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02 May 2013, 4:00 pm - 6:00 pm

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Alan J. Lutenegger
University of Massachusetts, Amherst, MA

Recommended Citation

Lutenegger, Alan J., "Underpinning a Residential Structure on Uncontrolled Fill With Helical Screw-Piles" (2013). *International Conference on Case Histories in Geotechnical Engineering*. 36.
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UNDERPINNING A RESIDENTIAL STRUCTURE ON UNCONTROLLED FILL WITH HELICAL SCREW-PILES

Alan J. Lutenegger
University of Massachusetts
Amherst, Massachusetts-USA 01003

ABSTRACT

Underpinning of a private residence using square-shaft helical Screw-Piles is described. A two story wood frame single-family residence constructed in 1996 in a small subdivision started to experience differential settlement not long after construction. The settlement continued for several years, leading to excessive cracking in the basement walls and floor, severe misalignment of doors and windows and cracking of interior walls. It was discovered that the area of the housing development had previously been used as a commercial sand and gravel pit which had subsequently been used as a local dumping area for miscellaneous refuse and which had then been covered by a layer of sand and gravel. In order to stop additional movement, a series of square-shaft helical Screw-Piles was installed around the perimeter of the structure extending through the fill to the underlying dense sand and gravel. Foundation brackets were attached to the existing concrete footings for transferring load to the Screw-Piles. The site conditions are described and the results of the test borings are presented to show the composition and variability of the underlying materials with focus on the fill. A description of the underpinning work is presented to illustrate successful use of Screw-Piles for underpinning lightly loaded structures.

INTRODUCTION

For a variety of reasons, many lightly loaded structures undergo distress at some time in their life cycle, often as a result of poor subsurface conditions that are insufficient to support the loads. In most cases, residential structures are constructed without the benefit of an initial site investigation to evaluate the soil conditions with respect to construction. The added cost of a site investigation and geotechnical report are seen as an additional expense that is generally unwarranted simply because of the degree of loading generally considered with one and two story wood frame buildings.

The causes of building movements for light residential structures can vary widely; from the presence of expansive soils with high or moderate shrink and swell behavior to the presence of underlying organic soil layers with low support properties to changes in groundwater conditions brought about by either natural or artificial dewatering to a long list of other potential causes. The challenge that is presented in these cases is to correctly identify the principal cause of movement at a specific site and then to develop a rehabilitation plan to produce an effective solution. In many cases, complete repair to return a structure to its original position and condition is often not practical, but instead, a solution that stops future movement can be applied so that structural and cosmetic repairs can be made. In this way, the homeowner can return to some sense of normality and be relieved of the anxiety of future problems.

This paper presents the results of a forensic evaluation of the cause of excessive settlement experienced by a single family wood frame residential structure and the subsequent repair work that was performed to underpin the foundation to arrest the movement. The case represents a very typical and common situation in which the use of small structural elements can be implemented with minimal invasive work to the homeowner and the structure to provide a safe and reliable solution. The repair work involved the identification of previously unknown subsurface conditions that were determined to be the primary cause of the movement and the use of helical screw-piles installed adjacent to the structure to transfer the building loads to underlying competent soils.

CONSTRUCTION HISTORY

The residence was constructed in a small housing development in Florence, Massachusetts, consisting of a cul-de-sac with eight single family residences. All of the homes had been constructed by the same contractor who had a reliable and good reputation. All of the homes consisted of two-story dwellings with a concrete cast-in-place basement and an attached garage. Several of the homes also had attached covered front porches consisting of either concrete raised slabs or slab-on-grade construction.

Prior to development the area likely resembled a small open relatively flat field surrounded by mature native softwood and hardwood trees although the topography rose to the west of the site and fell to the east.

A building permit was issued in August of 1996, construction proceeded, and a Certificate of Occupancy was issued in November of 1996. The Building Inspector visited the site and inspected the foundations which consisted of conventional cast-in-place strip footings at a depth of about 7 ft. below existing grade to accommodate a concrete basement. The soil conditions at the time consisted of sand and gravel and no groundwater was encountered in the excavation.

