



Title	Forensic investigation methodology for structures experiencing settlement
Authors(s)	Laefer, Debra F., Evans, Ashley, Frazier, Jon
Publication date	2006
Publication information	Laefer, Debra F., Ashley Evans, and Jon Frazier. "Forensic Investigation Methodology for Structures Experiencing Settlement" 37, no. 2-3 (2006).
Publisher	Association for Preservation Technology International (APT)
Item record/more information	http://hdl.handle.net/10197/2867

Downloaded 2024-04-19 05:16:53

The UCD community has made this article openly available. Please share how this access benefits you. Your story matters! (@ucd_oa)



© Some rights reserved. For more information

Forensic Investigation Methodology for Structures Experiencing Settlement

Debra Laefer, Ashley Evans, and Jon Frazier

The progressive settlement of a plantation in North Carolina is explored through a post-damage inspection.

If a building is experiencing settlement or other deleterious movement, the underlying causes must be established to prevent further damage and ensure effective repair. This article outlines a methodology for the forensic investigation of historic structures experiencing what may appear to be structural distress and provides a case history exemplifying the effectiveness of the proposed method for establishing settlement-related movements. Through simple and straightforward engineering principles, a logical and methodical approach can be applied to determine contributing factors to historic-building distress. Key elements of this method include documentation of the history of architectural damage and apparent distress, consideration of initial and existing structural loading capacity (including both the structural system and specific materials), exploration of soil conditions, and investigation of groundwater factors.

Methodology

Building settlement can be generated by a wide variety of natural actions and means that are imposed by humans and result in temporary or permanent changes to the structural, geotechnical, and hydrological conditions.-Determining sources of settlement requires a systematic elimination of factors from the most likely to the unexpected, including the effects of structural loading, soil behavior, and position of the groundwater table (e.g., the height of standing water in the soil, as evidenced through excavating). As such, the proposed forensic methodology addresses all of these factors, beginning at the structure and gradually moving away from it, thereby adopting an investigative approach from the local to the global. Using this paradigm, structural loading is the first factor to consider.

Structural causes. All structures are built with a specific anticipated load, even if load consideration is simply an empirically based, rule-of-thumb approach grounded in long-standing traditions of what has worked in the past. The predicted load determines the selection of the structural system, the sizing of structural members, the connection details, the transfer mechanisms into the foundation and the foundations' geometry. If a system was improperly designed, the original loads miscalculated, or additional loads — either natural (e.g., wind, earthquake) or those introduced by humans (e.g., adding extra floors, conversion from a private structure to a public one) are applied, the original structural elements may no longer be able to function properly. Post-construction structural assessments must consider the original expectations of the design, as well as the actual usage and the visible performance of the building. As determining loading is an inexact science, the performance of the materials must be relied upon as the final arbitrator. If the distress does not have a structural origin, geotechnical considerations should be investigated next.

Soil causes. Both long-term and short-term soil-based settlement can be induced as a direct outgrowth of the soil materials and changes in the water content of the soil. Depending on the subsurface conditions, changes may continue to occur for decades, if not centuries, as in the case of the Leaning Tower of Pisa, where long-term consolidation has been a problem since the erection of this twelfth-century monument.¹ If there is no apparent soil cause, groundwater sources should be considered.

Groundwater causes. When a groundwater table recedes, a loss of buoyancy occurs, and the load that was previously carried jointly by the soil particles and the water must now be borne completely by the soil-particle matrix. The water lowering results in an approximate 50 percent increase in the load carried by the soil-particle matrix. Lowering the groundwater level can densify sand and other granular materials. Particles in the soil-particle matrix may be able to reorganize themselves into a denser configuration and occupy space previously filled by the water, a condition that may result in settlement at the ground surface. In soils composed of silts and clays, the extra load onto the soil matrix induces consolidation, but

unlike the densification of the in the granular material, where the change is nearly instantaneous, the settlement during consolidation of silt and clay occurs over weeks and years, depending upon the drainage conditions and the thickness of the soil layers from which the water has been removed.

Application

This article applies the above-outlined investigation methodology to Somerset Place, a nineteenth-century plantation and designated state historic site located in Washington County in northeastern North Carolina. Somerset Place is the largest extant plantation in the state. By 1992 buildings at the site began to exhibit signs of structural distress.² Under the auspices of the North Carolina Department of Cultural Affairs, an investigation of some of the buildings on the plantation was initiated at the end of 2001. Some of the findings of that investigation are included herein.

