Non-invasive underpinning technologies in historic settings

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ABSTRACT: Among the desired attributes of any intervention in buildings, particularly in historic or archaeological settings, are (1) reversibility, (2) low impact on existing materials, (3) non-disturbance of the subsurface where cultural stratigraphy exists, and (4) strength, compatibility, and visual non-invasiveness. This paper will describe recent developments in the underpinning of historic buildings within the confines of these parameters using the helical pier as the basis for the system.

1 INTRODUCTION

One of the more intriguing aspects of historic preservation is the re-discovery and re-use of ancient technologies that have been forgotten or have been replaced with modern approaches. This is seen in the re-emergence of ancient technologies, including the use of permeable mud and lime renders in the United States where they had been subsumed by the rush to harder, “more permanent” cementitious materials more than 50 years ago.

In the same vein, there are lessons to be learned from archaic construction techniques that can be applied, and in some cases upgraded, to solve modern conservation problems. An example of this is the piling, or pier, technology as exemplified by the wooden supports under the majority of buildings in Venice. Those pilings are now approaching the end of their useful life and failing, leaving conservators faced with one of the more challenging technical issues of our time. Clearly, pilings or piers represent not only the original technology, but also offer the best chance for a long-term solution to the problems of differential settlement and subsidence. It is appropriate, however, to upgrade them with modern materials for both structural and environmental reasons if such an adaptation makes sense.

Not all adaptations based on original materials or techniques have been successful. For example, millions of dollars have been spent seeking chemical amendments for soft renders leading, in most instances, to spectacular failures and a return to the original, unadulterated mixes. In other cases, technical upgrades have proven effective indeed, among them various types of seismic retrofitting.

This paper will examine the use of a thoroughly modern technology including steel hardware that had unsteady first steps but has developed into a steadfast, proven, and reliable method of stabilizing buildings on unstable footings and soils and in marshlands and lagoons.

The attributes of any intervention, particularly in historic or archaeological settings, should include: reversibility, low impact on existing materials, non-disturbance of the subsurface where cultural stratigraphy exists, and the obvious issues of strength, compatibility, and visual non-invasiveness.

The technology described here was developed with these parameters clearly in mind.

1.1 Helical technologies

The repair of loosely consolidated footings – stone in mud mortar, for example – has historically been accomplished in one of two ways: the wall base is removed/replaced or repaired using similar materials in controllable sections, or Portland cement is either injected into the subsurface or cast in a grade beam beneath the wall. For buildings with more substantial foundations, stabilization typically involves either drilling concrete caissons beside the wall and attaching it to the stem wall of the building or installing driven piers.

None of these methods satisfy all the specialized needs of historic settings. Concrete remediations are intended to be permanent alterations of what is often a culturally sensitive site, and grout injection carries the additional disadvantage of eliminating other options should it prove unsuccessful. Installing driven piers can involve substantial vibration, which may damage adjacent historic structures. To varying degrees, all approaches fail the tests of
invasiveness (both archeological and structural) and reversibility.

The author and his colleagues have been developing the technologies described below in response to the accelerated loss of stone and earthen buildings. This loss is clearly reflected on a global level and the lessons learned have distinct applications in other settings. Each of the systems described here can be modified, adapted, and applied at will in a very broad range of interventions without the encumbrance of market- and patent-based restrictions.

The helical pier is a 90-year-old technology that has historically been used primarily for the installation of utilities including pipelines and transmission towers. Its potential for replacing deep concrete pilings and caissons in new construction has been realized only in the past 15 years, and its use in historic settings has only been developed in the last five or six years. For that reason, there is a paucity of published data available comparing helical technology with other technologies.

This paper, broken into three parts, will discuss (1) the theoretical issues of conservation and the adaptation of the helical pier as an appropriate technology within that context, (2) the engineering and installation of the helical pier in settings where the indications are load, wall thickness, unstable soils, seismic potential, ground water, reversibility, historic fabric and archeology, and (3) case histories in Europe and the United States.

