of the data collected in the case history study were summarized by the students in figures and tables. Laboratory test results were place on lab sheets. The information from each team was combined, checked and submitted to the engineer of record responsible for evaluating the structural integrity of the building and making recommendations for repair. The students signed and dated all of the documents sent to the design professional.

Case History Project

In order to assess the student class performance, a final project was developed using the Colonial Hall case history study. The project focused on estimating the settlement and bearing capacity of the Colonial Hall foundations based on the results of the field studies and laboratory tests. Foundation loads were obtained from a preliminary report prepared by the design professional (Eagle Engineering 2012). The building was evaluated for static and seismic bearing capacity/settlement. Settlements were also estimated assuming saturation of the loess beneath the structure. The final task was to prepare a report outline from which the information would be provided and conclusions drawn on the cause and origin of the damage in Colonial Hall.

CONCLUSIONS

Damage to Colonial Hall occurred as a result of settlement including water saturation of the loess. The lack of angular distortion in the two halves of the building indicate that the settlement occurred over a long period of time. The case history of Colonial Hall illustrated the design process to the students and technically the need for proper drainage when structures are built on loess. The student evaluation of the course and in particular the opportunity to implement the geotechnical design process and to provide actual input in the ultimate repair of Colonial Hall was very favorable. In my opinion, the most insightful use of a case history in teaching the design process is one in which the student actually participates in the project. Local examples of building behavior can be found in campus settings and can be utilized as case history studies in engineering education.

REFERENCES

Doser, D.I. (1989). Extensional Tectonics in northern Utah and Southern Idaho, USA and the 1934 Hansel Valley sequence: Physics of the Earth and Planetary Interiors, v. 54 no. 1-2, pp. 120-134

Eagle Engineering . (2012). Structural Engineering Report Colonial Hall (#35) ISU report to JHS Architects, 13 March

JHS Architects. (2012). Engineering Study for ISU Colonial Hall, report to Idaho State University, 13 March

Peterson, M.D. et. al. (2008). 2008 United States National Seismic Hazard Maps: U.S. Geological Survey Fact Sheet 2008-3018. http://pubs.usgs.gov/fs/2008/3018/ accessed on 16 August 2012.

--- Salt Lake Tribune Articles for 1934 Hansel Valley Earthquake: Five Shocks Shake Wide West Area,http://www.seis.utahedu/lqthreat/nehrp___htm/ 1934hans/n1934ha2.shtml, pp 10-11 accessed on 16 August 2012

Shenon, P.J. (1936). The Utah Earthquake of March 12, 1934, in Neuman editor, United States Earthquakes, 1934: U>S> Coast and Geodetic Survey, Serial 593, pp. 43-48.

USGS. (2012). Quaternary Fault and Fold Database and USGS/NEIC (PDE) Earthquake Catalog.

engineering education, design process, case histories, building damage studies, loess