Not long after construction was complete, the homeowner requested that the Building Inspector visit the site to examine some areas surface depressions in the yard surrounding the house. The Inspector visited in October, 1996, about one month after the end of construction, and noted “problems with ground subsiding at rear of house”.

Only one other adjacent house in the subdivision showed similar signs of distress and differential settlement, the house located about 70 ft. south of the house described. This structure showed similar crack patterns in the basement walls and similar surface depression in the front and side yards in between the two house.

PERFORMANCE HISTORY

An initial site visit performed by the author in November of 2007 included a walk over the site and the surrounding area, including adjacent properties, a preliminary surface survey of the topography, and an inspection of the outside and inside of the structure, especially the basement. At that time, several large open cracks were identified in the exposed concrete basement walls on the south side and west side of the house, as shown in Figures 1 and 2. The opening on both cracks was about 1 in. at the top and they appeared to extend downward for a considerable distance. It wasn’t until the inside walls of the basement were examined that it became clear that the cracks extended the full height of the walls and were connected by a crack extending across the concrete floor slab.

At the same time, signs of settlement of the concrete floor slab in the attached garage were noted and separation between the slab and concrete perimeter walls was noted, as shown for example in Figure 3. The author attempted to perform several hand auger borings near the structure and in the yard but was met with refusal on gravel at about 2 ft. in all locations.

Fig. 1. Basement Wall Crack on South Side.

Fig. 2. Basement Wall Crack on North Side.

Fig 3. Separation of Garage from House.

Between 1997 and 2007, the homeowner observed numerous locations both inside and outside of the house that suggested that the house was moving. In addition to cracks that developed in the concrete basement walls a number of windows and doors experienced chronic binding and difficulty opening and closing. The movements were not sudden but continued at a slow, gradual pace and in the homeowners perception the movements did not correspond to any particular seasonal variations or dependency. Additionally, the homeowner felt that the movements were cumulative with the cracks in the basement walls becoming progressively larger with time. A level survey indicated that as much as 4.5 in. of differential settlement had occurred.

In 2007 the homeowner again contacted the Building Inspector because several more depressions had developed at a number of locations around the property. The Building Inspector became concerned that the "subsidence" noted in the yards night lead to distress of utility lines located near the properties and extending under the street. After visiting the site in late 2007, the author suggested to the homeowner and Building Inspector that a series of test borings should be performed in the area around the two houses in order to determine the subsurface conditions.

SITE INVESTIGATION & SUBSURFACE CONDITIONS

In September of 2008 a site investigation consisting of 8 test borings drilled to depths of 23 ft. using a truck mounted Mobile Drill Rig was performed at the site, Figures 4 and 5. Borings were placed as close as possible to the house and at several locations in the yard where depressions had been identified as well as in areas where no depressions were present. All of the borings were conducted on the same day and consisted of soil sampling and Standard Penetration Tests as well as ground water observations in each boring; very routine site investigation practice.

Fig.4. Test Drilling Adjacent to House.

Fig.5. Test Drilling Between Adjacent Houses.

Samples were taken through 4 1/4 in. Hollow-Stem Augers using AWJ Rods. Standard Penetration Tests were performed using a Safety Hammer with a cable and freewheeling hydraulic spool. The results of the borings showed that the soils immediately under the footings (at a depth of about 7 to 8 ft. below existing grade, consisted of well-graded sand and gravel, but at a depth of about 10 ft. (about 4 ft. below the footings) test borings encountered loose random fill, consisting of wood, wire, coal, glass, plastic, paper, brick and concrete fragments, metal and other miscellaneous debris within a matrix of sand and gravel and also included a few isolated pockets of highly organic materials. This zone extended to depths ranging from about 12 to 19 ft. below grade. Underlying this material appeared to be compact native sand and gravel. Figure 6 gives combined results of Standard Penetration Tests.