2 MATERIALS AND METHODS

2.1 Description

The helical pier has two basic configurations. The first is a square, solid-shaft design fitted with helices, which, unlike an augur that is continuous, are comprised of one pitch of a screw. The helices are spaced along the shaft according to an engineered pattern. The second configuration is a hollow-shaft pier that is considerably larger in cross-section and is fitted with helices in the same manner as the solid-shaft. Both types are designed to carry loads of up to 45,000 kg. Although rated for the same capacity, the hollow-shaft pier is more rigid and is designed for use in exceptionally soft soils where little or no lateral support can be expected (AB Chance 2000). Figure 1 shows a typical installation of a helical pier.

In either configuration, helical piers are constructed of hot-dipped galvanized steel. The solid-shaft piers are either 3.8 or 4.4 cm in cross-section, and the hollow-shaft is 8.9 cm outside diameter (OD). The helices are typically 1.3 cm thick and range in diameter from 15 to 36 cm.

Figure 1. Schematic of helical pier in situ (AB Chance 2000).

The selection of solid- or hollow-shaft piers and the diameter and number of helices varies depending on soil profiles, loads, and accessibility.

2.2 Engineering/Design

One of the most appealing aspects of helical technologies is that they are essentially self-engineering. This aspect of self-engineering compares very favorably against, for example, a drilled caisson, each of which must be individually load tested before being placed into service.

As the piers are turned into the soil, the torque can be roughly determined by a gauge on the hydraulic drive system or may be measured precisely through the use of a shear pin indicator. This device is extremely accurate and works on the principle that a certain grade of steel of a certain diameter will shear at a given torque. The indicator is "loaded" with a prescribed number of steel pins, each with a shear value of 678 Nm of torque. If six pins are inserted, the cumulative value is 4,068 Nm at the moment the pins shear.

The torque-to-capacity relationship is attractive because of its mathematical simplicity. If 4,068 Nm of torque is developed, the ultimate capacity of the pier is 10 times that number, or 40,680 kg. Ultimate capacity is defined as the maximum load the pier will safely bear with a safety factor of two. Thus the working load, which is the actual calculated capacity for which the pier is designed, is one-half of 40,680 kg, or 20,340 kg. Table 1 provides helical pier system ratings.

A 3.8 cm helical pier has a design capacity of 15,876 kg, and an ultimate capacity of 31,752 kg. Installed for maximum capacity, the desired torque is 9,491 Nm of torque, which is equal in value to the shearing of 14 pins in the indicator (Pack 2000).

Such simplicity allows the technician in the field to determine the bearing capacities of one or a series of piers. It also modifies the necessity (although not the desirability) of a full geotechnical report. When soils
Table 1. Helical pier system ratings.

<table>
<thead>
<tr>
<th></th>
<th>Square shaft</th>
<th>Pipe shaft 8.9 cm OD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.8 cm</td>
<td>3.8 cm</td>
</tr>
<tr>
<td>Minimum ultimate torque capacity (kN-m)</td>
<td>7.5</td>
<td>9.5</td>
</tr>
<tr>
<td>Ultimate strength (kN) for axially loaded foundation Torque limited</td>
<td>310</td>
<td>300</td>
</tr>
<tr>
<td>Torque limited Working capacity (kN) with 2.0 safety factor</td>
<td>240</td>
<td>300</td>
</tr>
<tr>
<td>Torque limited Ultimate strength per helix - tension/compression (kN)</td>
<td>160</td>
<td>150</td>
</tr>
<tr>
<td>Torque limited Working capacity per helix - tension/compression (kN) with 2.0 safety factor</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Ultimate strength per helix - tension/compression (kN)</td>
<td>180*</td>
<td>180*</td>
</tr>
<tr>
<td>Working capacity per helix - tension/compression (kN) with 2.0 safety factor</td>
<td>90*</td>
<td>90*</td>
</tr>
</tbody>
</table>

* For 36 cm-diameter helices, reduce ultimate capacity by 20%.
** For 36 cm-diameter foundation anchors, reduce allowable capacity by 20% per building code requirements. Not applicable to hollow shaft.

analyses are available, the technician can predict with 90% certainty where the piers will found based on the n-values, or blow counts, of the material.

One of the more common misunderstandings concerning helical piers is the issue of slenderness buckling. It seems unlikely to many who see them that a 3.8-cm shaft 12 to 15 meters long could support a load of over 30,000 kg. There are two reasons they work: one is a function of the soil; the other, of installation. Slenderness buckling will not occur in soils with a blow count greater than four, as the soil itself provides resistance to lateral movement. This is a valid assumption that can be built into design calculations for piers that are installed vertically or within 0.5 radians of the vertical.

