Classroom Integration of a Construction Case Study Using Active Learning

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Abstract — *A group of homeowners in a residential subdivision reported extensive settlement damage approximately two weeks after the groundwater in the vicinity of the subdivision was lowered during the installation of a 27-inch-diameter sanitary sewer main with an invert elevation about 19 ft below existing grade. Groundwater was lowered 12 ft during construction, down to a depth of 23 ft below existing grade. A lawsuit was filed by private homeowners against the general contractor, city municipality, engineering design firm, and geotechnical engineering firm as a result of alleged damages to residence structures. The interesting ramifications of this case are organized into a hands-on active learning exercise for a senior-level civil engineering course. This paper illustrates how complex technical issues can be organized and used as a valuable case study for university students to learn about the legal process of construction claims and the consequences of overlooking or misinterpreting technical data.*

The following key questions are addressed by students during the class exercise:

1. *How could a decrease in groundwater elevation cause settlement?*
2. *Is this a highly unusual or atypical phenomenon that cannot be explained or estimated using science and engineering techniques available to the engineering profession?*
3. *Based on the standard of care at the time, should the reported settlement problems have been anticipated, or at least examined, by the engineering firms engaged on this project?*
4. *Who is ultimately to blame for the damages that occurred? What is a reasonable restitution/punishment?*

Index Terms — *active learning case study, construction claim, dewatering-induced settlement*

BACKGROUND OF CASE

Introduction

The description provided herein focuses on technical details of the lawsuit and the seemingly disparate and incongruous conclusions provided by experts involved with the case. A construction claim and subsequent lawsuit was filed by a homeowner in a city located in the Rocky Mountain region of the U.S. The homeowner claimed that nearby construction dewatering resulted in ground settlement of the residence and consequential damage to the house. The plaintiff in this case was the homeowner of the subject residence. The defendants of the lawsuit included the project owner, the general contractor, the lead civil engineer/designer of the project, and the geotechnical firm that was hired by the lead civil firm to conduct an investigation in support of the design. An evaluation of geotechnical and geohydrological information was conducted to determine if settlement damage observed in the subject residence could have been associated with construction dewatering, which occurred during the installation of a sewer line adjacent to the homeowner's subdivision. For privacy reasons, names of specific organizations and individuals involved in the case have been omitted from this paper.

Inspections and measurements of the residence conducted by various engineering firms and agents indicated that differential settlement damages likely exceeded one inch; possibly as much as two inches in some places. Reports prepared by representatives of the defendants indicated that settlement of the residence should have been less than one inch (about 0.75 in). In contrast, the plaintiff contended that settlement damage in the home was caused by construction dewatering and that settlement magnitudes were in the range of 1 to 2 inches.

This paper explores these apparently conflicting positions using data that was available during the claim discovery period. The interesting ramifications of this case are organized into a hands-on active learning exercise for a senior-level civil engineering course. This paper illustrates how complex technical issues can be organized and used as a valuable case study for university students to learn about the legal process of construction claims and the consequences of overlooking or misinterpreting technical data

Project Details

The construction project consisted of the installation of a 27-inch-diameter sanitary sewer main with a bottom elevation about 19 ft below existing grade in the vicinity of the residence. The actual trench depth was about 23 feet in this section to provide clearance for pipe bedding gravel. The construction plans and specifications required that all work in the trench be conducted in the dry, including placement of the pipe bedding gravel and installation of the sewer pipe. Consequently, because of the presence of groundwater, dewatering was required during trenching and pipe installation. As shown in Figure 1, groundwater was lowered about 12 feet in the vicinity of the structure during the construction operation. The structure consisted of an approximately 2,200 ft^2 one-story wood house with a finished basement. The subject house was constructed in the 1990s in a middle-class residential neighborhood. This house was the closest structure to the trench and the contractor's primary dewatering well. The trench was excavated approximately parallel to the long axis of the house, about 50 feet from the back wall. The dewatering well was located about the same distance from the house.

