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Historic Building Case Study: Measuring Differential Settlement Combined with Experiential Learning

Kyle Larson, Ph.D., P.E. and Steve Schaffner
Kansas State University
Manhattan, Kansas

Lindsay Anderson
Centric Homes
Kansas City, Missouri

Sagging floors along with cracked interior finishes and exterior masonry is commonplace for structures that have been in service for an extended period of time. Differential settlement is a phenomenon that many structures undergo. A historical building society had a building that was over 150 years old and was experiencing the aforementioned distresses. Wanting a second opinion they called a local university for their expertise and help. The faculty decided this project would be a great opportunity for an undergraduate construction science student to interact with a client and develop a solution. The project led to a great experiential learning opportunity for one student. The student was able to interact with a client and come up with real world solutions, just like they would have to endure once in industry. The student had to determine what was causing the cracking and find a way to prove if there were immediate safety concerns for the building. In the end everyone benefited from the project as the historical building society received a valuable second opinion and an undergraduate student found practical uses for ideas to solve problems and make decisions based on the findings.

Key Words: Differential Settlement, Experiential Learning, Historical Building, Assessment Report, Undergraduate Research

Introduction

What happens when the president of an historical building society in rural North America think they have rapid settlement and foundation concerns for a building initially constructed in the 1860's? In this instance the president called a local contractor who proposed expensive foundation and subflooring repairs and sold the building society that these repairs needed to be made immediately. The building society was convinced that the interior and exterior wall cracking and sagging floors were deteriorating rapidly by the day. They were convinced that the unevenness of the walls and floors, Figure 1, were getting worse by the day and not a result of long-term settlement and natural aging of the building. The building society wanted to get a second opinion prior to performing these expensive repairs. However, being in rural America they did not have many options. Thus, they called a local university that had an engineering and construction program to see if they could perform

a review of the building and provide opinions. Several faculty members agreed to take on the project. They saw this as an opportunity to not only provide help to the historical building society but also as an experiential learning opportunity for an undergraduate student in the construction science program. The student would have the opportunity to interact with the client, perform an onsite assessment, and prepare a written report for a client. The scope of the project entailed determining if the perceived settlement and interior finishes cracking were all an immediate concern or if the cracking and sagging floors were natural for a building of this age. Upon completion of the assessment, a final written report would be prepared for the historical building society.

Figure 1. Plumbness of header above doorway

Literature Review

The traditional lecture mode of teaching in the college classroom has shifted over the past few decades. The days of instructors lecturing and students taking notes the entire class period are being replaced with active learning and cooperative learning. Active learning is one that replaces the traditional method of relying solely on the instructor's lectures and introducing any activity that engages the student in critical thought. Dewey foresaw what employers and graduates see today, the need for general intellectual and analytical skills (problem-solving) through practical "hands-on" training (Davies et al., 1999). Much research on the topic of active learning has been completed over the last several decades as evidenced by both Faust and Paulson (1998) and Sims (1995) to just name a few. A simple internet search will result in numerous studies on the topic of active learning. Faust and Paulson (1998) define active learning as "any activity engaged in by students in a classroom other than listening passively to an instructor's lecture." As they conclude: "Active-learning techniques…are those activities that an instructor incorporates into the classroom to foster active learning." In short, anything other than passively listening to an instructor's lecture.

Many examples exist on what some would classify as active learning. One-minute papers, think-pair-share, skeleton style notes, field trips, cooperative learning, flipped classroom, and experiential learning are just a few of the active learning techniques that are being used in the classroom as evidenced by Faust and Paulson (1998). There are many branches of constructivist although most all denominations agree with the basic principle "learning is not a passive receiving of ready-made knowledge but a process of construction in which the students themselves have to be the primary actors" (Von Glasersfeld, 1995). Experiential learning is an active learning technique that has been

cited many times. Kolb (1984) defines experiential learning as "the process whereby knowledge is created through the transformation of experience." One learns new knowledge through four different modes; concrete experience, abilities, reflective observation abilities, abstract conceptualization abilities, and active experimentation (Kolb 1984). Lee et al. (2008) took the four learning modes and styles of experiential learning and applied them to the experiential learning process. They did this at both a macro and micro level. One of the major findings was that there was a positive correlation between the implementation of the aforementioned four modes of experiential learning and students learning.