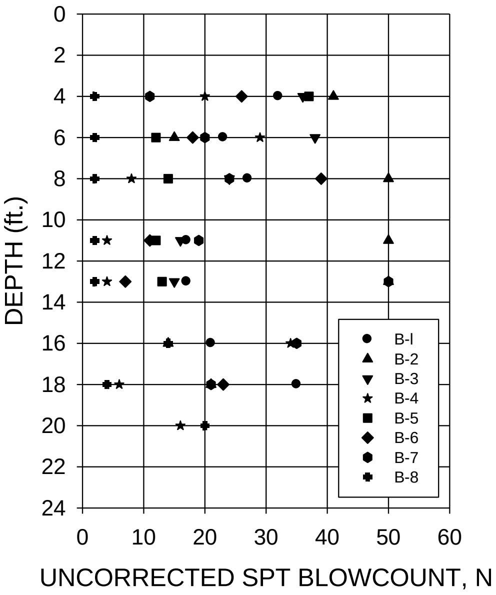

Fig. 6. SPT Results.

The SPT results show considerable variability across the site and a wide range with SPT values ranging from N = 2 to N > 50. The measured SPT Recovery also varied considerably with % Recovery ranging from 0 to 100%. No ground water was encountered in any of the test borings.

Even though the SPT N-Values show the average conditions to be reasonably dense, the composition of the materials encountered caused concern. Sometime after the drilling was complete it was discovered that the site had previously been used as a local sand and gravel pit and that after several years of removal of material the site had been uncontrollably used as a local dump site for a variety of construction waste and miscellaneous debris. This accounted for the wide range of fill materials encountered in the test borings below the upper sand and gravel. At the time of the inspection of the foundations by the local Building Inspector during construction, the materials in the excavation appeared to be natural sand and gravel, which had unknowingly been placed sometime at the site to cover the underlying debris materials.

UNDERPINNING WITH HELICAL SCREW-PILES

In many case, depending on the site conditions and site access, Screw-Piles are considered an economic and attractive alternative to the more traditional forms of underpinning, such as open-hole micropiles or jacked/driven minipiles. A Screw-Pile consists of a central steel shaft that may be either circular or square in cross section and one or more helical plates welded to the tip. Most screw-piles currently being manufactured and used in the Civil Construction industry have either a central hollow pipe section or square shaft steel bar as shown in Figure 7.

Helical foundation technology is not new to Civil Construction and was introduced in the mid 1800s by Irish and English engineers to support lighthouses, bridges, piers, buildings poles and signs, and a variety of other structures (Lutenegger 2011).

When underpinning with Screw-Piles there is a series of logical steps that the Contractor follows:

1. Make a small excavation adjacent to the structure to expose a section of the concrete footing;
2. Remove a short section of the exposed leg of the footing so that the footing is flush with the wall;
3. Clean the exposed footing concrete and slightly undercut soil along a short length;
4. Structurally attach a steel underpinning bracket (often L-shaped) to the exposed and undercut footing section;
5. Install a helical screw-pile through the underpinning bracket and advance into competent soil;
6. Attach the screw-pile to the underpinning bracket and use a hydraulic load system to prestress the pile;
7. Lock off the load and secure the pile to the bracket.

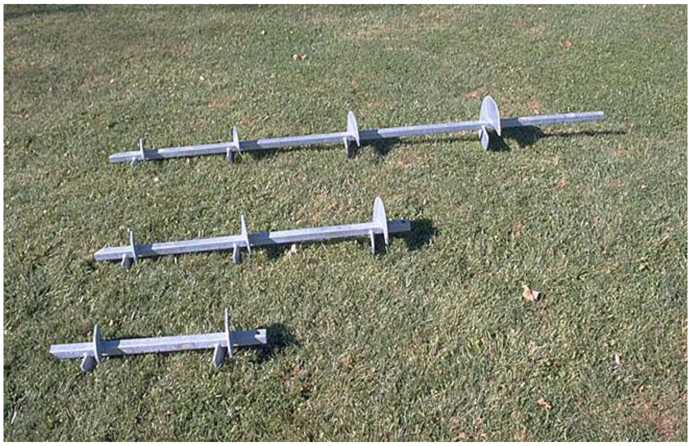

Fig. 7. Typical Square-Shaft Screw-Pile Lead Sections.