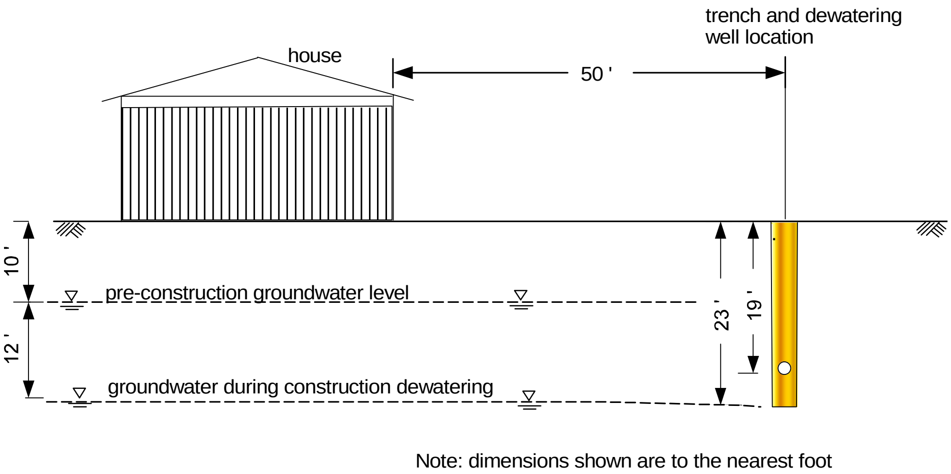


FIGURE 1. SUBSURFACE CROSS-SECTION AT THE SITE

Observed Damage in Residence

The plaintiff (homeowner) contacted the owner (City) and complained of settlement damage approximately two weeks after the contractor began dewatering. The subject house and other nearby houses in the subdivision were inspected for damage by four different engineers or engineering firms as well as representatives from law firms, constructions companies and insurance companies. Numerous irregularities in the interior of the subject home were documented, including drywall cracks in the ceiling, walls, and in many of the wall ceiling joists. Serviceability problems were observed, including: malfunctioning doors and windows, out of square door frames, and sloped and uneven floors and counters. Level measurements indicated the foundation and floor slabs appeared to have settled 2.16 and 1.60 inches, respectively. Independent measurements reported differential settlement of up to 1.38 inches

