# PRESERVATION OF HISTORIC STRUCTURES USING SCREW-PILE FOUNDATIONS

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*Structural Analysis of Historic Construction – D'Ayala & Fodde (eds)*
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## ABSTRACT

The structural integrity of historic buildings is often compromised as a result of foundation deformations over time. This can be created by a number of problems related to the subsurface conditions, groundwater removal, softening of the bearing soils, or simply from longterm soil consolidation. Often times, such deformations produce large and usually differential settlements that lead to a condition of imminent collapse or unsafe conditions which place the structure in jeopardy. The preservation of these structures requires innovative approaches to foundation repair that will not negatively impact the historic nature of the structure. This paper describes the preservation of several historic structures using helical screw piles to achieve foundation underpinning. Five case histories are presented in this paper, showcasing helical screw piles used to preserve the foundations, ranging in age and use from the 11th century to late 19th century. The cases illustrate the economic and effective use of helical screw-piles to retrofit the foundations with minimal intrusion to the structures. For each case, a brief historical review of the structure is presented and a summary of the foundation problems and site conditions are given along with a description of the screw-piles selected for the repair work.


## INTRODUCTION

Historic structures are subject to settlements overtime as a result of two primary sources. Settlement can occur as a result of the slow long-term consolidation process that occurs if a structure has been built on soft soils such as clays or organic soils. Alternatively, settlements can occur if subsurface changes have occurred at a site, for example, by lowering the water table, or removing support from under or adjacent to a structure by recent excavations. No matter the cause, the result of settlements is generally structural distress that must be addressed before additional problems arise or for that matter a partial or complete failure occurs. Structural intervention to provide an engineering solution in these cases generally involves some form of underpinning. Other methods are successful, such as soil extraction, which was successfully used to stabilize the bell tower at Pisa (Burland et al. 2003).

The foundation restoration of historic structures can present some unique challenges for the engineer to design appropriate remedial support techniques. These challenges often include such issues as: unknown existing foundation conditions, unknown or unexpected soil and groundwater conditions, heavy loads, limited access, sensitive status of the historic fabric of the structure (Ciancia, et al. 2006). It can also include, maintaining adequate support during restoration, sensitivity to specific construction activities, such as vibration or noise, and the desire to create the least amount of intrusion to the structure or disrupt the current use of the structure. Historic structures can be particularly sensitive to structural intervention. To stabilize the foundation, the structural connection between the foundation and the overlying structure may be weakened from the original construction techniques used during construction.

A number of examples may be cited in which foundation repairs have been made to historic masonry structures using a wide variety of techniques, including, drilled micropiles, jacked minipiles, jet grouting, chemical grouting and conventional piles (e.g., Dooff et al. 1995; Avellan and Lange 1997; Chartres 1997; Rodriguez Ortiz and Monteverde 1997; Niehoff 2004). Five case histories are presented in this paper that illustrate the application of helical screw-piles for the preservation of historic masonry structures. The cases represent applications in a wide range of soil conditions and a wide range of loads and demonstrate that screw-pile present a unique approach for engineers who are faced with such problems.

## SCREW-PILE FOUNDATIONS

Screw-pile foundations are a product of mid-19th century, Victorian engineering. Most historians give Alexander Mitchell, a self-taught, Scottish engineer, credit for the use of screw-piles as viable foundations. Mitchell initially developed iron screw-piles for use as offshore lighthouse foundations around England's coasts. In 1848, Mitchell described the mechanics of screw-pile functionality as, "Broad spiral flange, or 'ground screw' as it may be termed, be applied... to support a superincumbent weight, or be employed ...to resist an upward strain, its holding power entirely depends upon the area of its disc, the nature of the ground into which it is inserted, and the depth to which it is forced beneath the surface".