In some cases, a small concrete “buttress” or “haunch” may be poured to encapsulate the new underpinning bracket and create a monolithic concrete section integral with the existing footing. After the bracket and pile are secured to the existing footing, the work is complete and the excavation can be backfilled. This sequence is illustrated in Figure 8 and is similar to many other forms of structural underpinning used throughout the industry, with the exception that in this case the structural element being used to transfer load from the structure to an underlying competent soil is a helical Screw-Pile.

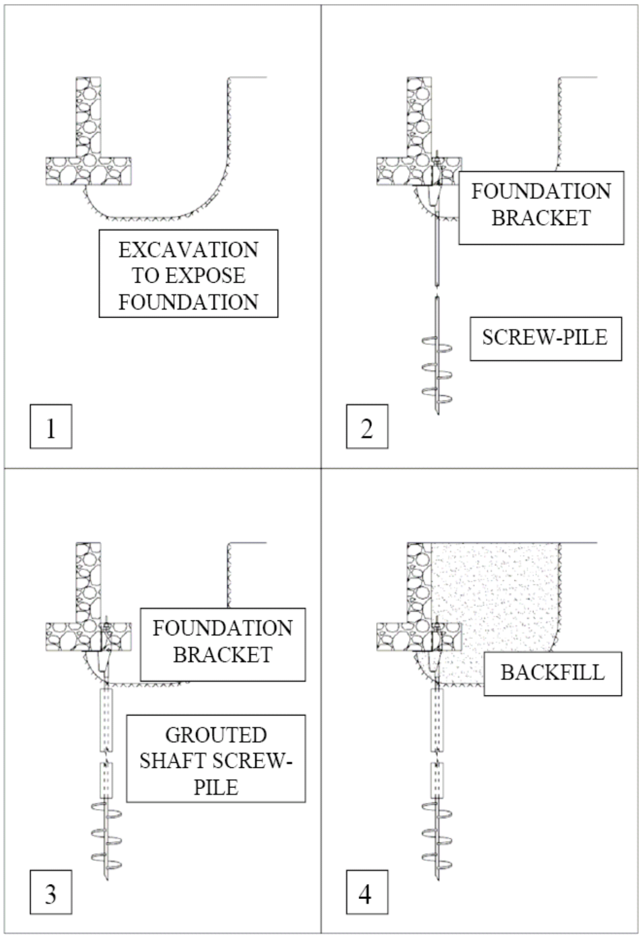

Fig. 8. Sequence of Underpinning Existing Foundations with Screw-Piles.

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. 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 concrete also provides additional protection against corrosion of the steel, although in most cases the foundation brackets are hot-dipped galvanized.

Note that Figure 8 illustrates that the Screw-Pile can also include a column of grout around the central shaft to increase the structural rigidity or it may be installed without a grout column, depending on the soil conditions and the design of the pile for bearing capacity. The entire steel bracket may be encased in concrete creating a new integral foundation system. The concrete also provides additional protection against corrosion, although in most cases the foundation brackets are hot-dipped galvanized. Figure 9 shows a typical L-style foundation bracket.

Fig. 9. Typical L-Style Foundation Bracket

REMEDIATION/UNDERPINNING

The Engineer recommended that underpinning would only be needed in about 1/3 of the footprint of the structure, mostly in the back corner of the house in the area where the most prominent wall and floor cracking had occurred and in the back and side of the attached garage. The footings for the garage were only located at a depth of about 5 ft. below existing grade while the footings for the house were about 8 ft. below grade. The repair work was performed in June of 2009.