History

For nearly 80 years Somerset Place was an active plantation, encompassing 100,000 acres.³ The site has significant archaeological importance due to its connection with both antebellum and slave life. The plantation is open to the public in conjunction with Pettigrew State Park — one of the last surviving natural swamps in North Carolina. The proximity of swampland and water to Somerset Place has always been an integral feature of the property (Fig. 1).⁴

In 1755, a group of local hunters investigated the Eastern Dismal Swamp in hopes of cultivating arable farmland. Surrounded by what would later be named Lake Phelps, highly fertile land was identified but not developed until 1784. Local property owners Nathaniel Allen, Samuel Dickinson, and Josiah Collins initially proposed that the lake should be drained for cultivation but instead formed the Lake Company to build a canal.⁵ In 1788, the Lake Company built a canal to connect the Scuppernong River for irrigation of the surrounding area and transportation of goods to the Albemarle Sound (Fig. 2).⁶

Josiah Collins would later become the sole owner of the property now known as Somerset Place, which he used exclusively as crop acreage.⁷ In 1790 Collins built the first structure on the property, the

Great Barn, which was destroyed by fire in 1849. Slave quarters and many of the plantation's functionary buildings were constructed by Josiah Collins Jr., after his father's death in 1819. Both the elder Collins and his son resided in the city of Edenton (twenty miles north of the plantation) and initially managed Somerset Place as non-tenant farmers. Prior to his death in 1839, Josiah Collins Jr. began to develop Somerset Place into a homestead for his son, Josiah Collins III, primarily through the construction of the Collins House, also known as the Collins Mansion. The structure was the largest and most expensive building on the property and is presently considered the most important extant structure at Somerset Place. Josiah Collins III was the first owner to live on the property, and he immediately expanded the Collins House to keep pace with building trends at nearby properties. He resided in the Collins House until his death in 1863.⁸

The Collins House was constructed in at least two phases. The first phase, undertaken in the late 1830s, is believed to include the large section of the house nearest to the canal. The second phase, closer to Lake Phelps, was added in the 1840s and built over an older cistern. After Josiah's death and the accidental death of two of his heirs in a boating incident, the plantation passed to Josiah's wife, Mary Collins, who maintained the plantation until just after the Civil War.⁹

The Collins family was forced to auction the property in 1867, and after passing through several different owners, Somerset Place was acquired by the Rocky Mountain Bank in the 1920s. The Farm Security Administration acquired the plantation in 1937, and in 1939 the State of North Carolina became the owner of Somerset Place, which, after 70 years of neglect, then became part of Pettigrew State Park. By 1967, when the plantation was transferred from the Division of Parks and Recreation to the Department of Archives and History, only a handful of buildings remained. The plantation's surviving buildings and 33 surrounding acres were designated a state historic site in 1969 and a National Historic Place in 1970.⁽¹⁰⁾

Buildings at Somerset Place

At its peak, the plantation housed more than 300 enslaved Africans, who cultivated wheat, rice, and corn and built and maintained the structures.¹¹ The more than 50 buildings included the family's dwellings, an overseer's house, a kitchen, a smokehouse, a dairy, a church, a school, and over 20 slave quarters (Fig. 2). Most prominent among the remaining buildings are the Collins House and the overseer's house.

Problems

The focus of concern of a 1980 investigation was on the Collins House. It is a two-and-a-half-story, wood-framed structure covered with clapboard, resting on a series of brick piers. A brick skirting surrounds the 2-to-3-foot-high crawl space. The house has 13 rooms, a large central hallway, and measures approximately 60 feet by 30 feet in plan.

In April 1980, investigators sought to determine the cause of structural deformations and architectural distress identified during a major restoration. The investigation primarily focused on a visual inspection of the house, an approximation of loads and their paths to the foundations, and four boreholes drilled to obtain soil specimens and establish groundwater position. A soil boring to the depth of approximately 30 feet was taken near each corner of the Collins House. No laboratory or destructive testing was conducted. That study concluded that all extant deformation and damage was due to long-term soil settlement and that 140 years after construction no additional movement of the Collins House should be expected.¹²

In 1989, when the site's current director was hired, no structure on the site exhibited any specific distress, yet by 2001, the Collins House was experiencing deformation that interfered significantly with the building's functionality. Most noticeable were that doors and windows had become inoperable and interfered with safety and maintenance. Further investigation by the authors revealed splintering of architectural features, shearing of porch rails, and cracks in the brick piers.

By 2001 the portion of the house that had been built over an old cistern had moved so much that the lid of the cistern had become wedged between the house and the cistern to such an extent that it could

not be removed without jacking the house. The cistern now acted as a load-bearing pier beneath the house.

The site staff initially thought that the cause of the distress on the property was related to increased visitor traffic in the Collins House and the placement of several heavy filing cabinets on the second floor of the overseer's house, which was also showing signs of distress. Concern for structural overloading motivated the staff to close various parts of the Collins House for fear of exacerbating the damage.

A cursory inspection of the property by the authors showed that all of the buildings exhibited cracking in both the structural and ornamental brickwork along the foundations. The Collins House and the kitchen building both showed signs of previous movement and subsequent repair. The kitchen hearth had shear cracking in the brickwork similar to that found in the brick foundations. The doors in the house had been severely planed along the top and additional material was added at the bottom (Fig. 3). First floor doorways exhibited racking (or localized deformation) of 3 to 7 degrees (1 to 3 inches across a 2-foot width of door), with the majority of deformation occurring in the east-west direction (i.e., towards the lake). The windows showed less deformation but also sloped towards the lake. Doors and windows measured on the second floor showed similar results. The building was clearly tilting in a direction towards the lake. The cause of the distress needed to be identified so that additional damage could be forestalled and effective repair initiated.