A study (Stice 1987) of the retention of knowledge showed 20% retention when only abstract conceptualization was used. Stice further indicated as more of the Kolb's modes are used, the retention rate increased. The study also shows a 90% retention when all four modes are used, concrete experience, abilities, reflective observation abilities, abstract conceptualization abilities, and active experimentation. These are the four building blocks used during the undergraduate research.

What is Experiential Learning

When discussing practice theory, often Sophocles' is often quoted from 400 B.C., "one must learn by doing the thing, for though you think you know it, you have no certainty until you try", (Gentry 1990). Undergraduate research is one method of experiential learning. Bresnen (2009) postulated that practice theory has been offered as a useful approach for investigation of actual work practices. Another step to practice theory is the pedagogy of project-based learning. This style of learning is action based and allows the student to put the classroom instruction to practical use as noted by Figgess (2017). The faculty focused on using Kolb's four modes of learning while working with the student to assist in all aspects as well as knowledge retention. In this particular research the student experienced both the hard skills for monitoring the differential settlement as well as the soft skills for dealing with a client.

What is Differential Settlement

The behavior of differential settlement for a building is influenced by the soil beneath the structures foundations, (Lahri, 2015). This is especially true with historical buildings due to the decades of soil settlement and freeze thaw cycles. If this settlement is uniform there is no impact on the building structure. However, when the building experiences non-uniform, or differential settlement damage often occurs to the structure (Lahri, 2015). This depends on many factors such as the type and loading of the structure, soil conditions, and the rigidity of the building frame (Arapakou & Papadopoulos, 2012). Additionally, a historic building often has renovations and additions throughout its life, which may increase the likelihood of non-uniform settlement. Determining the cause of differential settlement can be challenging. Common causes are "expulsion of water from the soil mass, flooding, frost heave…tree root systems and inappropriate foundation designs" (Lahri, 2015). Often the issue is determining whether the settlement is continuing, or has ran its course. There are a myriad of tools for monitoring the settlement of a building. The most common measuring technique is determining movement of cracking with electronic or analog equipment and leveling instruments (Rossi, 2001).

Ways to Measure Differential Settlement

The authors decided the best way to measure any settlement would be with a zip level. A zip level is a high precision pressurized hydrostatic altimeter (Corporation 2022), Figure 2. Spot elevations can

be measured at various locations and compared to a zero-elevation datum. Then future measurements can be made and compared to the original measurements to see the magnitude of settlement. The zip level was advantageous as only one person is needed to operate, which was carried out by the undergraduate student. The authors determined that any short-term settlements under 0.5-inches could be attributed to tolerance of the zip-level or spot elevations not taken directly in the same exact location. Any change in elevation over 0.5-inches would be considered extreme and constitute settlement at a rate that would be unsafe for the building.

Figure 2. Zip level used for elevation change measurements

Project Background

Ellsworth Building

Ellsworth, Kansas, is a small town located in the central portion of the state. In the late 1860's during the Kansas Pacific Railroad period, the town became popular by operating a major stockyard for all cattle entering town to then be shipped to eastern markets. During the years 1874 through 1876, Ellsworth experienced unexpected and detrimental fires to the town which consumed many residences and other buildings on both north and south Main streets. To avoid any more damaging fires, Perry and Phoebe Hodgen owned the first private home with a stone exterior in 1876, Figure 3. The famous and historic Hodgen House is located between the Smokey Hill River and the towns historic railroad tracks. Even though the historic house still stands tall amongst the Ellsworth community, there lies concerns of foundation settlement issues that may cause further problems if not serviced.