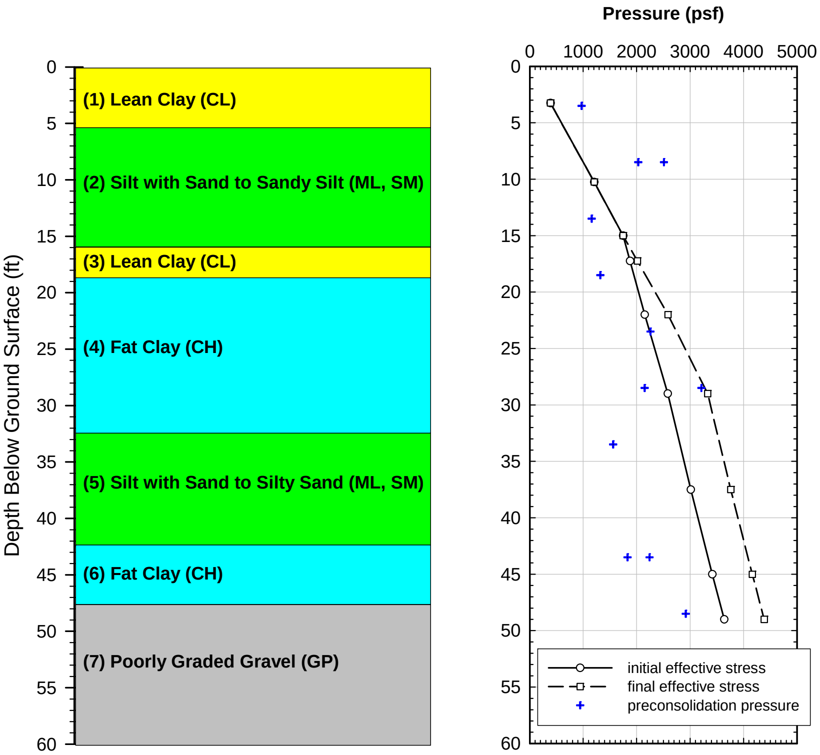
SOIL CONDITIONS

Subsurface Information

A limited geotechnical investigation was conducted along the sewer line alignment during the design phase of the project. However, as typical with these types of cases, a considerably more detailed investigation was conducted in the vicinity of the residence subsequent to the construction claim. The post-claim investigation included five soil borings, geophysical testing, and laboratory testing of split spoon and Shelby tube soil samples. Geotechnical reports compiled for the project site indicate that subsurface conditions in the vicinity of the residence consist of fine-grained alluvial soils underlain by coarse-grained alluvium over shale bedrock. Data and information from the geotechnical reports indicate soils at the site generally consist of a stiff surficial crust underlain by soft compressible fine-grained soils to a depth of about 50 ft below the ground surface. Data from five soil borings drilled at the site show the presence of a stiff layer from the ground surface to a depth of about 5 ft. Standard penetration (SPT) N-values in this region generally range between 10 and 30, and the estimated average undrained shear strength is about 1100 psf. The SPT N-values and estimated undrained shear strength values decrease markedly below this layer. The reported N-values are quite low from a depth of 5 ft down to the top of the sand and gravel layer, which was encountered at a depth of about 50 ft. Static groundwater was reported at a depth of about 15 ft. In general, the alluvial deposit encountered at this site is quite variable in both vertical and lateral extents.

Consolidation Settlement Analysis

The heterogeneous soils at the site exhibit the typical randomness of alluvial soils that were transported and deposited in a flowing water environment. The simple representative soil model shown in Figure 2a was developed using test data and boring logs from geotechnical and hydrological reports that were prepared for this case. The vertical pressure distribution shown in Figure 2b was calculated using measured soil unit weights and water contents. The change in vertical stress ($\Delta\sigma_v$) is based on a 12 ft drop in groundwater at the subject property as a result of construction dewatering. The calculated final vertical stress, during drawdown, is shown as a dashed line in Figure 2b. This information was used in the consolidations analysis discussed in the next section.



(a) Soil profile.

(b) Vertical stress distributions.

FIGURE 2. Representative Soil Model for Settlement Analyses

A consolidation analysis was conducted using laboratory test results generated during the post-construction investigation in conjunction with the subsurface model shown in Figure 2. A computer program that uses a numerical analysis procedure was employed to calculate the magnitude and rate of consolidation settlement. Conventional Terzaghi consolidation equations were used to determine the magnitude of the ultimate consolidation settlement, after the excess pore pressures are dissipated. A finite difference approximation was used to calculate the rate of consolidation settlement and the rate of dissipation of excess pore pressures. Time rate values of soil consolidation are represented by the coefficient of consolidation, c_v, which are determined from laboratory consolidation tests. The available geotechnical data (including both consolidation and strength tests) indicate the soil deposit is normally consolidated. Using measured data from the defendant's geotechnical report, the calculated primary consolidation settlement amounts range from about 3 to 3.5 inches, as shown in Figure 3. The solid line in Figure 3 was calculated using a constant groundwater drawdown level of 12 ft, while the dashed line was calculated using the drawdown and recovery curve obtained from a dewatering test adjacent to the site. The magnitudes of settlement shown in Figure 3 are consistent with the settlement damage that was observed and documented at the residence.

A report produced by the defendants presents a calculated settlement estimate approximately 75% less than the amount shown in Figure 3. The discrepancy is believed to occur in the assumptions used to evaluate the data and inconsistencies in the data itself. As with most analyses involving the prediction of soil response, there is seldom a single "correct" answer, but rather a predictive range or probable outcome. Variability introduced in calculations as a result of inaccurate assumptions or erroneous data can decrease the reliability and precision of calculated settlements. The following section further explores Potential reasons behind the apparent discrepancies in calculated settlements include assumptions regarding in-situ physical conditions, both past and present, and inaccuracies in soil test data.

The relative size of the predictive range of outcomes depends upon many factors including:

1. variability of the soil deposit,
2. stress history of the soil,
3. fluctuations in historic and construction groundwater levels,
4. limitations and sources of error inherent with geotechnical soil sampling and testing, and
5. inaccuracies in analytical methods for modelling the complex nonlinear and time-dependent behaviour of soils.

Variability introduced in calculations as a result of inaccurate assumptions or erroneous data can decrease the reliability and precision of calculated settlements. This aspect of the case study is used to help students understand the ramifications of uncertainty in engineering calculations.