Possible Causes of Settlement

Settlement causes were investigated using the above-outlined methodology of structural, geotechnical, and hydrological analyses.

Structural loading. With the exception of heavy filing cabinets on the second floor of the overseer's house, changes in the permanent and semi-permanent loading were not evident during the property's transformation to a historic site. There was, however, a substantial change in the repetitive, periodic

loading caused by visitor traffic. This change could be considered as profoundly different from the original anticipated loadings caused by family members and household staff, but key transit points in the house, namely areas of egress and stairwells, did not appear to exhibit exceptionally high levels of distress, as is often the case in historic sites.¹³

In contrast, widespread foundation cracking was present in nearly all structures on the property, even the lightly loaded ones. Damage manifested itself mostly in shear cracking in the brick piers, with a clear directional orientation towards the lake. This directional orientation further discredited the supposition that additional loading was causing the distress, since excess structural loading should have generated either a uniform or a random settlement pattern. Tourists and school groups also did not account for signs of differential movement prior to 1989, as most clearly seen in the prior planing of the doors (for which there is no historic record, despite a widespread implementation of this technique throughout the Collins House). Since visitor loading did not appear to be responsible, the competency of the building materials was the next consideration.

Structural System and Material Evaluation

Wood. The Collins House is framed with large ~~components~~ of bald cypress, a strong, stiff wood. The framing elements ranged in size from 2 by 10 inches to 12 by 10 inches, with spans up to 52 feet. Initial inspection of ceilings, floors, and the underside of the structure showed no sagging or obvious wood deterioration, even in the large rooms and hallways.¹⁴ The strength of cypress was cited in an eighteenth-century source as 450 to 600 pounds per square inch (psi).¹⁵

In 2003 three-point bending tests were performed to estimate the strength and stiffness of the existing framing-system components. Specimens (4.375 inches by 4.126 inches by 15.937 inches) were hand-planed from local cypress trees and were then oven dried. The specimens came from recently felled cypress trees that were the approximate age of the house. These trees showed signs of degradation near the heart of the trunks; a condition most likely due to a fungus that is typical of cypress. Despite the rotting, the beams were able to carry high stress from 138 to 250 psi in bending; based on present day

wood-design guidelines, modern bald cypress beams have an allowable design-bending stress of 304 psi.¹⁶ The tested beams should be considered as a worst-case scenario for the actual lumber found in the house, as the visible elements of the structural system appeared sound.

Based on the framing plan of the house, the maximum deflection under current loading should be 1½ inches, using a highly conservative assumption of a cantilevered support condition, with a clear span of 52 feet for an 8-inch-by-12-inch framing member and a stiffness based on laboratory testing. Observable deformation did not appear to exceed this deformation. Age-based material deflections of the flooring or framing were excluded as a contributing cause to the recorded damage.

Bricks. With the framing eliminated as the cause of distress, the foundation was investigated. The bricks had a wide color range (brown, red, yellow, and orange), showing their different levels of firing. The geometry of the bricks suggested hand molding. Water absorption and compression testing (traditionally inverse indicators of each other) were conducted on 20 bricks taken from previously repaired piers under the Collins House. The bricks had absorption levels ranging from 8 to 13 percent by weight, as compared to 16 to 25 percent absorption for other pre-Civil War bricks and 2 to 4 percent for modern bricks.¹⁷ In compression, the bricks averaged 920 psi for flat loading, 450 psi for end loading, and 498 psi for edge loading; other pre-Civil War bricks averaged 2,933 psi, 664 psi, and 323 psi; and modern bricks averaged 15,947 psi, 6,009 psi, and 5,094 psi, respectively. Despite their lower absorption than other pre-Civil War bricks, the Collins House bricks were generally weaker, although more than sufficient to support the current loading levels. Additionally, despite some areas of brick cracking, the damage appeared to have been caused from ground movement, as opposed to brick failure, as evidenced by little deformation or crushing of the brick piers themselves.

Mortar. The mortar was a patchwork of original and modern materials. Some joints had hard Portland cement, others were a soft lime-based mix, and in some vertical joints the mortar was simply missing. Although there were clearly areas of distress, the mortar, like the brickwork, did not show a systematic

pattern of failure that could account for the buildings' displacements. As in the case of the bricks, the mortar damage appeared as the result of the distress and not the cause. The general state of the brickwork did not indicate a systematic degeneration sufficient to account for structural movements. With structural deficiencies eliminated, geotechnical factors were investigated.