The Hodgen House was built in 1876 with many additions that were to follow over the next few years. The original structure of the house is a two-story wood frame building that sits upon a rock foundation along with a stonework exterior which was later added around 1878. In 1879, a one-story addition was built along the East backside of the house which consisted of two additional rooms to the house. The following year in 1880, there was a second floor constructed above the East addition that included another two rooms to the household. In 1882, a two-story addition was constructed on the West backside that included four more additional rooms. Aside from other improvements to the house that come in later years, approximately six years of construction transpired to develop the full structure of the house as it is today.

Figure 3. Hodgen House on North East elevation

Experiential Learning

The undergraduate student was responsible for interacting with the client by using soft skills that were further developed in many classes throughout their undergraduate studies. This included setting up site visits and learning about the history of the building. Technical (hard) skills were needed to complete the survey and determine if the building was undergoing short-term settlement. The student had to research the best way to measure any settlement and determined the best course of action for that would be with the use of wall mounted strain gages and the aforementioned zip level. At the end of the project the student was responsible to preparing an assessment report for the client and verbally delivering the results to the client.

Initial Survey

The Hodgen House was first visited on September 28th, 2021 and the initial observations noted were cracks found on a few walls as well as the slopping and sagging floors seen throughout the house. Figure 4 shows the typical sagging floor at room entry thresholds.

Figure 4. Typical floor conditions

During this visit, strain gages were installed on two wall crack locations. Figure 5A shows the strain when it was first installed with the cross-hairs near the zero-zero intersection. On January 26th, 2022, observation of the same strain gage was captured to investigate if there was any difference or comparison of when it was first installed shown in Figure 5B. The results were to determine if there is to be any widening of those cracks occurring over time as the cross-hairs are still near the zero-zero intersections. It can be seen from these figures (5A & 5B) that negligible movement occurred and short-term settlement was not occurring at a noticeable rate.

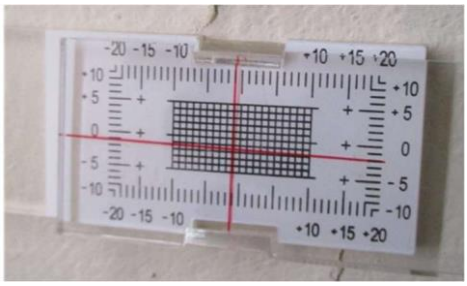

Figure 5A. Strain gage 1 on Sept 28, 2021

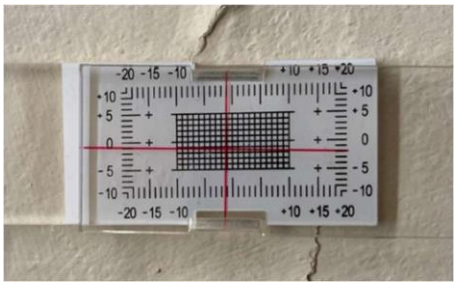

Figure 5B. Strain Gage 1 on Jan 26, 2022

Data Collection

On November 13th, 2021, a zip level was utilized to measure floor elevations throughout the Hodgen House. A zip level is a measuring tool that calculates elevation differences from a known benchmark (indicated by the red dot in Figure 6). The zip level measured elevations at different locations throughout the house to determine exactly how much the floor elevations had changed over a given time frame. After determining the floor elevations at approximately four-foot increments throughout the first floor, a survey map was designed to display the high and low areas within the house. The total difference between the highest and lowest recorded elevation points calculated to a value of 5.5 inches. On March 3, 2022, the zip level was used for a second time to collect another set of elevation points to then compare those values to the original data. In the second survey map, the total difference between the highest and lowest locations calculated of 5.7 inches which is a 0.2-inch increase from the first survey. Refer to Figure 6 to view the survey elevation maps conducted on November 13, 2021, and March 3, 2022.

Conclusions and Discussion

Results

After observing the strain gages installed at the set locations compared to when they were first installed, there is a near zero difference between the two periods. Therefore, the data from the strain gages indicates there has not been any significant movement within those wall crack locations in the four months after being installed and recording data. From the conducted floor elevation observations

that transpired before and after the winter season, a net change map was created to determine how much the building's foundation moved within those few months.

