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HELICAL SCREW PILES

Alternative support for post-frame buildings

Post-frame buildings have a wide range of applications for both commercial and agricultural markets and are also often used in rural residential settings as outbuildings. As is true for all structures, the design of the foundation is critical to the successful long-term performance of the building. The foundation must be capable of providing support for compression, uplift, lateral and combined loading. The foundations for most post-frame buildings derive support near the ground surface because basements are not typically part of these structures. This means that the foundation is installed to a relatively shallow depth and therefore must count on the behavior of near-surface soils for support. In this article the use of steel helical screw piles is presented as an economical alternative to traditional foundation systems for post-frame buildings.

Traditionally, post-frame buildings have been supported on a number of different foundations. Outside of simple direct embedment, typical foundations for post-frame buildings might include open-hole (auger) drilled and cast-in-place concrete piers or drilled shafts; open-hole drilled and backfilled precast concrete pedestals; open-hole drilled, cast-in place and backfilled concrete pedestals; and short driven steel piles (see, e.g., Bohnhoff, 2006). All of these foundations have been successful in various degrees in different areas. The final selection of a foundation often is based on cost and convenience.

What are screw piles?

A screw pile consists of one or more helical blades attached to a central shaft that is then screwed into the ground to provide structural support. Screw-pile foundations were the invention of Alexander Mitchell (1780–1868), an Irish brick maker turned engineer. In 1838, Mitchell used screw piles consisting of a solid wrought iron shaft 5 inches in diameter with a cast-iron helical blade having a diameter of 4 feet installed to a depth of 12 feet below the mudline to support a lighthouse in shallow water at Maplin Sands off the coast of England near the mouth of the Thames estuary. The lighthouse survived into the early 20th century without significant problems but was destroyed by a strong storm that removed the light keeper's house but left some of the screw piles in place.

As applications progressed to other civil engineering projects around the globe, engineers replaced the solid central shaft of screw piles with a hollow iron pipe shaft. Most modern screw piles have an open-pipe central shaft; only a few exceptions are currently found where the central shaft consists of a solid round shaft. In most cases, the term screw pile is used for both. Mitchell and other engineers constructed a number of lighthouses and other structures supported on screw piles right through the end of the 19th century (Lutenegger, 2011). Other terms have been used interchangeably for screw piles, including helical pier, screw pier and helical pile.

For application to post-frame buildings, most typical screw-pile foundations will range from about 4-1/2 to 10-3/4 inches in diameter with a single helical blade 10 to 16 inches in diameter. The helical blades are typically one full revolution of a continuous screw with a pitch

Figure 1. Typical screw-pile foundation used for post-frame buildings

on the order of 3 to 4 inches. Lengths of the pile will vary from 4 to 10 feet. The final geometry and length will depend on specific site conditions and the expected building loads. Nearly all manufacturers of screw piles use a hot-dipped galvanized coating to provide protection from corrosion. The top of the screw pile is usually completed with a square steel plate welded to the pipe shaft that has mounting holes for attaching a bracket for the building posts. **Figure 1** shows a typical screw-pile foundation with a length of 5 feet, a pipe diameter of 8-5/8 inches and a helix diameter of 12 inches. The pipe is typically schedule 40 (1/4-

Figure 2.
Typical construction equipment used to install screw piles:
(a) backhoe
(b) mini-excavator
(c) skid steer
(d) small extend-a-boom

inch) wall. Most manufacturers provide finished foundations with fixed lengths, typically 4, 5, 6, 8 and 10 feet.