Soil Behavior

Effects of organic soil decomposition. Organic soil material, including peat, decomposes over many years, leaving voids in the soil fabric that facilitate localized collapse and result in surface settlement. Random decomposition of organic material can cause differential movement across a site. Given the proximity of Somerset Place to swampland, organic material in the soil was speculated as a potential cause of settlement.¹⁸

At a nearby property on the western edge of Lake Phelps, large cracks in a 1960s house were investigated. This house exhibited slanting windowsills and doorways like the Collins House, but dissimilarly, the deformations throughout the newer house occurred in multiple directions, even within a single room. Localized differential settlement did not exceed 1 inch across 2 feet (2.4 degrees), and most settlement was significantly less. Unlike the tilting at the Collins House, the irregular pattern of the deformations of this structure was indicative of the effects of the high concentration of organic material in the immediate area. Despite the many peat bogs throughout the swamp and the proximity of this damaged structure to Somerset Place, the Somerset soil borings yielded no peat and only a small amount of other organics. Organics-based soil deterioration was, thus, excluded as a major contributor to the building movements.¹⁹

Soil profile. In 1980, multiple soil borings around the perimeter of the Collins House demonstrated a gradual transition between soil types, mostly 2-to-10-foot layers of inter-bedded silts and sands overlain by 6 to 12 inches of organic topsoil (Fig. 4). Minimal organics and layers of shell fragments were found.

Dry soil densities ranged from 41 to 91 pounds per cubic foot, and liquid limits varied from 30 percent to 47 percent.²⁰

Self-weight settlement. The 1980 investigation concluded that in the 150 years since the building of the Collins House all primary and secondary consolidation of the silt in the soil profile should have occurred, that no additional settlement was to be expected, and that all existing deformations were due to the two phases of house construction.²¹ This conclusion was largely based on the thicknesses of the silt layers and assumed consolidation rates based on widely employed geotechnical consolidation equations. Yet, substantial additional settlement did occur; in 1992 a large crack in the plaster was discovered on the third floor of the main house in the ceiling of the nursery, where the two parts of the house are joined.²²

In 2001 brick nogging was discovered in the exterior walls (as a means of insulation), adding 5 to 10 percent more weight based on the number of brick layers. However, this information did not change the validity of the 1980 soil-consolidation analysis.²³ The clear tilting of the structure towards the lake further discounted the concept of a self-weight settlement or soil overloading, as was previously described in the contesting of live load as the cause of distress.

Groundwater Position

Since visitor traffic, structural deterioration, soil decomposition, and long-term, self-weight-induced consolidation were all dismissed as the direct causes of the settlement, changes in the groundwater needed to be considered.

Proximity of water. Through the mid-twentieth century the Lake Phelps waterline at its highest level came within 50 feet of the Somerset buildings,²⁴ but in 2002, the lake was as far away as 560 feet (Fig. 5).²⁵ The recession of the shoreline confirmed a lowering of the surficial groundwater table. A preliminary analysis implied a drought-related settlement. The rain level was compared to the adjacent lake level over several decades (Fig. 6). In 1975 the lake level began to recede faster than the loss of rainfall. If the

lowering of the groundwater table was strictly drought related, then lake levels should not have decreased faster than changes in rain levels. There is a unique relationship between every soil profile or body of water and the groundwater position, but relative changes between the two should always be consistent, unless there is an external catalyst.

Additionally, since the upper layers in the soil profile are composed of silt and sand, as seen in Figure 4, the maximum movement in those layers could only be the total water loss of free water. Typically, this value is restricted to two-thirds of water removed, and laboratory experiments conducted as part of this investigation showed that a worst-case scenario generated a volume loss of only 44 percent of the removed water.²⁶ Since the doors were operable in 1989, the majority of the measured deformations are assumed to be subsequent from that date. Average drought-related water loss was less than 6 inches according to the change in rainfall levels from 1989 to 2001. A calculation of drought-related, dewatering-induced stresses that would have generated in the remainder of the top silt layer resulted in insubstantial settlements, as compared to the movements measured within the house. Using the measured house deformations to gauge the extent of soil settlement, the dewatering would appear to be concentrated in the second silt layer at depths of up to 20 feet. Thus, the thickness of the dewatered portion of the second silt layer was back-calculated, through which a change in the groundwater table was estimated. The 1980 readings were used as a starting point, selecting an average value of 2 inches for the measured house deformation. A 6-foot-3-inch lowering of the groundwater table would have had to occur to sufficiently dewater 1 foot 3 inches of the second silt layer to induce 2 inches of building settlement, but there was less than 1 foot of draught-related rainfall loss recorded. Thus, an additional cause of water loss was sought.

The 1980 borings also showed a clear differential in the groundwater position from one side of the house to the other. The groundwater level was documented at a 5-foot-6-inch depth east of the house near the canal. Approximately 60 feet away, on the west side of the house towards the lake, the groundwater level was in the range of 2 feet 6 inches higher (Fig. 7).²⁷ Although the change in groundwater position is dramatic and may in part reflect insufficient consistency in taking the readings,

the canal provides a natural outflow for water, and thus the 1980s readings are not unreasonable. What becomes critical is that the outflow was definitively towards the canal, which is the same direction as the coast and is the natural flow pattern for the region.²⁸ Yet, this was not the direction of the tilt of the Collins House, nor was it the direction of the shear cracking in the brick foundations. Had the movement simply been caused by the drought, resulting in a uniform lowering of the groundwater, the tilt of the Collins House would have been expected to be minimal and in the direction of the canal, based upon the previous groundwater readings. Instead, what appeared in the patterns of deformation was a possible change in the direction of the slope of the groundwater position.