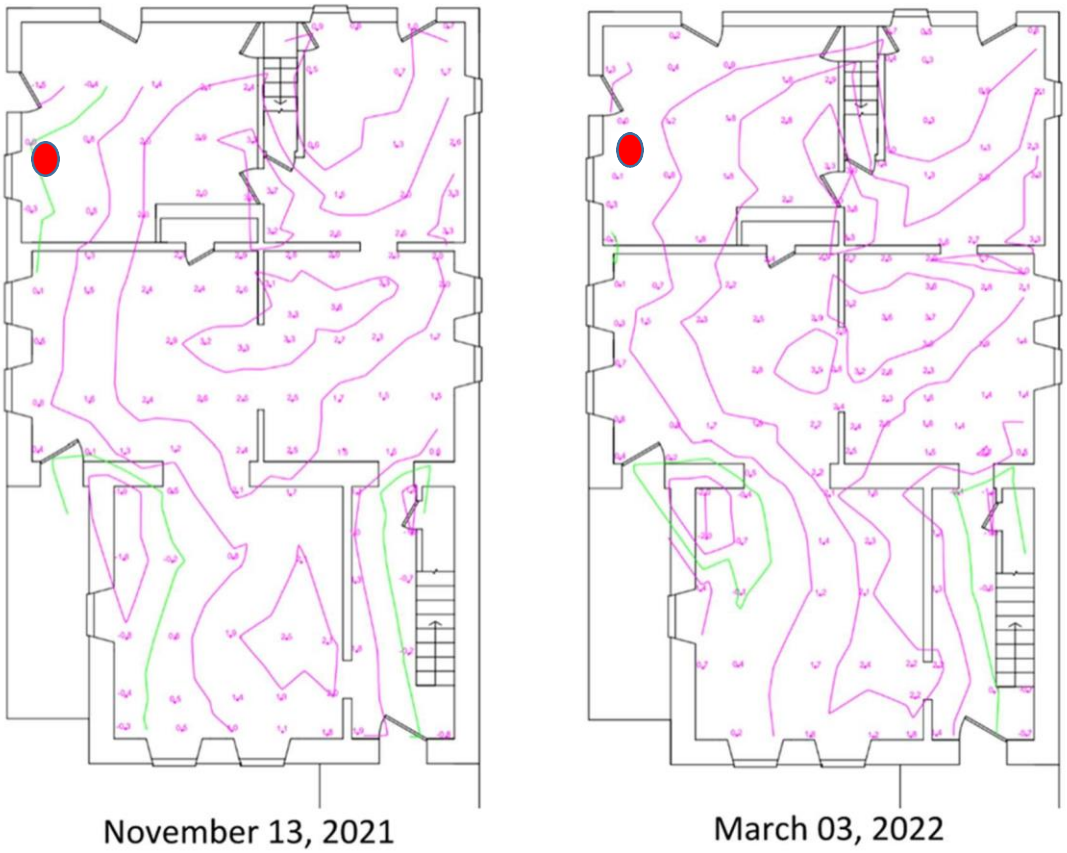

Figure 6. Survey Elevation Maps

Figure 7 shows the net changes in elevations off an absolute value. According to the data observed, there was not a floor elevation change larger than half an inch and that occurred in a few isolated locations. The lack of large deflections indicates there was very little movement within the structure that took place. Slight movement in a building is typical since numerous freeze-thaw cycles can occur in a short period of time. Regardless of a building's age, experiencing settlement is inevitable to happen. Additionally, due to its age, differential settlement is common to occur. Due to the lack of large net elevation changes greater than 0.2-inches in the 4-month period between readings the building is not undergoing rapid settlement, rather the building has experienced long-term differential settlement. Thus, the sagging floors and cracked finishes are not an immediate concern but should be repaired from both a moisture intrusion and serviceability standpoint.