The helical plate or blade serves two purposes: (1) it facilitates installation by rotation of the central shaft, with the pile ideally advancing into the soil one blade pitch for each full revolution; and (2) it provides increased load capacity in both compression and tension as a result of the increased cross-sectional area of the blade.
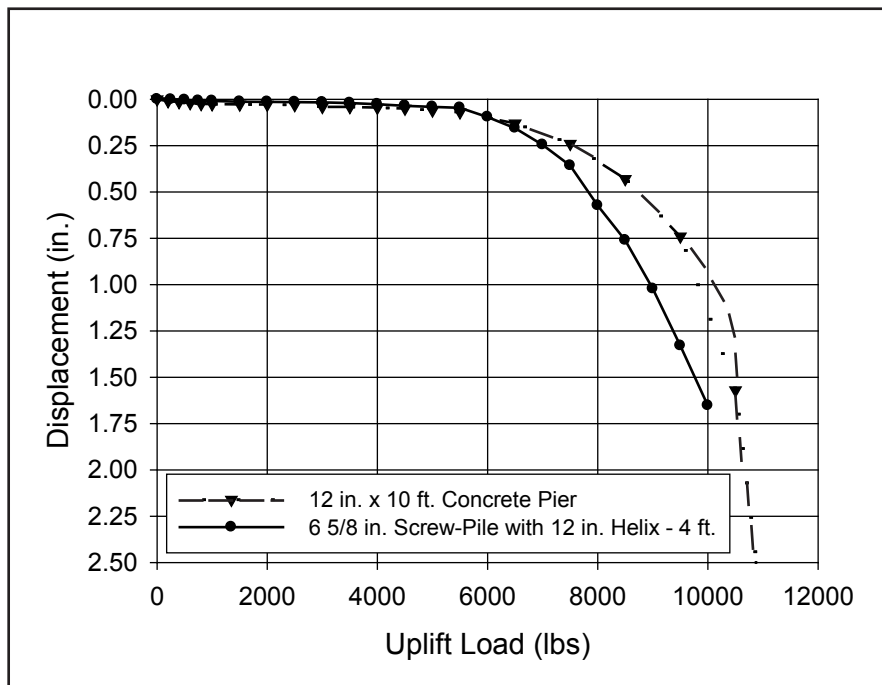
Installation

Installation of shallow screw piles is very straightforward and accomplished using a hydraulic torque head mounted on conventional construction equipment. The torque head uses the hydraulics directly from the machine and is usually attached with quick-disconnect hydraulic hoses. The most common machines used for installation include backhoes, skid steers, mini-excavators and mid-sized tire or track excavators, as shown in **Figure 2**. Small equipment is particularly useful where accessibility
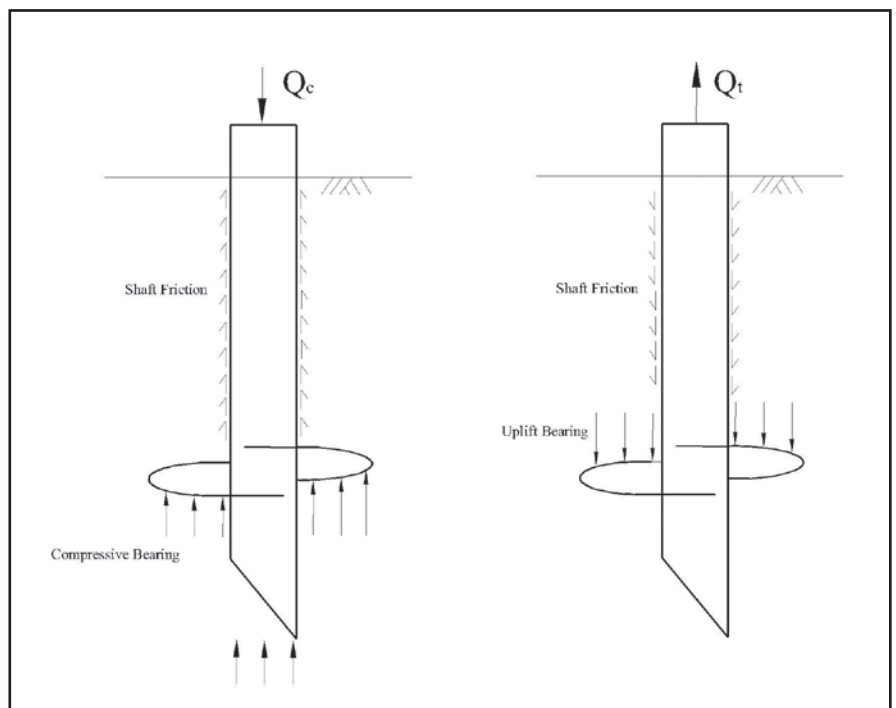
Figure 3. (a) Development of load capacity in compression (left); and (b) development of load capacity in tension (right)
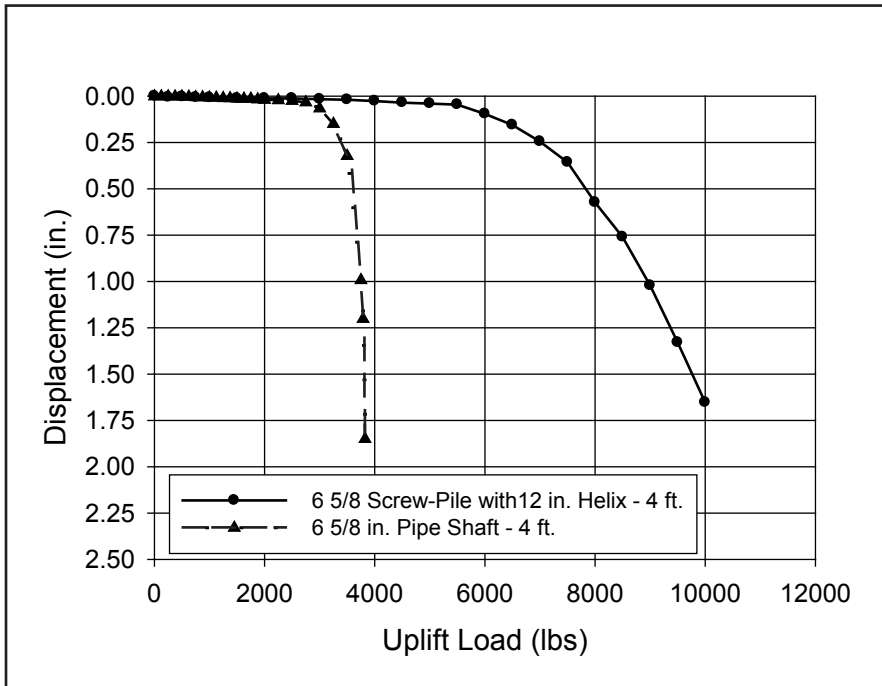
Figure 4. Comparison of uplift load tests on a screw pile and straight-pipe pile in medium stiff to stiff clay