In 2001, a small amount of pavement immediately north of the house collapsed. Upon removal of the brick pavers, much of the sand around a buried pipe appeared to be missing, leaving the impression that the phenomenon of localized piping (i.e., the transport of fines from flowing water) had occurred. As a result, the hydrology in the region was examined.²⁹

Hydrology. The subsurface conditions at Somerset Place are typical of a region consisting of sands interbedded with clays dating from the Pleistocene to the present geologic age.³⁰ Somerset Place is located atop the Northern Atlantic Coastal Plain aquifer system, which is composed of six regional aquifers. The most prominent is the Castle Hayne aquifer, which spans an area from New Jersey to North Carolina. In North Carolina the Castle Hayne has two subdivisions: the larger Castle Hayne aquifer made of limestone, sandy marl, and coarse, limey sand and the lesser Beaufort aquifer, containing thin beds of shell and limestone (Fig. 8). Although the exact height beneath Somerset is undocumented, in the adjoining Beaufort and Washington counties of North Carolina, the upper portion of the aquifer is located close to sea level, at a depth of 185 feet.³¹

Historically, water in the Castle Hayne aquifer ran from recharge areas in higher altitudes towards rivers, estuaries, and the Atlantic Ocean, moving eastward from a maximum altitude of only 50 feet above sea level towards the North Carolina sounds, which are tributaries to the Atlantic Ocean. Due to its deeply embedded location, the aquifer near Somerset Place recharges only from other below-ground sources or

surface contributions hundreds of miles away and not directly from local precipitation.³² Damage patterns at Somerset were indicative of a southwesterly groundwater flow, contrary to the historical aquifer pattern of water flow to the southeast. Consequently, changes in the aquifer flow were explored.

Peat mining. Several peat- and phosphate-mining operations were identified in the region as possibly impacting the hydrology. The potential was significant because of the highly continuous Castle Hayne aquifer system throughout the region. Large-scale peat mining had occurred in the area since the 1970s (peat is used to improve crop and timber production, as well as provide a source of fuel). In 1984, the North Carolina State University Department of Forestry, Biological, and Agricultural Engineering conducted a peat-mining study to assess potential hydrologic and water-quality impacts of peat mining by First Colony Farms, Inc., which had received a permit to mine peat in April 1975.³³ Peat mining requires dewatering from the aquifers. The initial mining operation was projected to impact drainage of 14,800 acres in Washington, Dare, Hyde, and Tyrell counties, including Somerset Place. There were concerns about the ability of the Castle Hayne aquifer to recharge properly. Despite these concerns, First Colony Farms, Inc., was permitted to pump 210 thousand gallons a day beginning in 1975.³⁴ The effects of peat mining were assessed to be negligible, indicating limited impact of peat mining on the groundwater.³⁵ A wide-spread fire in 1985 ended peat mining in the area.

Phosphate. In 1965 a large phosphate mining and chemical plant began operation at Lee Creek in Beaufort County near Aurora, North Carolina, approximately 35 miles southwest of Somerset Place (Fig. 9). The plant has the capacity to produce 6 million tons of phosphate ore per year. There is a 60 to 70 foot thick layer of phosphate, the top of which is located approximately 30 feet below the ground surface, requiring all soil above to be removed by bucket wheel excavators and the 60 to 70 feet of phosphate below to be removed by draglines. Before the mine commenced operation, the groundwater was close to the surface. For proper mine operation the excavation must be kept dry; consequently, water is pumped

out, so that the groundwater level is at the maximum excavation depth. In 2002, this was approximately 100 feet from the original ground surface.³⁶

In addition, each day tens of millions of gallons of water for processing the phosphate are pumped from the underlying Castle Hayne aquifer. This water is routed through the plant and cooling systems and mixed with phosphate ore to form a slurry that is then pumped to the processing plant. During 2000, the Aurora plant mined 4.73 million tons of phosphate ore, using up to 78 million gallons of water per day. Initial permitting information projected a depression cone causing measurable drawdown over a large area (about 1,440 square miles), to which Somerset Place was immediately adjacent.³⁷

Preliminary data collection between 1969 and 1975 clearly demonstrated expansion of this drawdown zone over time.³⁸ In the first six years, the drawdown cone expanded to over 2,200 square miles and included Somerset Place (Fig. 10).³⁹ The industrial pumping resulted in a lowering of the hydraulic head of the aquifer, thereby forming a depression cone in the potentiometric surface and diverting the water flow towards the inland pumping center. The potentiometric surface, also known as the piezometric surface, is the height to which groundwater will rise, if given a venue such as an observation well.