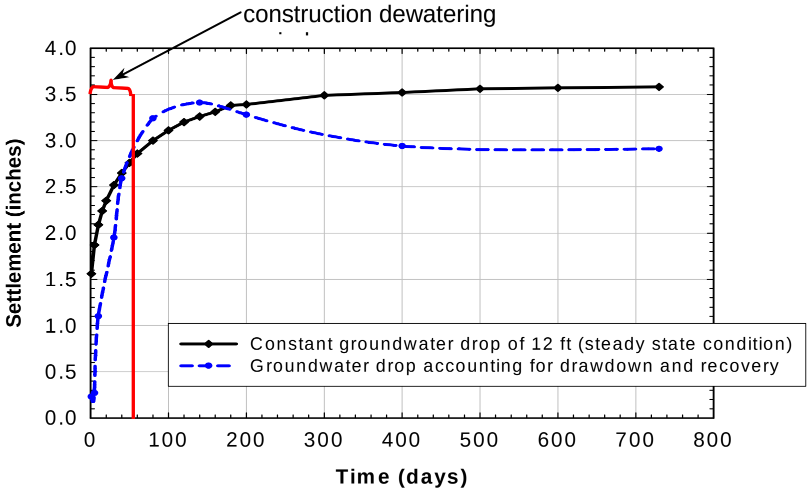


FIGURE 3. CALCULATED SETTLEMENT ASSUMING SOIL IS NORMALLY CONSOLIDATED

ACTIVE LEARNING CLASS EXERCISE

Overview

This case study provides students with a role-playing opportunity to gain experience and learn about the construction claim process, which also necessitates the integration of technical issues from engineering courses. Students are provided a brief introduction that consists of a general overview of the project and claim, with only enough detail to get them started. Figure 4 is used to explain the contractual relationship of the parties involved with the claim. After the brief overview, the instructor quickly divides students into six groups that represent the primary parties involved with the claim. One group represents the 1) plaintiff (**Homeowner**), another group represents the 2) **Judge and Jury**, and the other four groups represent the defendants, consisting of: 3) project owner (**City**), 4) Construction Company (**Contractor**), 5) Civil Engineering Company (**Civil**), and 6) Geotechnical Engineering Company (**Geotech**). The following paragraphs describe the information that is provided to the student groups.

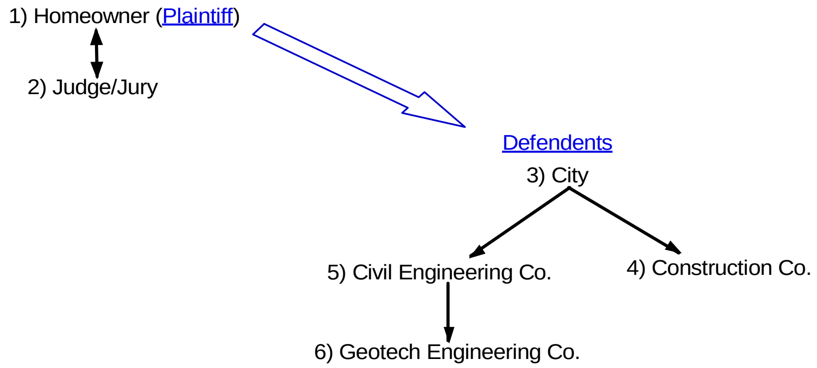


FIGURE 4. CONTRACTUAL RELATIONSHIP BETWEEN ENTITIES INVOLVED WITH THE CASE

Plaintiff (Homeowner)

- Primary plaintiff in the case.
- Contacted City with complaint two weeks after construction dewatering commenced.
- Numerous irregularities in the interior of the subject home were documented; settlement problems were obvious and rather extensive.
- Homeowner felt the City was unresponsive.
- Homeowner hired a lawyer who subsequently hired experts to develop technical support for the lawsuit. Cost of the claim escalated substantially as the case progressed.
- Additional lawsuits were filed by other homeowners in the area.

Judge/Jury

- Students in this group take the role of a dispute regulator or arbitrator. The primary role of this group is to focus on dispute resolution and compromise.

Project Owner (City)

- Hired Civil Engineering Company to be the lead design agency and develop contract documents.
- Awarded construction contract to Construction Company based on lowest submitted bid.
- City took no apparent or visible direct action after being contacted by the Homeowner.
- City assumed a position that all construction-related issues and third-party complaints were the Contractor's responsibly to resolve.