However, the question is commonly asked, Doesn’t the action of screwing the helices through the soil break it down to a density that is less than the four blow count value?

Helices are one pitch of a screw and, like the threads on a wood screw, they are designed to track. In other words, the second and third helices on a shaft will follow precisely the same track as the lead helix, provided the installation allows for penetration to match the pitch. Piers are designed to penetrate 7.5 cm for each full rotation. If the soils allow for self-feeding, or if the installer provides enough “crowd” or “pull-down” to maintain that rate of penetration, the soils remain essentially undisturbed.

Importantly, particularly in tidal littorals and lagoons such as those surrounding Venice, helical piers are pre-engineered to transfer projected, and very large, loads into bearing strata deep beneath incompetent muds and silts. Helical piers have been successfully installed and tested in open water and to depths of up to 60 meters for lighthouses, harbor moorings, and wetland walkways.

In permanent installations, longevity of materials is obviously an issue. For this reason, piers are hot-dip galvanized to add 5–20% to the projected bearing life of the components. The chief consideration in estimating the life of the piers is the electrochemical makeup of the soils in which they are installed. Good engineering practice requires an understanding of the electrochemical characteristics of local soils during the design process.

Published research (AB Chance 2003) and empirical data demonstrate that soil and water characteristics do affect the expected life of galvanized steel. Soils with pH readings in mid-range, such as those in the Southwestern United States, have very little impact on zinc coatings. In our area, we can anticipate a service life well in excess of the design life of buildings and retrofits.

In high acid or alkaline soils, the anticipated life is reduced, and in salt water the zinc coating provides little protection. There are, however, methods of countering corrosion in these settings, most typically with the use of a sacrificial anode and/or epoxy coatings.

### 2.3 Installation

Helical piers may be efficiently installed either with mobile equipment if space allows or with hand-held equipment if space is limited. Figures 2 and 3 illustrate the potential of working within very confined spaces and of installing the piers through floors with very little loss of historic fabric.

Hand-held equipment will typically limit the achievable torque to 7,457 Nm of torque, thus allowing for a maximum load of approximately 25,000 kg per pier. Piers installed using a mobile vehicle can reach over 45,000 kg capacity.

Whether the pier is installed with mobile or hand-held equipment, the drive train is essentially the same. Hydraulic power is supplied through hoses from either the operating system of a tractor or excavator, or from a portable hydraulic power unit. Hydraulic pressure
3 HELICAL TECHNOLOGY IN HISTORIC SETTINGS

3.1 Principles
Underpinning any structure requires that the footing or wall base have enough tensile strength to accommodate point loading at given intervals. In other words, the wall or footing must have the capacity to span an open space. In a modern building with a reinforced concrete foundation, the span strength can be considerable and helical piers can be safely installed at intervals of 2 to 4 meters.

It is seldom the case that a historic earthen building has a footing or a wall with any tensile strength whatsoever. In these cases, the soft materials must be supported on a continuous load-bearing beam. A further complication is that many earthen buildings have very thick walls that must be supported from both sides to avoid eccentric loading and a "rollover" effect.

In response to these issues, as well as to accommodate the principles of reversibility, compatibility, strength, and low impact, we have developed several technologies, which are illustrated in the following case histories (Crocker 2003).

3.2 Case histories
3.2.1 Leaden Hall School, Salisbury Close, Great Britain, UK
This case history combines the requirements of new construction conducted in a setting with sensitive historic structures in the surrounds, and Roman era archaeological remains in the subsurface. Other conditions, as will be noted, made this site virtually impossible to develop without the use of helical piers.

Leaden Hall School is a girl's academy located within the historic Cathedral Close in Salisbury, England (Fig. 5). The school, having reached capacity in the existing buildings, had selected to expand with the addition of several classrooms and a gymnasium.
Figure 5. Salisbury Cathedral from the site of pier installations. The subsurface of the site is rich with cultural deposits.