The directional change in the Castle Hayne aquifer would appear to account for the reversal of the direction of water flow at Somerset Place from the southeast towards the southwest. Before the mine opened in 1965, the top of the Castle Hayne aquifer was 300 to 350 feet below sea level at Somerset Place. The potentiometric surface in June 1965 was 8 feet 6 inches above sea level.⁴⁰ In July 1975, the rate of pumping increased to 65 million gallons a day, and the potentiometric surface dropped to 4 feet and 11 inches above sea level. Pumping rates in 1980 increased to 67 million gallons a day, causing a further decrease of the potentiometric surface to 4 feet and 8 inches above sea level.⁴¹ In 1990 pumping rates continued to increase to 78 million gallons a day, causing a further decrease of the potentiometric surface to 4 feet and 2 inches above sea level.⁴²

Analysis

To determine whether the mining operation was indeed the source of the troubles at Somerset Place, the rate of drawdown that was needed to induce sufficient primary consolidation (i.e., gradual reduction of soil layer heights due to water removal) in the silt layers to generate significant structural movement was back-calculated to be 3.72 inches per year from 1965 to 2001. Between 1965 and 1973 the drawdown rate in the vicinity of Somerset is projected to have been 10.44 inches per year, and from 1973 to 1975 the rate rose to 1 foot and 10.80 inches per year, or six times the rate needed for sufficient consolidation.⁴³

Although not highly common there are other incidents of industrial pumping causing large-scale settlement.⁴⁴ One recent case occurred along the southern coastal plain of North Carolina (a region adjacent to Somerset Place), which resulted in over 7 inches of settlement in the town of New Bern. Located in similar hydrogeology, this documented settlement was caused by dewatering a pair of aquifers at the relatively modest level of 200,000 gallons per day (only 4 percent of that of the phosphate mine).⁴⁵

Despite Somerset Place's status as a historic landmark, sufficient pressure is unlikely to be brought upon the mine to curb its operations. Under the North Carolina Department of Environment (NCDENR) regulations, the mine is theoretically liable for damage, but only if the damage can definitively linked to the mining operations. Despite five years of effort, the site has still been unable to secure funding for the installation of groundwater monitoring wells to definitively prove what is occurring. Additionally, the mine wields significant influence: the operation is one of the few large employers in the region and thus a major source of both jobs and tax revenues. There is however an increasing concern evolving regarding water usage for the region. The State of North Carolina has been considering a water-usage evaluation study for the entire region. Whether this will actually occur is unclear. Given the long-term, widespread, and highly political nature of regional water management, Somerset Place has been advised to seek funding for a jacking system that can be periodically adjusted, as the dewatering-induced settlement problem is not anticipated to abate. A similar system was installed to accommodate significant long-term settlement of the Kansai airport in Japan. To date that system has provided compensation for up to a meter of movement.⁴⁶ In the interim, at Somerset Place doors continue to be shaved, window glass replaced, and porch rails mended.

Conclusions

Using a fairly simple three-part forensic investigation methodology of structural, soil, and groundwater assessments, many likely causal agents were fully eliminated, and the underlying cause of the damage at Somerset Place was largely established. The differential movement of the structures, along with a lack of organics in the soil and a groundwater table receding at a faster rate than the decrease in rainfall were all indicators of a non-local cause. The quantity of movement of the Collins House with respect to the geology was indicative of a significant change in subsurface conditions, although the impact of the mine was established by analysis of long-term, regional groundwater monitoring. The conclusions have allowed the site's interpretive staff to continue to allow public access to the Collins House without fear that visitor traffic or other user-based activities will further imperil the building. Additionally, through the use of this methodology, limited fiscal recourses were conserved, resulting in a recommendation for a low-cost reversible, intervention scheme [QA: Are you referring to the jacking system? Yes This is a low-cost solution? Yes, compared to many other things].

DR. DEBRA LAEFER is a lecturer at the University College Dublin in Ireland. She specializes in the protection of historic structures from construction activities. She serves as chair of the Heritage and Existing Structures Committee for the Earthquake Engineering Research Institute.

ASHLEY EVANS is a former research student at North Carolina State University pursuing dual degrees in civil engineering and anthropology. Her main interest is in the application of new technologies to further cultural assessment and protection.

JON FRAZIER is a professional engineer trainee for the Florida Department of Transportation, working in construction project management. He is currently a master's degree candidate at North Carolina State University.

Acknowledgements

Thanks to Dot Redford of Somerset Place and Linda Cairns-McNaughton of the North Carolina Department of Cultural Resources and their staffs for access and assistance.

Notes

1. John Burland, "Preserving Pisa's Treasure," *Civil Engineering* 72, no. 3 (2002): 43.
2. Dot Redford, Somerset Place Site correspondence to Bill McCrea. June 1, 1992.
3. North Carolina Office of Archives and History [NCOAH(a)], Welcome to Somerset Place. "The Site Today." North Carolina Historic Sites.
<http://www.ah.dcr.state.nc.us/sections/hs/somerset/somerset.htm>. (Accessed May 21, 2006).
4. NCOAH(b), Somerset Place. Welcome to Somerset Place. "The Lake Company and the Origins of Somerset." North Carolina Historic Sites.
<http://www.ah.dcr.state.nc.us/sections/hs/somerset/somerset.htm>. (Accessed October 1, 2005).
5. NCOAH(b),
6. North Carolina Department of Environmental and Natural Resources [NCDENR(a)]. *Pasquotank Basin Wide Water Quality Management Plan*. (Raleigh, NC: 1997).
7. NCOAH(b),
8. NCDENR.