Figure 1 shows the geometry of a typical screw-pile used by Mitchell at the Maplin Sands Lighthouse in the Thames estuary. All of the screw-piles used by Mitchell were fabricated by a combination of cast-iron plates and wrought-

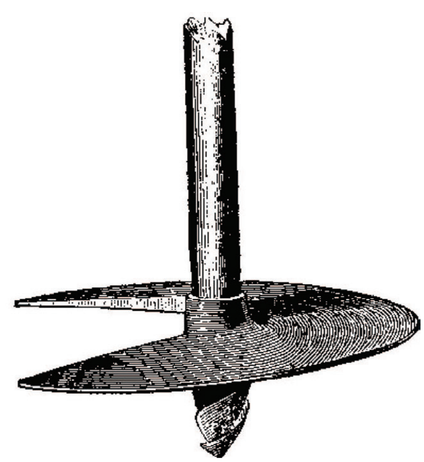

FIGURE 1. TYPICAL GEOMETRY OF SCREW PILE USED BY MITCHELL (1836–1880).

In nearly every case of screw-pile installation before about 1900, the screw-piles were installed by manual labor using a large capstan attached to the top of the shaft and turned by as many as 40 men. No vertical load was applied to assist the installation, the pitch of the screw blade was sufficient to produce advance of the crew with rotation of the shaft. During the mid-to late 19th century, screw-piles were used throughout the world to provide support for offshore and onshore lighthouses, ocean front piers, bridges, slope stabilization and underpinning. Duckham (1889) described the use of screw-pile foundations to underpin the town hall at Great Yarmouth which had undergone several inches of settlement.

Since the early 1950s, the screw-pile has taken on a different form, to solve a different kind of problem. Albert Bishop Chance, founder of A.B. Chance, recognized that a helical screw element could be used to provide tension support for electrical transmission tower and other tall structures and developed a screw anchor industry that still is in use today. Since about the 1970s however, screw-pile foundations have returned to applications similar to those in which they were originally developed by Mitchell and others. Modern screw-piles have a variety of geometries and applications and include both single helical and multi-helix configurations on both square shafts and round shafts. With the advent of modern hydraulics in the construction industry, which largely took off after World War II, screw-piles could be installed with ease using a variety of, commonly available, construction equipment.

Modern screw-piles have a variety of names, such as helical pier, screw anchor, or helical pile, but they are all generally fabricated as one of three general configurations as shown in Figure 2. They may consist of a single helical element, a multi-helix lead section or a helical lead section with a grout column. The central shaft may be square or round. If a grout column is used, an appropriate amount of time is allowed for the grout to achieve sufficient strength before load transfer. Grout columns may be used to provide additional load capacity, working in combination with the lead helical section, or they may be used to simply transfer the load to the lead helical section, as in the case of short screw-piles end-bearing on rock or other hard material. The grout column typically consists of a Portland cement based neat grout or some similar material. Crocker (2005) previously described the potential for using helical piers in historic settings.

The screw-piles are generally attached to existing foundations using a foundation bracket that can be bolted to the existing foundation and then attached to the shaft of the screw-pile. In some cases, strengthening of the existing foundations, which often consist of stone or other masonry, may be necessary using a thread bar or a grouted bar before installing the screw-pile support system. This may be particularly important, given the age of most of the structures that predate the use of concrete for foundations.

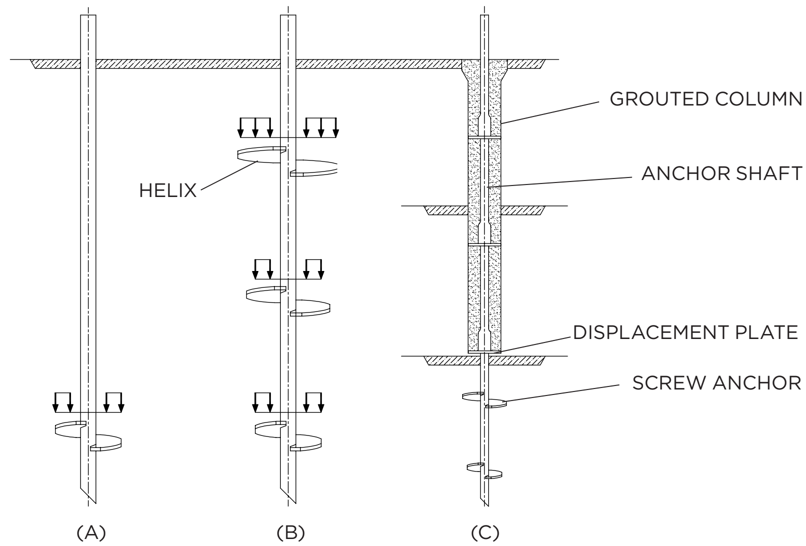


**FIGURE 2. CONFIGURATION OF MODERN SCREW-PILES: (A) SINGLE HELIX; (B) MULTI-HELIX; (C) GROUTED SHAFT.**

*"Broad spiral flange, or 'ground screw' as it may be termed, be applied...to support a superincumbent weight, or be employed ...to resist an upward strain, its holding power entirely depends upon the area of its disc, the nature of the ground into which it is inserted, and the depth to which it is forced beneath the surface".*