The Contractor, who had extensive experience with similar projects and with the installation of helical piles selected 1.5 in. x 1.5 in. square-shaft helical piles with a triple-helix configuration consisting of an 8 in., 10 in. and 12 in. helix at spacings of 24 in. and 30 in. between successive helices. The pitch on all helical plates was 3 in. A total of 14 Screw-Piles were installed; 6 Screw-Piles were installed from the outside along the side and back of the garage to support the garage footings; 5 Screw-Piles were installed inside the house through the basement floor to support the side and back footings and walls of the house; and 2 Screw-Piles were installed in the center of the house to support steel columns supporting the floor joists.

The Contractor elected to work inside the finished basement for two reasons; 1) there was no exterior access to the side wall since this wall was adjacent to the existing garage and would have required removal of the garage floor to allow access.; and 2) there was a large attached deck on the back side of the house which would have been required to be removed to provide access to the back wall. Instead, to reduce disturbance to the perimeter of the property as much as possible, the Contractor installed all of the screw-piles for the house footings from inside through the unfinished basement.

Also, rather than remove all of the concrete from the perimeter on the sides where screw-piles were to be installed, the Contractor only cut small access holes of about 2 ft. x 2 ft. and removed the concrete and existing soil to expose the footing. This eliminated the need to replace the entire floor slab and only required a small amount of concrete to be replaced after the screw-piles and foundation brackets had been installed. The screw-piles were placed about 7 ft. on center around both the garage area and the house area to support the footings and transfer load through the fill and into the underlying dense sand and gravel.

The screw-piles ranged in total length from 8 ft. to 22 ft. with the two longest screw-piles of 20 and 22 ft. installed on the back corner of the garage where the fill materials seemed to be thickest. All screw-piles were installed to a minimum torque of 2500 ft.-lbs. When the load was transferred to the screw-piles the Contractor was able to raise the perimeter walls of the garage and back wall of the house slightly to reduce the differential settlement to about 50% of what had been surveyed.

Along the perimeter of the garage, the soil was removed and a trench dug down to the level of the footings using a small rubber tired track excavator. It was necessary to temporarily move an air conditioning compressor during the installation of the screw-piles. Installation of the screw-piles inside the structure was accomplished by using portable hydraulic equipment with the power pack setting outside the building and hydraulic hoses run through a basement bulkhead doorway. The low headroom in the basement presented no difficulties since square-shaft pile extension rods with lengths of 3, 5 and 7 ft. are readily available.

POTENTIAL ADVANTAGES OF SCREW-PILES FOR UNDERPINNING

The use of Screw-Piles for underpinning shallow foundations of lightly loaded structures such as the case described her offers a number of potential advantages that in many cases cannot be realized by most traditional underpinning techniques.

Minimal Disruption to Existing Structure

The installation of Screw-Piles is generally minimally invasive work involving slow rotation using a high torque hydraulic torque head. There are no excess soil cuttings to dispose of 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 many cases, the structure may still be used while the work is in progress. In this case, the homeowner retained full use of the structure while the work was accomplished with only minor noise nuisance.

Flexibility of Pile Geometry

Screw-Piles are available from a number of manufacturers 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 to suit the soil stratigraphy. 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 this project the same lead helix section was used and was able to be screwed through the existing site soils into a suitable bearing strata below the fill. Extension sections are also available with additional helical plates that could be used to achieve higher bearing capacities.

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, such as historic structures. Most Screw-Piles for restoration work may be installed with small light duty construction equipment such as a rubber track mini excavator or skid steer or portable hand held equipment.

Installation in High Ground Water

The installation of Screw-Piles is unaffected by high ground water condition since only minor excavation is required below the foundation level. Of course if ground water is above the foundation level, dewatering may be required as in most other foundation upgrading methods. Working inside the basement in this project reduced the potential for ground water issues as the basement had never experiences water problems and the test borings encountered no ground water table at the time of drilling.