Construction Company (Contractor)

- Relevant construction activities included dewatering, trench excavation, and pipe installation.
- Contract documents required the contractor to hire a specialty subcontractor to conduct dewatering.
- Contract documents required the contractor to submit a dewatering plan developed by the specialty subcontractor.
- A subcontractor was not hired. No dewatering plan was submitted.
- Contractor made no apparent alteration to construction methods as a result of the claim.
- After the lawsuit was filed, Contractor claimed the construction documents including the geotechnical report did not provide any warnings or guidance regarding potential dewatering-induced settlement.

Civil Engineering Company (Civil)

- Civil was hired by the City to design the project and prepare contract documents (plans and specifications).
- Contract documents required Contractor to hire a specialty subcontractor to conduct dewatering.
- Contract documents developed by Civil required Contractor to submit a dewatering plan developed by a specialty subcontractor.
- Civil hired the Geotech to conduct a subsurface investigation for the sewer line project and provide written recommendations regarding geotechnical related construction issues.
- Civil provided no feedback or comment to the City regarding Contractor's dewatering operation or lack of a specialty dewatering subcontractor.
- After lawsuit was filed, Civil claimed Geotech was responsible for any settlement-related damage to adjacent structures.

Geotechnical Engineering Company (Geotech)

- Conducted subsurface investigation along sewer alignment.
- Provided Civil with a written report containing recommendations on construction-related soil conditions.
- Geotech reported that dewatering, trench bracing, and excavation safety were the contractor's responsibilities.
- After the lawsuit, Geotech claimed that an evaluation of dewatering-induced settlement was outside of their scope of work and not their responsibility.

MARGIN OF ERROR IN THE SETTLEMENT CALCULATIONS

Interestingly, eight of twelve samples tested by the defendants had overconsolidation ratios (OCR) less than one, indicating an underconsolidated deposit. This would indicate the layer has not yet come to equilibrium under the weight of the overburden load. If pore water pressures were measured under these conditions, the pressures would be in excess of hydrostatic. If the soils were truly underconsolidated, they would be highly compressible and would continually settle until a stress-equilibrium condition was reached. Any additional load or stress increase would result in comparably large settlements.

Based on the geologic setting and past land use practices in the area, there is no evidence indicating the soils at the site are underconsolidated. Rather, it is more likely that some of the consolidation test data may not be accurate. The defendant's report attributes inconsistencies in their consolidation test data to sample disturbance. As discussed in their report, it is very difficult to obtain high-quality undisturbed samples in soft compressible clay deposits. The amount of disturbance is proportional to the strength and compressibility of the deposit and the care used in obtaining and testing the samples. Even if the highest standards of practice are followed in the drilling, sampling, and testing methods, some disturbance will occur and this disturbance will have adverse effects on the data obtained from laboratory consolidation tests. Based on the soft compressible nature of this soil deposit, as illustrated in the low SPT blow counts and the low values of undrained shear strength, it is not surprising that the geotechnical firm had difficulties obtaining accurate laboratory consolidation test results. In addition, past and present groundwater levels will influence the consolidation calculations because groundwater directly affects the soil stress state and the relationship between stress increase and strain. Surprisingly, the project geotechnical company assumed the soils were not underconsolidated, as their data suggested, but were actually overconsolidated (OC). They based this assumption on approximations and estimates described in a hydrology report, which inferred that historic groundwater levels prior to irrigation were lower than at present.

Settlement Calculations

The defendants' settlement estimate is based on the premise that the soils are overconsolidated, in which case the calculated settlement will be directly proportional to the slope of the recompression curve (C_r). Error factors as large as 2.67 and 3.10 were backcalculated for C_r and the other pertinent consolidation parameters. Based on this observed variability, the calculated range of settlement by the defendants could be in error by as much as 200% (0.6 to 1.8 in).

Figure 5 shows the variation in calculated settlement in relation to the assumed historic water level. Uncertainty in the settlement prediction increases as additional variables are examined. In this case, the assumption regarding historic water levels is superimposed with the error factor in the C_r soil parameter. Considering these two parameters, the variability in the settlement prediction (or margin of error) now increases from 1.2 in to 3.4 in. The high end of this range corresponds to a condition in which the pre-irrigation groundwater level is similar to the current groundwater level, in which case the soil deposit would be normally consolidated.