*-Alexander Mitchell*
*On the mechanics of screw-pile functionality*

### SEQUENCE OF FOUNDATION UNDERPINNING USING SCREW PILES

When using screw-piles for underpinning, it is first necessary to make a small excavation to expose the base of the existing foundation. The screw-pile is then installed using hydraulic torque motor to the required design depth or a sufficient depth as determined by the installation torque to develop sufficient load capacity. A foundation "L" bracket is then attached to the shaft of the pile and to the existing foundation to provide a structural connection between the two and provide for load transfer.

If appropriate, given the condition of the structure and the degree of distress, a small amount of lifting may also be performed using hydraulic jacking system to provide vertical adjustment to the structure and preloading of the screw-pile. This load is then locked off and the final position of the foundation bracket is achieved. If needed, the existing foundation may also be reinforced using either thread bars or grouted bars inserted into the existing foundation blocks or a small section of reinforced concrete may be cast in place and tied to the existing foundation. The underpinning sequence is illustrated in Figure 3. Note that Figure 3 illustrates that the screw-pile can include a grout column around the central shaft or it may be installed without a grout column, depending on the soil conditions and the design of the pile for bearing capacity.

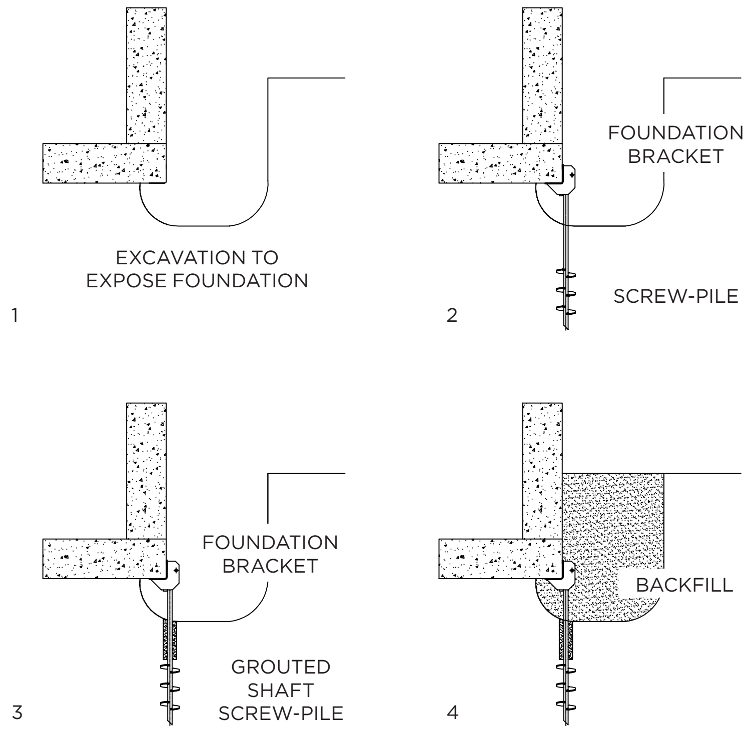


**FIGURE 3. SEQUENCE OF UNDERPINNING EXISTING FOUNDATIONS WITH SCREW-PILES.**

### CASE HISTORIES

In Table 1, a summary is given of the five historic masonry structures described in this paper. It should be remembered that what may be considered as an historically significant structure may vary depending on the current usage of a particular structure, the age, location and setting of the structure in context to the surrounding environment. A description of each of the cases will be given describing the state of distress and the intervention applied.