Figure 5. Comparison of uplift load tests on a screw pile and concrete pier in medium stiff to stiff clay

is limited, and mobilization and operation of smaller equipment are more economical. Installation typically proceeds very quickly by rotation only, with little to no down force or "crowd" required to advance the pile. The helical blade does most of the work to install the screw pile to the required depth. Rotation advances the pile at a rate of about 4 to 6 revolutions per minute, so a typical installation time for a 5-foot screw pile is about 5 to 8 minutes, including time for location and attachment to the equipment.

The author has used all of the equipment shown in Figure 2 to install screw piles with diameters up to 8-5/8 inches to depths of 8 feet in both clays and sands.

Developing load capacity

Screw piles develop load capacity in axial vertical compression or tension loading in different ways. Under vertical compression loading, the load is distributed along the steel shaft and under the projected area of the helix, as shown in **Figure 3a**. The actual load distribution depends on the geometry of the pile and the soil type. Under uplift or tension loading, load is also taken by the pipe shaft, but only the net area of the helical plate (i.e., helical plate minus pipe shaft) is available to develop load capacity, as shown in **Figure 3b**.

How much capacity is provided by the helix? The answer is a bit complex. It depends on a number of factors, including the soil conditions, the direction of loading, the ratio of helix diameter to pipe shaft diameter and the pipe length. In general, for shallow installations of typical screw piles that might be used to support post-frame buildings, the helical plate contributes about 60 percent of the load capacity.

Figure 4 shows the results of two full-scale parallel uplift load tests performed at a site consisting of medium stiff to stiff clay. The screw pile was compared with a straight-driven steel-pipe pile of the same length and diameter as used on the screw pile. In this case the screw pile provides an increase in ultimate load capacity of about 6,000 pounds over the straight pipe, or an increase of about 250 percent.

How does a screw-pile foundation compare with a conventional foundation?