9. NCDENR.
10. NCOAH(a),
11. NCOAH(c). Welcome to Somerset Place. "A Representative Antebellum Plantation." North Carolina Historic Sites. <http://www.ah.dcr.state.nc.us/sections/hs/somerset/somerset.htm>. (Accessed October 1, 2005).
12. David Fischetti, "Subsurface Exploration, and Analysis for the Collins Mansion, Somerset Place Historic Site." (Research Triangle Park: Soil Testing Services of Carolina, Inc, 1980), 1.
13. Susan Haake. Discussion with Ashley Evans on deformations due to visitor traffic. September 26, 2003.
14. Forest Products Laboratory. 1999. Wood handbook—Wood as an engineering material. General Technical Report FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 4-4.
15. Asher Benjamin, *Practice of Architecture the Builders Guide*. (New York: Da Capo Press, 1994), 105-106.
16. Forest Products Laboratory.
17. Debra F. Laefer, "Emergence, Development, and Prevalence of Brick Nogging in American Vernacular Architecture," *Proceeding of the Fourth International Seminar on Structural Analysis of*

Historical Constructions. 10-13 November 2004, Padova, Italy. Structural Analysis of Historical Constructions: Possibilities of Numerical and Experimental Techniques. Padova, ed. C. Modena, P. B. Lourenco, and P. Roca (Leiden, The Netherlands : Balkema, 2005), 199.

18. Department of Agriculture, *Soil Taxonomy. Agriculture Handbook No. 436* (Washington: USPO, 1977), table A-1.

19. Fischetti, 6.

20. *Ibid.*, 5.

21. *Ibid.*, 7-8.

22. Redford.

23. Laefer, 199.

24. NCOAH(a).

25. NCOAH(d), Welcome to Somerset Place. "Grounds Map." North Carolina Historic Sites <http://www.ah.dcr.state.nc.us/sections/hs/somerset/somerset.htm>. (Accessed October 1 2005).

26. Patrick Powers, "Soils and Water" in *Construction Dewatering* (New York: Wiley-Interscience Publications, 1981), 65.

27. Fischetti, 6.

28. NCDENR(b), "Pasquotank Basin Wide Water Quality Management Plan," *Interim Report On Ground-Water Conditions in Capacity Use Are No.1 Central Coastal Plain, North Carolina 1974-1975. Report of Groundwater Investigation no. 13, September.* (Raleigh, N.C.;1976), 48.
29. Department of the Interior [DOI(a)], United States Geological Survey, "Aquifer Basics." <http://capp.water.usgs.gov/aquiferBasics/index.html> (Accessed May 21, 2006).
30. DOI(b), United States Geological Survey, "Ground-water atlas of the United States: Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia-HA 730-L," http://capp.water.usgs.gov/gwa/ch_1/L-text3.html (Accessed May 21 2006)
31. DOI(b).
32. Ibid.
33. NCDENR(b),
34. NCDENR(b), 12.
35. J. D. Gregory, R. W. Skagga, R. G Broadhead, R. H. Culbreath, J. R. Baily, and T. L. Foutz, "Hydrologic and Water Quality Impacts of Peat Mining in North Carolina," (Raleigh: North Carolina State Univ., 1984): 3.

36. R. J. M. De Wiest, A. Nelson Sayre, and C. E. Jacob, *Evaluation of Potential Impact of Phosphate Mining on Ground-water Resources of Eastern North Carolina* (State of North Carolina Department of Water Resources, January 1967), 1.
37. *Ibid.*, 99.
38. Harry Peek and Nelson Perry, "Castle Hayne Aquifer," *Potential Effects of Withdrawals from the Castle Hayne Aquifer for Expanded Phosphate Mining in Beaufort County North Carolina Report of Groundwater Investigation no.11* (NCDENR Raleigh, N.C., September 1975): 3-10.
39. Peek and Perry, 9.
40. *Ibid.*, 6.
41. *Ibid.*, 7.
42. Bruce Henderson. "Little-used Source Could Be a Bonanza," *The Charlotte Observer*, Dec. 29, 2002. <http://www.charlotte.com/mld/charlotte/news/4833393.htm> (Accessed August 23 2003).
43. Peek and Perry, 11.
44. P. L. Younger, "Coalfield Closure and the Water Environment in Europe," *Transaction of the Institution of Mining and Metallurgy Section A – Mining Technology* 111, (Sept.-Dec. 2002): A201-A209.

45. Ralph Heath and Richard Spruill, "Creataceous Aquifers in North Carolina: Analysis of Safe Yield Based on Historical Data," *Hydrogeology Journal* 11, no. 2 (2003): 256.
46. P. Dilley, and K. Taga, "Kansai International Airport Terminal," *Proceedings of the Institution of Civil Engineers, Civil Engineering* 108, no. 1 (1995): 2-11.
47. Department of Interior, Division of Parks and Recreation, "Pettigrew State Park," *Monthly State Park Use Report* (1993-2001).
48. Department of Agriculture, "Table A.3- Monthly Modeled Lake Levels- 1955-1976." *Chart. Soil Taxonomy. Agriculture Handbook No. 436*, (Washington: USPO, 1977), A-3..