**TABLE 1. SUMMARY OF CASE HISTORIES**

| Case No. | Structure | Location | Age of Structure |
|---|---|---|---|
| 1 | Mark Twain Hotel | Hannibal, Missouri | 1906 |
| 2 | Ralls County Courthouse | New London, Missouri | 1857 / 1936 |
| 3 | Our Lady of Lourdes Church | Minneapolis, Minnesota | 1854 - 1857 |
| 4 | Forest Lodge, Hulne Park | Alnwick, Northumberland | 1853 |
| 5 | University of Missouri | Columbia, Missouri | 1892 |

## CASE NO.1 - MARK TWAIN HOTEL, HANNIBAL, MISSOURI

The Mark Twain Hotel in Hannibal, Missouri is a four story brick building built in 1906. The existing structure was founded on timber piles. The hotel was being converted to senior housing and required the addition of two new four story stairways and the underpinning of an existing stairway. It was decided not to disrupt the existing structure by attaching the new stairways to the existing building. Soils at the site also consisted of low plasticity silts and silty clays in the upper 9.1m which overly loose to medium dense alluvial sand and gravel extending to about 18.3m. The ground water was located between 4.6 and 6.1m below ground surface.

Screw-piles with grouted shafts (pulldown micropiles) were installed to the sand and gravel to provide support. Triple helix lead sections (8/10/12) were used with either a 38.1 or 44.4mm square shaft to depths ranging from 5.8 to 16.8m although most were between 9.1 and 16.8m in length. A 127mm diameter grout column was used. A total of 21 screw-piles were installed using either heavy duty foundation brackets in the case of the existing stairwell or new construction brackets as shown in Figure 4 for the new construction.

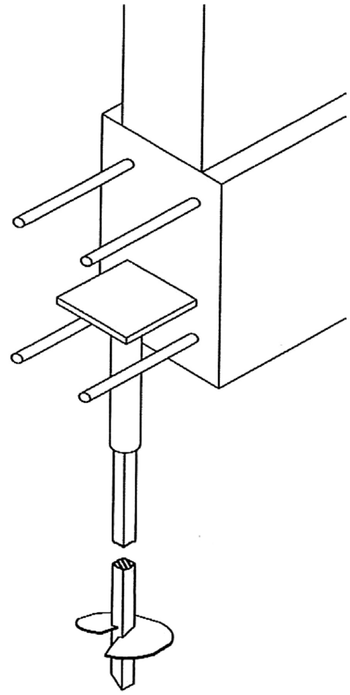

FIGURE 4. NEW CONSTRUCTION BRACKET ATTACHED TO SCREW-PILE FOR NEW FOUNDATION OR EXTENSION OF EXISTING FOUNDATION.

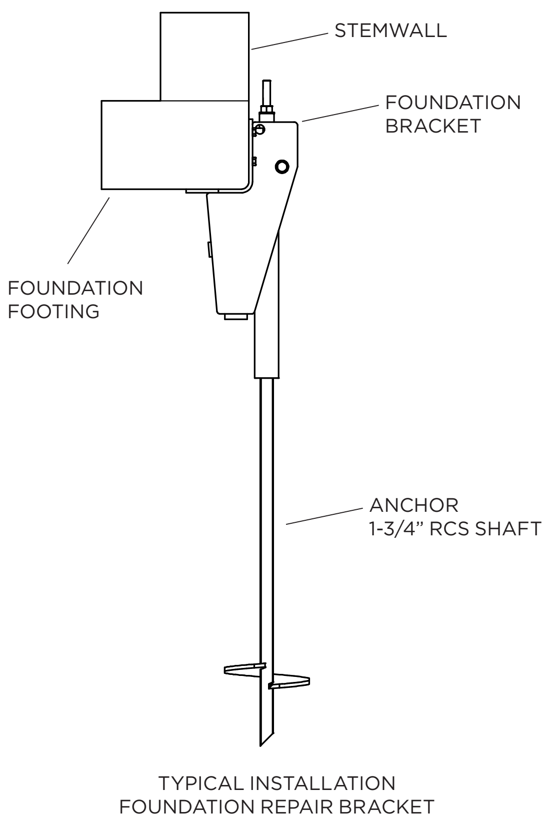


FIGURE 5. HEAVY DUTY FOUNDATION BRACKET ATTACHED TO SCREW-PILE AND EXISTING FOUNDATION.