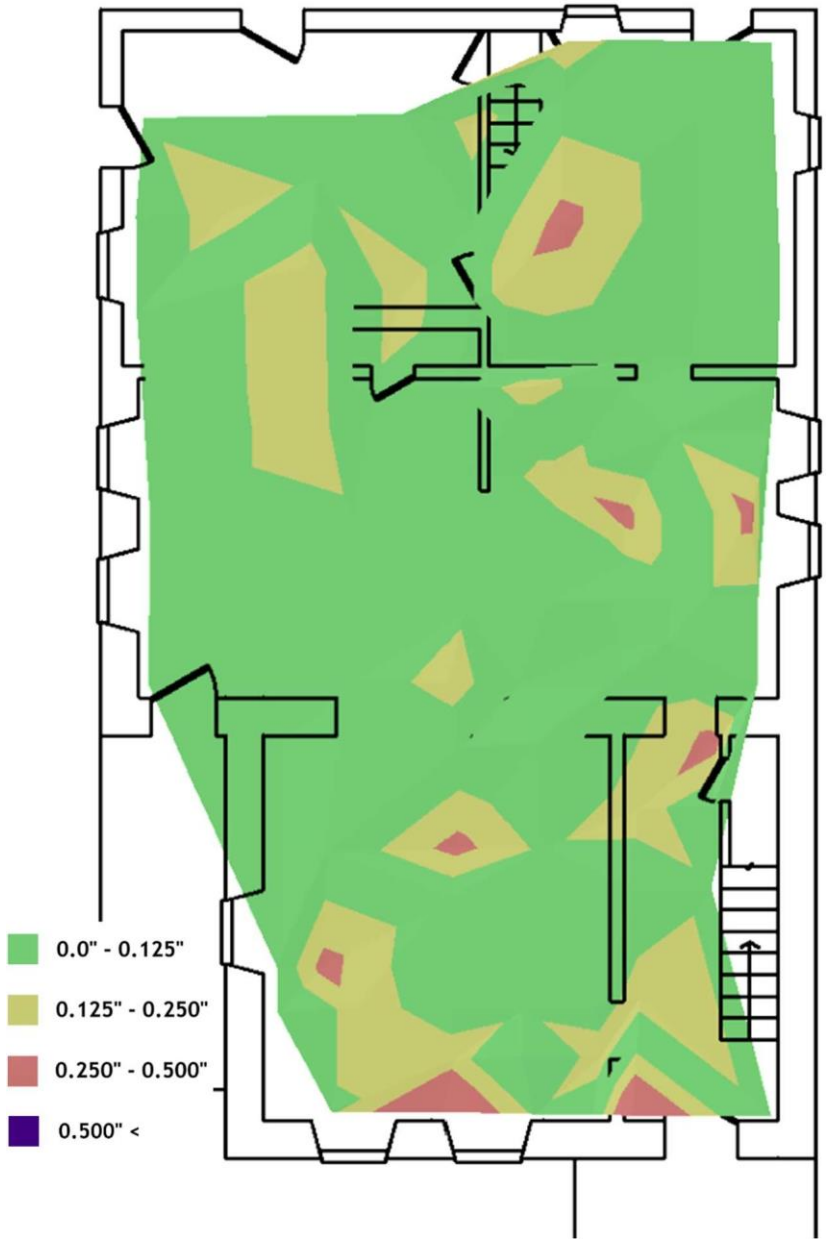

Figure 7. Net change in elevation of first floor

Experiential Learning Results

"Tell me, and I will forget. Show me and I may remember. Involve me, and I will understand." This is a famous quote that many have attributed to Benjamin Franklin or Confucius. It can also explain the importance of active learning as opposed to passively sitting in the back of a classroom listening

to an instructor lecture for class periods on end. Through this research, the student gained experience in both hard and soft skills by actively learning. The student was presented with a problem, from a specific client, collected data, analyzed the data and developed a finding. Additionally, the student interacted with the client, using and developing soft skills. This entire research project helped to prepare the student for a career in construction management. Using the four modes of experiential learning the faculty determined the student found practical uses for ideas to solve problems and make decisions based on the findings.

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