Figure 5 shows the results of load tests performed at the same site previously shown in Figure 4 comparing a screw pile with a straight-sided cast-in-place concrete pier, installed directly against the soil (no form). In this case similar load behavior is indicated by both foundations, with an ultimate uplift capacity of about 10,000 pounds. It should be noted, however, that the screw pile, which was installed with the helix at only a depth of 4 feet, was installed in about 5 minutes using a skid steer, while the drilled pier, which was installed to a depth of 10 feet, required several hours' work to drill the hole, pour concrete, set rebar, dispose of soil cuttings and clean up the site. Also, the concrete was allowed to cure for several days after construction and prior to being loaded. Because of the high water table at the time of construction, a small pump was used to remove standing water in the base of the hole before the concrete was placed.

Resistance against frost heave

In areas where the designer must consider frost action against a foundation and possible uplift, a screw-pile foundation can provide superior performance over a traditional drilled and cast-in-place concrete foundation. **Figure 6** shows a comparison of the measured frost heave of a screw-pile foundation and a concrete pier over a single winter (2010–2011) in Amherst, Mass., where the measured frost penetration was about 3 feet. Provided that the helical blade is located just below the expected maximum depth of frost penetration, the use of screw piles gives much enhanced resistance to heaving.

Design

The ultimate capacity of a single-helix screw pile is the sum of the shaft resistance and the helical plate capacity.

$$Q_{ult} = Q_{shaft} + Q_{helix}$$

The distribution of load between the shaft and the helix depends on the soil type, the diameter and length of the shaft and the diameter of the helix.

In saturated clays, the total stress analysis (TSA) or undrained approach is
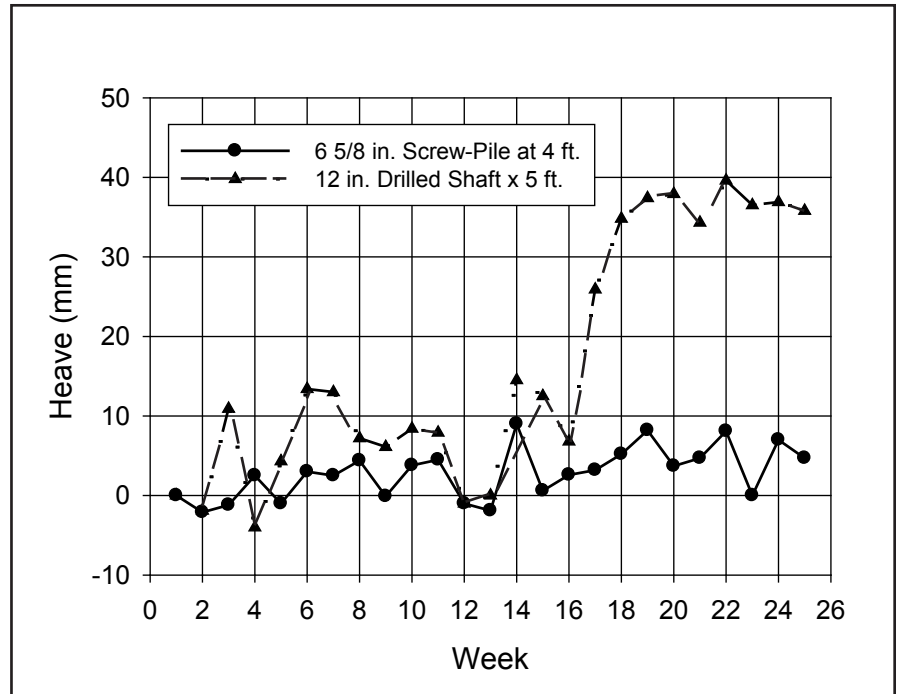

Figure 6. Comparison of frost heave between screw pile and concrete pier, Amherst, Mass., 2010–2011

usually taken for design, and the ultimate capacity is obtained from

$$Q_{ult} = [(A_{shaft}) \times f_s] + [A_{helix} \times q_h]$$

where

f_s = unit side resistance = $s_u \times \alpha$
s_u = undrained shear strength
α = shaft adhesion factor
q_h = unit end bearing of the helix = $s_u \times N_c$
N_c = bearing capacity factor

Values of α and N_c may be obtained from most foundation engineering texts. The value of N_c depends on the helix diameter-to-depth ratio, that is, the relative embedment below the ground surface. In uplift, N_c is replaced by N_u to denote uplift. Values of N_u are also available in many texts (see, e.g., Das, 1990).