## CASE NO.2–RALLS COUNTY COURTHOUSE, NEW LONDON, MISSOURI

The Ralls County Courthouse, located in New London, Missouri, is a limestone structure built in 1857 with a limestone addition added in 1936. Because of the settlement of the addition away from the original structure had become a concern it was necessary to underpin the addition to arrest further settlement. Based on test borings performed at the site, the soils consisted of silty clay and clay with a layer of limestone present at a depth of about 5.2m. No groundwater was encountered in test borings at the time of drilling. Estimated settlements at the time of repair were on the order of 44.4mm.

A total of 57 screw-piles were installed to depths ranging from 2.4 to 7.6m below existing foundations to support loads ranging from 50 kips to 86 kips. Both double and triple helix screw-piles with 44.4mm square shafts were installed around the perimeter of the structure to develop the required loads. While most piles were installed along the footings from the outside, a few piles were required inside the structure using a hand held portable torque head. Piles were attached to the existing foundations which were located at a depth of about 2.7m below ground surface using a heavy duty foundation bracket assembly, as shown in Figure 5. Piles were spaced approximately 1.5m apart around the outside of the structure. Installation torque was monitored on each pile. A small excavation was required at each location to allow the foundation bracket to be attached to the existing foundation.

### CASE NO.3 - OUR LADY OF LOURDES CHURCH, MINNEAPOLIS, MINNESOTA

Our Lady of Lourdes Church in Minneapolis, Minnesota is the oldest, active church in the city of Minneapolis and was built between 1854 and 1857 in the Greek temple style. The building is built of native limestone and was designated a U.S. historic landmark in 1934. Soils at the site consist of about 2.5m of sandy fill overlying dense gravely sand. At the time of drilling no water table was encountered in the upper 10 m. During installation of new water service to the church, the existing foundation at one location was undermined which caused some settlement of a wall.

Screw-piles were used to underpin the foundations to prevent additional subsidence. Triple-helix screw-piles (8/10/12) with 44.4mm square shafts were installed to a depth of about 4.6m below existing foundation levels and were attached using heavy duty foundation brackets from the outside of the structure to provide load capacity of 120 kips each. Figure 6 shows a typical heavy duty foundation bracket attached to an existing foundation.

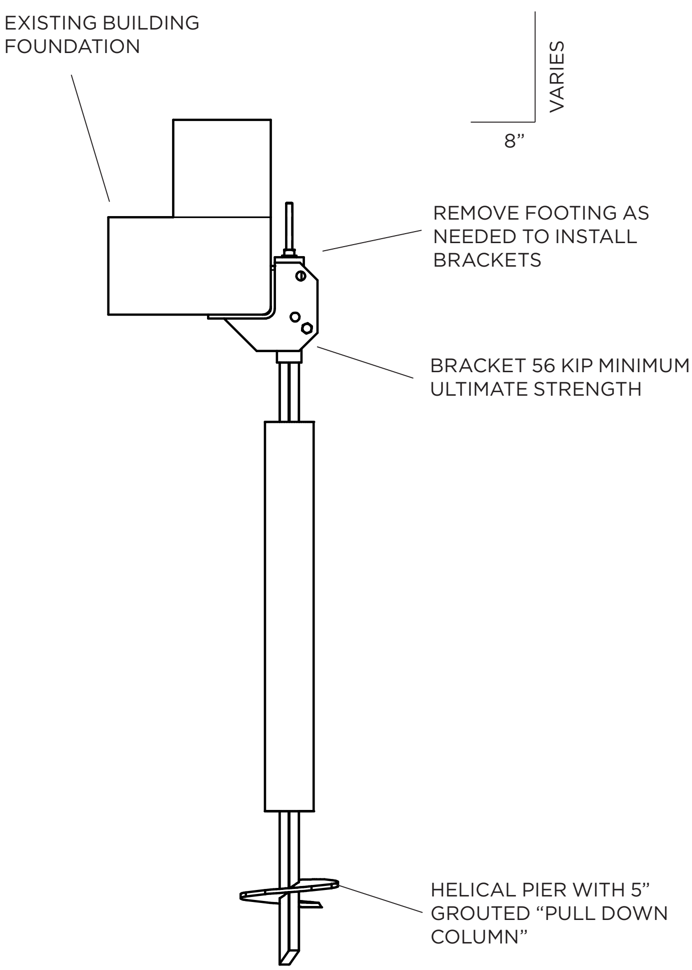


FIGURE 8. SCREW-PILE WITH GROUTED SHAFT USED FOR UNDERPINNING.