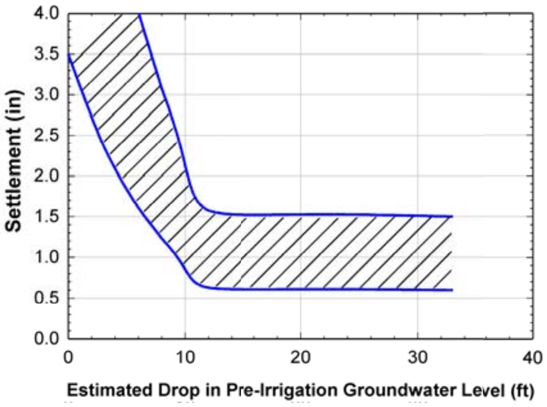


FIGURE 5. VARIATION IN CALCULATED SETTLEMENT AS A FUNCTION OF HISTORIC GROUNDWATER LEVELS

SUMMARY

As with any analysis that involves approximations and assumptions, there is seldom a single absolute solution, but rather a range of possible outcomes. It is emphasized with the students that often more than one answer is feasible even when analyses are conducted using proper mechanics, because there will always be some margin of error and potential contentiousness. Following is a summary of key technical issues associated with this case:

1. The soils beneath the residence consist of very soft, compressible, saturated clayey and silty soils.
2. Groundwater beneath the residence was lowered by as much as 12 ft during the dewatering operation.
3. A drop in the groundwater level (at any site) will result in a stress increase within the soil deposit because of the reduction in buoyancy (Archimedes principle). A stress increase will be accompanied by strain (Hooke's Law). Settlement (or deformation) is the integration of strain over the effected volume of material. The amount of settlement depends on the stiffness (or modulus) of the soil and the soil stress history. In other words, consolidation settlement due to an increase in effective stress will occur when groundwater is lowered in compressible soils.
4. Saturated clayey and silty soils experience stress-strain-time-dependent settlement known as consolidation settlement.
5. The subject residence experienced obvious settlement damage and the homeowner first filed damage reports about two weeks after the contractor began construction dewatering adjacent to the residence.
6. There are two possible scenarios regarding the defendants geotechnical test data: i) the data is correct or mostly correct, in which case the soil is normally consolidated; or ii) the data is erroneous, in which case a specific value of settlement cannot be calculated with any degree of reliability.
7. Based on the author's analyses, both consolidation and strength data indicate the soils are normally consolidated. Settlement of about 3 inches would be predicted using state-of-the-practice conventional geotechnical engineering procedures.

CONCLUSION

Currently available scientific methodologies and analytical methods indicate the subject residence in this case experienced damaging settlement as a result of groundwater lowering caused by nearby construction dewatering. However, there is more to the story than the technical result. Case studies incorporated into the classroom provide opportunities for discussing "gray areas" of engineering design and construction. For example, one aspect that arises in this case involves the difficulty in interpreting and modelling current and historic subsurface conditions. Paraphrasing Ralph Peck: *our ability to analyze far exceeds our ability to accurately characterize soil conditions*. This adage is quite relevant for the circumstances at this site and should be kept in mind when evaluating geotechnical engineering and foundation reports. Lesson learned — there will always be uncertainties associated with geotechnical analyses and these uncertainties will be proportional to the complexities and the unknowns of the site and the underlying soils.

A bumper sticker saying nicely summarizes an important benefit of studying construction case studies: "*Good judgment comes from experience. Experience comes from bad judgment.*" In terms of construction claims, bad judgment could be interpreted as mistakes made by haste, oversight, lack of technical skills in a particular area, misinterpretation of technical data, etc. Recently graduated engineers or engineering students may have confidence and technical skills but they lack experience and judgment, which can only be developed over time. These important skills are enhanced and fostered through quality mentoring by senior-level colleagues and supervisors. Students can begin to develop good judgment by learning from the good and the bad decisions (or mistakes) made by others. Case study exercises such as this example provide a controlled environment for students to actively begin the cultivation of experience and judgment. These types of in-class activities also provide excellent venues to introduce and further explore ethical issues that can develop in the course of an engineering/construction project.