In compression, the full projected area of the helical plate is used because the pipe shaft generally plugs with soil during installation. In uplift, the net area of the helical plate (the area of the helix minus the area of the shaft) is used. Also

it is general practice to reduce the area of the shaft for one diameter immediately above the helix for tension loading. Some engineers reduce the undrained shear strength about 25 percent for uplift loading when calculating the unit end bearing to account for soil disturbance produced by the helical plate during installation.

In sands, the effective stress analysis (ESA) or drained approach is typically used. In this case, the side resistance and end bearing are given by

$$f_s = (L/2) \times \gamma' \times K \times \tan \varphi'$$

$$q_h = D_h \times \gamma' \times N_q$$

where

K = lateral earth pressure coefficient (which is related to φ')
φ' = effective stress soil friction angle
L = length of shaft
D_h = depth of helix below ground surface
γ' = soil effective unit weight
N_q = bearing capacity factor (a function of embedment and φ')

Again, for uplift loading, the N_u is substituted for N_q. Values of N_u may be obtained from Das (1990).

Design Example: Let's say that a 6-5/8 inch diameter screw pile with a 14-inch diameter helix is installed in a saturated clay with the helix embedded to a depth of 5 feet. The clay has an undrained shear strength of 1,250 pounds/square foot. We want to determine the ultimate capacity in both compression and tension. $b = $ 6-5/8 inches (0.4 feet); $B = $ 14 inches (1.17 feet); $r = b/2 = 0.2$ feet; $R = B/2 = 0.585$ feet; $L = D = 5$ feet; $\alpha = 0.8$; for $D/B = 4.2$, $N_c = 9$; $N_u = 5$.

Compression:

$Q_{ult} = [(\pi \times b \times L) \times 1{,}250$ pounds/square foot $\times 0.8] + [(\pi \times R^2) \times 1{,}250$ pounds/square foot $\times 9] = 18{,}378$ pounds.

Tension:

$Q_{ult} = [(\pi \times b \times (L - b)) \times 1{,}250$ pounds/square foot $\times 0.8] + [((\pi \times R^2) - (\pi \times r^2)) \times 1{,}250$ pounds/square foot x $5] = 11{,}712$ pounds.

Round-shaft screw piles can also be designed for lateral loading using the same traditional procedures used for concrete and steel-pile foundations. A number of approaches (e.g., Brom's method and p-y method) are available in most foundation engineering texts (see, e.g., Coduto, 2000; Murthy, 2003) or may be evaluated using available software (e.g., L-Pile). It is important to note that the proper design of screw piles requires site-specific soil properties and an engineering analysis by a geotechnical engineer. It is also important that screw piles be installed by an experienced qualified contractor to ensure that the design assumptions are not compromised by poor installation practices.

Potential advantages of screw piles

The use of steel screw piles for support of post-frame buildings offers a number of advantages in addition to the increased load capacity and resistance to frost heaving that are often not realized by most traditional foundation systems. Many of these advantages are related to the ease and economics of construction.

1. Minimal site disruption. The installation of screw piles is generally minimally invasive work involving slow rotation using a low-speed high-torque hydraulic torque head. The installation takes up very little space on the site. The use of lightweight equipment means that the site won't get torn up.

2. Minimal soil cuttings. The installation of a screw pile produces no soil cuttings to dispose of after installation. The screw pile advances like a corkscrew or a wood screw and basically displaces the soil sideways during installation.

3. Minimal site cleanup. Because there are no soil cuttings generated during installation, site cleanup is easy. In many cases, essentially no cleanup is required.

4. Minimal disruption to underground utilities. In locations where underground utilities may be present, the installation of screw piles produces minimal disruption to existing utilities because the actual structural member is relatively small and produces minimal ground disturbance. The footprint needed to install a screw-pile foundation is only as large as the diameter of the helical plate.