FIGURE 6. HEAVY DUTY FOUNDATION BRACKET ATTACHED TO EXISTING FOUNDATION.

FIGURE 7. FOUNDATION BRACKET AND LEVELING JACK USED AT FOREST LODGE.

### CASE NO.4 - FOREST LODGE, HULNE PARK, ALNWICK, NORTHUMBERLAND, U.K.

Forest Lodge is the gate house into Hulne Park, which is part of the Duke of Northumberland's estate in Northumberland, United Kingdom. The lodge was built in 1853 of local stone. Over the years, the north wing of the gate house had experienced excessive settlement. To prevent additional settlement, screw-piles with grouted were installed. The soil at the site consisted predominantly of miscellaneous fill overlying bedrock at about 7.5 meters below the ground surface.

Screw-piles consisted of twin helix lead sections (10/12) with a 38.1 mm square shaft with a grouted column as shown in Figure 8. Displacement plates were used to produce a 100 mm grout column. The piles were installed to bedrock which varied between 6 and 8 meters below existing foundations so that they would act in end bearing. Work was performed both inside the cellar of the gate house which included a vaulted ceiling with a kitchen above using a hand-held portable hydraulic torque head.

A total of fourteen screw-piles were installed to support the structure. Foundation brackets were then attached to the shaft of the screw-piles and then bolted to the existing foundation stones.

Figures 9 and 10 show some of the Screw-piles and foundation brackets installed at the Forest Lodge Gate House during the underpinning and restoration work.

FIGURE 9. INSTALLING SCREW-PILES AT FOREST LODGE.

FIGURE 10. CORNER OF FOREST LODGE GATE HOUSE AFTER INSTALLATION OF SCREW-PILES AND FOUNDATION BRACKETS.

**CASE NO. 5 – ENGINEERING BUILDING EAST UNIVERSITY OF MISSOURI, COLUMBIA, MISSOURI**

Engineering Building East is located on the University of Missouri campus in Columbia, Missouri and is a two story brick structure with a central bell tower built in 1892. The building was experiencing serious movement attributed to expansive soils and drainage issues around the facility. Soils at the site consisted of silty clays, sandy silt in the upper zone with weathered limestone rock at depths between 6.1 and 11.0m deep. The structure also had a basement. The building also needed to remain in use during the foundation repair which posed another issue for restoration.

Repair of the existing foundation required installation of screw-piles both inside and outside the structure in areas of limited access. Twin helix screw-piles with 44.4mm square shafts were used spaced on 1.2m centers along the building walls and 0.6 to 0.9m centers beneath the bell tower. A skid loader was used to install the screw-piles on the outer perimeter while a portable hand held hydraulic torque head was used inside, where the work space was limited. Screw-piles were attached to a heavy duty foundation bracket attached to the existing masonry rubble foundation which was then encased in a new cast-in-place concrete block to tie the existing foundation to the screw-piles.

Table 2 gives a summary of the different configurations of screw-piles used for each of the cases.

**TABLE 2. SCREW-PILES USED IN CASE HISTORIES**

| Case No. | Screw Pile Configuration | Engineer | Foundation Contractor |
|---|---|---|---|
| 1 | Grouted shaft triple helix (8/10/12) | Klinger & Associates, P.C., Hannibal Missouri | Tri-State Concrete Correction, Co. |
| 2 | Square shaft double- and triple-helix | Klinger & Associates, P.C., Hannibal Missouri | Tri-State Concrete Correction, Co. |
| 3 | Square shaft triple-helix (8/10/12) | Meyer Borgman & Johnson, Inc. | Atlas Foundation, Co. |
| 4 | Grouted shaft double-helix (10/12) | Patrick Parson Ltd. | Subsurface Technologies, Ltd. |
| 5 | Square shaft double-helix | Structural Engineering Association, Kansas City, MO. | Kidwell Construction and Pro Services |

### ADVANTAGES OF SCREW-PILES FOR STRUCTURAL REPAIR/RESTORATION

One of the highest priorities is preserving the historic fabric of the existing structure during construction activities. The use of screw-piles for the structural restoration and underpinning of historic structures has a number of advantages that in most cases cannot be realized by traditional underpinning techniques.