Permits were issued based on the following parameters:

1. the footing must be reversible at any time in the future and must, therefore, contain no Portland cement that would require heavy, possibly vibratory, equipment to remove;
2. no subsurface excavation was permitted that would reveal or disturb Roman-era archaeological remains;
3. the installation must be non-invasive with regard to heavy equipment and vibrations that might damage adjacent historic structures; the footing must withstand periodic flooding, as it is located in the flood plain and within a meter of the Avon River;
4. point loads required a capacity of up to 27,000 kg (Fig. 6); and
5. piers must be installed within 3.8-cm tolerances in any direction to accommodate the steel substructure of the buildings (Fig. 7).

Perhaps the most challenging of the specifications was the geology. Soil borings indicated that a thin bed of gravel would bear the loads, but should the piers penetrate through the gravel, an extremely thick layer of saturated, incompetent chalk would be encountered. In other words, we had to achieve torque within 5.5 meters of the surface, or the piers would not work. 

The question of depth and torque was answered by the use of multiple-helix piers with diameters of up to 36 cm. In several instances where torque was not achieved at the prescribed depth, the piers were removed, helices added, and they were reinstalled to full required capacity.

Logistical considerations included the importation of the hardware to England and the acquisition of installation equipment locally. The installation was achieved through the use of a regional contractor with a top-drive auguring machine with modifications.

The installation of 87 piers, monitored throughout by the engineer, architect, and building officials, was completed in two weeks' time and met all requirements.

3.2.2 Zia Diner, Santa Fe, New Mexico, USA

A National Register site in the Guadalupe Historic District in Santa Fe, the Zia Diner (Fig. 8) is a restaurant converted from an adobe warehouse on a rubble footing. The building was constructed ca. 1925, and at some later date was rendered with a
Portland-based pebble-dash plaster. Asphalt paving and concrete sidewalks abut the walls on three sides.

The encasement and surrounding of the adobe with hard finishes led to the predictable invasion of moisture and subsequent failure of the wall bases. The first wall to slump was on the north side of the building, where ice build-up and slow melting exacerbated the process.

Figure 9 illustrates the solution used here: the installation of adobe “cages” – steel shutters that are through-bolted and tightened into place – against a thick layer of lime-rich mud. The process eliminates the need to repair and replace the slumped adobe while still complying with the necessity of interventions using soft, vapor-permeable materials. The steel frames of the cages are only one inch thick, and the expanded metal of the shutter allows for roughly 70% exposure of the wall surface.

The cages are designed to provide span strength for soft or compromised materials and to provide an attachment mechanism for the helical piers (Fig. 10).

The encasement and surrounding of the adobe with hard finishes led to the predictable invasion of moisture and subsequent failure of the wall bases. The first wall to slump was on the north side of the building, where ice build-up and slow melting exacerbated the process. The hard plaster is removed, the cages installed sequentially, and the plaster replicated (Fig. 11). In this instance, the installation included a subsurface interceptor drain and an electrically heated pad under re-graded asphalt.

Once the cages are in place, helical piers are installed and the load transfer brackets are bolted or welded to the bottom rail.

3.2.3 Las Barrancas, Jacona, New Mexico, USA

In this instance, early 20th century double-wythe adobe walls rested on a very shallow footing comprised of stone rubble and mud. The failure of two walls came about as a result of a leak in an irrigation pipe that saturated the sandy clay soils beneath. The owner was first advised by an engineer to retrofit a concrete and steel footing in 1-meter sections. However,
Figure 12. The wall is undermined in sections to accommodate custom-fabricated baskets. Baskets are supported by load transfer brackets and filled with gravel, which is capped with a filter fabric. A mud bed is applied to the fabric and the damaged wall is rebuilt on the basket. The basket is lifted into the damaged wall, providing structural support.

We installed adobe “baskets” – steel constructs engineered to bear the anticipated loads – filled with gravel to break capillarity and supported on helical piers. The baskets were custom fabricated to fit the width of wall and were installed in four-foot sections as seen in Figure 12.

4 CONCLUSIONS

Because they offer the advantages of:
1. low impact to both the building and the subsurface,
2. extremely high load bearing capacity,
3. reversibility,
4. speed and economy of installation, and
5. no visible evidence of the intervention,

helical piers have been demonstrated to be a viable and preferable alternative to the use of concrete and other invasive systems for the underpinning of historic earthen and stone buildings.

REFERENCES