5. Minimal installation vibration. There are essentially no vibrations produced by the hydraulic plant during installation of the screw piles, only those from the engine of the equipment being used. This may be particularly important in situations where a new structure is being built adjacent to an existing structure or facility that is sensitive to vibrations.

6. Minimal noise during installation. Since small equipment is typically used, the noise levels during installation are no greater than what is produced by the skid steer or mini-excavator.

7. Installation in tight areas. Screw piles may be installed in areas of limited site access or tight space, such as between existing structures or right next to an existing structure.

8. Rapid installation. 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 5 minutes for a screw pile

with a length of 5 feet. A single setup is used by the operator, and a complete building site can easily be completed in a few hours. Above-ground construction can then begin.

9. Installation in high groundwater conditions. The installation of screw piles is unaffected by high groundwater conditions because no excavation is required below the grade level. This means that delays in pouring concrete are avoided, there is no need to keep an excavated hole clean, and the possibility that water in an excavation would compromise the load capacity of a poured foundation is eliminated.

10. Installation by conventional construction equipment. One of the great advantages to using screw piles as foundations for post-frame buildings is that there is no need to mobilize any special equipment. An auger rig to drill holes is not needed, and no concrete truck is required.

11. Low cost of equipment mobilization. Screw piles do not require the mobilization of large specialized foundation installation equipment, such as pile hammers or large rotary drill rigs. This keeps installation costs low. Most contractors can easily fit existing equipment with the hydraulic torque head.

12. Immediate load transfer capability. In most soils screw-pile load can be applied to the foundation immediately after installation. This is a great advantage and time saver because no delay in construction time is needed for curing of concrete. In nearly all soils, the capacity of a screw pile will actually increase slightly with age.

13. Flexibility in available geometry. As previously indicated, typical screw piles that would be used for post-frame buildings are available in a variety of configurations, with a wide range of pipe and helix diameters and lengths. This allows considerable flexibility for the designer to select an appropriate geometry for a specific project. Increasing the helix diameter, pipe diameter or pipe length to achieve the required load capacity is generally very easy. Most manufacturers maintain a plentiful stock of materials, so lead time is minimal.

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14. Removability and reusability. One of the unique features of steel screw piles is that they may be removed almost as easily as they are installed, simply by rotating the pile backward. In situations involving temporary structures or modifications to an existing structure, this feature can be very attractive.

15. Quality assurance during installation by monitoring torque. During installation of a screw pile, most qualified contractors monitor the torque as the pile advances to provide a continuous record of the installation torque. This attribute of screw piles allows for field verification of the soil conditions at each pile location and for verification of load capacity. The installation torque record provides an excellent quality control tool and should be included as a part of every project.

In addition to these potential advantages, many manufacturers of screw-pile foundations use recycled steel in the fabrication. The rapid installation with small construction equipment reduces the carbon footprint of the work as compared to traditional foundation systems and uses fewer natural resources. No wood, no aggregate or Portland cement for concrete and no chemical preservatives are needed.

Limitations

As with every foundation system, screw piles are not without limitations, mostly related to installation. They cannot be used to penetrate bedrock, although they can be installed to effectively become end-bearing elements on bedrock. They are difficult to install through debris fill or large granular materials such as cobbles or boulders. In these situations other types of foundations might be better suited.

Alignment and attachment

During installation, the operator needs to be sure the required alignment is maintained so a suitable connection may be made from the screw pile to the frame post at each foundation location. A structural connection bracket can be fabricated with some room for movement in both the hori-

zontal and vertical direction to allow for exact alignment of the post. If the top plate of the screw pile is not level, steel shims may be inserted between the plate and the post mounting bracket to provide vertical alignment of the post.

Conclusions

Screw-pile foundations offer an attractive alternative for support of post-frame buildings. They can be installed quickly without special construction equipment, can be installed in nearly all soil conditions, can be installed in high groundwater situations, can be used immediately and provide large load capacity and resistance to frost heave. Screw piles represent another possibility for engineers to consider when they are selecting an appropriate foundation system for post-frame buildings. The use of screw-pile foundations has been added to the latest ASABE Shallow Post and Pier Design Standard ANSI/ASAE EP486.2 (ASABE, 2012). *FBN*

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