### MINIMAL DISRUPTION TO EXISTING STRUCTURE

The installation of screw-piles is generally minimally invasive involving slow rotation using a high torque hydraulic torque head. There are no soil cuttings to dispose from installation of the screw-piles. soil from the excavation to expose the existing foundation may be carefully stockpiled and used as backfill at the completion of the repair work. In some cases, the structure may still be used while the work is in progress.

### FLEXIBILITY OF GEOMETRY

As indicated with cases presented, screw-piles are available in a variety of configurations, including single and multi-helix lead sections with a variety of diameters. This allows considerable flexibility for the designer to select an appropriate geometry for a specific project. Increasing the helix diameter and/or number of helices or modifying the installation length to achieve the required load capacity is generally very easy. In cases where increased bending stiffness is needed to support eccentric loading, the use of the grouted shaft may be desirable. Even when a grouted shaft is used, the additional equipment needed to mix and place the grout is minimal.

### MINIMAL CONSTRUCTION VIBRATION

There are essentially no vibrations produced by the hydraulic plant during installation of the screw-piles. This may be particularly important in situations where the existing structure may be sensitive to construction vibrations.

### INSTALLATION IN HIGH GROUND WATER

The installation of screw-piles is unaffected by high ground water condition since no excavation is required below the foundation level. If water is above the foundation level, directing may be required, as in most other replacement methods.

### CONSTRUCTION IN CONFINED SPACE

Screw-piles may be installed in areas of limited access or low head room. The portable equipment can easily be managed by a single operator. Short extension section may be use inside to install the screw-piles to the required depth. The power unit used to operate the portable torque motor can be placed outside and hydraulic hosed can be routed through a window or small opening in the structure.

### FIELD VERIFICATION OF CAPACITY FOR QC

During installation, the hydraulic torque can be monitored to provide a record of the installation torque. This screw-pile attribute allows for field verification of the soil conditions at each pile location and for verification of load capacity. This is particularly important in regard to historic structures where the soil conditions under the structure are often unknown and difficult to determine, especially with interior locations. The installation torque record provides an excellent quality control tool and should be included as a part of every project.

### RAPID INSTALLATION AND CONSTRUCTION

In most soil conditions, screw-piles may be installed very quickly. A typical installation time using conventional construction equipment such as a skid steer or mini excavator is about 1 hour for a 10 m length of pile. Only a small amount of additional time is needed, when using a grouted shaft screw-pile.

### INSTANT CAPACITY/LOAD TRANSFER

In most soils Screw-piles allow for load transfer to essentially take place, as soon as the pile has been installed. This can be important in some cases where emergency repairs are needed before additional damage can occur. In the case of grouted shaft Screw-piles, sufficient time, usually 5 to 7 days may be required for the grout to attain sufficient strength before being loaded.

## CONCLUSIONS

Several case histories have been presented describing the use of helical screw-piles for providing structural repair and restoration of the integrity of the foundation of historic structures. The primary advantages of screw-piles in this application, which often involves sensitive structures, is the minimal disruption to the historic fabric of the existing structure, the minimal intrusion to the site and surroundings, minimal noise and vibrations that can accompany other more invasive methods and the speed at which the work may be performed. The methods described in this paper may be applied to other structures to achieve a cost effective intervention for preserving the structural stability of historic structures that have undergone or are continuing to exhibit additional movements because of subsurface conditions.

## ACKNOWLEDGEMENTS

The authors wish to gratefully acknowledge the assistance of a number of individuals who provided details and important project information on these projects; Ron King of King Waterproofing & Foundation Repair Solutions. Quincy, Illinois; Don Bobbit, P.E. of Centralia, Missouri; Mike Moeller, Structural Anchor Supply/Atlas Foundation Company; and Duncan Robson, Subsurface Technologies, Ltd., Alnwick, Northumberland.

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