Works Sited

- Burland, John. "Preserving Pisa's Treasure." *Civil Engineering*, vol. 72 issue 3 (2002): 42-49.
- Benjamin, Asher. *Practice of Architecture the Builders Guide*. New York: Da Capo Press, 1994.
- Department of Agriculture. Chart. *Soil Taxonomy. Agriculture Handbook No. 436*, Washington: USPO, 1977.
- Department of Interior (DOI), Division of Parks and Recreation. "Pettigrew State Park." *Monthly State Park Use Report*. 1993-2001.
- Dilley, P. and K. Taga. "Kansai International Airport Terminal" *Proceedings of the Institution of Civil Engineers, Civil Engineering*, vol. 108, no. 1 (1995): 2-11.
- DOI, United States Geological Survey (USGS). "Aquifer Basics."
<http://capp.water.usgs.gov/aquiferBasics/index.html> (Accessed May 21, 2006).
- DOI, USGS. "Ground-water Atlas of the United States: Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia-HA 730-L" http://capp.water.usgs.gov/gwa/ch_1/L-text3.html (Accessed May 21 2006).
- Fischetti, David. "Subsurface Exploration and Analysis for the Collins Mansion, Somerset Place Historic Site." Research Triangle Park: Soil Testing Services of Carolina, Inc, 1980.
- Forest Products Laboratory. 1999. Wood handbook—Wood as an engineering material. General Technical Report FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 463.
- Gregory, J.D., R.W. Skagga, R.G Broadhead, R.H. Culbreath, J.R. Baily, and T.L. Foutz. "Hydrologic and Water Quality Impacts of Peat Mining in North Carolina." Raleigh: North Carolina State University, 1984.
- Haake, Susan. Curator of the Lincoln House, National Park Service. Discussion on deformations due to visitor traffic with Ashley Evans. Personal Communication, September 26, 2003.
- Heath, Ralph and Richard Spruill. "Creataceous Aquifers in North Carolina: Analysis of Safe Yield Based on Historical Data." *Hydrogeology Journal*, vol. 11, no. 2 (2003): 249-258.

Henderson, Bruce. "Little-used Source Could Be a Bonanza." *The Charlotte Observer*. Posted on Sun, Dec. 29, 2002. <http://www.charlotte.com/mld/charlotte/news/4833393.htm>. (Accessed August 23 2003)

Laefer, Debra F. "Emergence, Development, and Prevalence of Brick Nogging in American Vernacular Architecture". *Proceeding of the Fourth International Seminar on Structural Analysis of Historical Constructions. 10-13 November 2004, Padova, Italy. Structural Analysis of Historical Constructions: Possibilities of Numerical and Experimental Techniques. Padova*. Ed. Modena, C., Lourenco, P.B, and Roca, P., Leiden: Balkema, 2005, pp. 191-202.

North Carolina Department of Environmental and Natural Resources [NCDENR(a)]. *Pasquotank Basin Wide Water Quality Management Plan*. September 1997.

NCDENR(b). "Pasquotank Basin Wide Water Quality Management Plan," *Interim Report On Ground-Water Conditions in Capacity Use Are No.1 Central Coastal Plain, North Carolina 1974-1975. Report of Groundwater Investigation no. 13, September*. Raleigh, NC, 1976.

- North Carolina Office of Archives and History [NCOAH(a)], Welcome to Somerset Place. "The Site Today." North Carolina Historic Sites.
<http://www.ah.dcr.state.nc.us/sections/hs/somerset/somerset.htm>. (Accessed May 21, 2006).
- NCOAH(b), Somerset Place. Welcome to Somerset Place. "The Lake Company and the Origins of Somerset." North Carolina Historic Sites.
<http://www.ah.dcr.state.nc.us/sections/hs/somerset/somerset.htm>. (Accessed October 1, 2005).
- NCOAH(c). Welcome to Somerset Place. "A Representative Antebellum Plantation." North Carolina Historic Sites. <http://www.ah.dcr.state.nc.us/sections/hs/somerset/somerset.htm>. (Accessed October 1, 2005).
- NCOAH(d), Welcome to Somerset Place. "Grounds Map." North Carolina Historic Sites
<http://www.ah.dcr.state.nc.us/sections/hs/somerset/somerset.htm>. (Accessed October 1 2005).
- Peek, Harry and Nelson Perry. "Castle Hayne Aquifer." *Potential Effects of Withdrawals from the Castle Hayne Aquifer for Expanded Phosphate Mining in Beaufort County North Carolina 1975. no.11* (NCDENR Raleigh, N.C., September 1975).
- Powers, Patrick. "Soils and Water." *Construction Dewatering*. New York: Wiley-Interscience Publication, 1981.
- Redford, Dot. Somerset Place Site Director, General correspondence.
- Wiest, R.J.M, N. Sayre, and C.E. Jacob. *Evaluation of Potential Impact of Phosphate Mining on Ground-water Resources of Eastern North Carolina*. State of North Carolina Department of Water Resources, January 1967.
- Younger, P.L. "Coalfield Closure and the Water Environment in Europe." *Transaction of the Institution of Mining and Metallurgy Section A – Mining Technology* vol. 111, Sep.-Dec. (2002): A201-A209.