Construction in Confined Space

Screw-Piles may be installed in areas of limited access or low head room, such as basements of existing structures, as in this case. The portable equipment can easily be managed by a single operator. Short extension sections may be used 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 hoses can be routed through a window or small opening in the structure. Since lead helix sections may be as short as 1 ft. and shaft extension rods typically range in standard lengths of 3 to 5 ft. installation in low headroom situations is relatively simple. No axial reaction is required to advance the Screw-Pile and reaction for a hydraulic torque motor was provided by the existing concrete wall using a lightweight torque arm. Figure 10 shows a worker installing a screw-pile through a floor access in a basement of an existing structure using light-duty hand-held portable hydraulic equipment.

Fig. 10. Installation of a Screw-Pile Through a Cutout in a Basement Floor.

Minimal Disruption to Existing Utilities

The installation of Screw-Piles produces minimal disruption to existing utilities since the actual structural member is relatively small and produces minimal ground disturbance. Figure 11 shows the successful installation of a Screw-Pile adjacent to an existing drain line.

Field Verification of Installation for QC

During installation of screw-piles the hydraulic torque can be monitored 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. In effect, measurement of the installation torque means that load capacity of each Screw-Pile can be validated during installation; much like using a Pile Driving Analyzer during the installation of driven piles. This is particularly important when installing Screw-Piles for an existing structure where the soil conditions under the structure are often unknown and difficult to determine at ever pile location ahead of time, especially at interior locations. The installation torque record of every Screw-Pile provides an excellent quality control tool and should be included as a part of every project. The engineer can also use available empirical correlations to estimate capacity based on installation torque. Figure 12 shows a typical Screw-Pile installation torque profile.

Fig. 11. Installation of a Screw-Pile Adjacent to Existing Drain Line.

In addition, field quality control can also include the number of rotations and time for each foot of advance. This will assist the engineer to evaluate if proper installation has occurred. The combination of these field measurements can also allow for rapid field modifications of the geometry of Screw-Piles to insure that the required load capacity will be achieved.

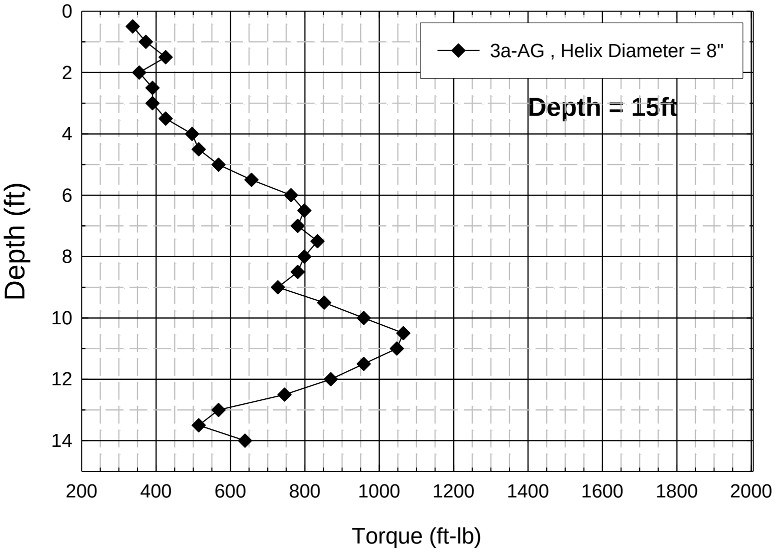

Fig. 12. Typical Screw-Pile Torque Installation Record.

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 30 minutes for a 30 ft. length of pile. Only a small amount of additional time is needed when using a grouted shaft Screw-Pile. In this case, the project was completed in a week while the actual total time needed to install the screw-piles was only a day. With concrete removal, exterior excavation and concrete and soil replacement, the total project lasted a few days longer.

Immediate Capacity/Load Transfer

In most soils Screw-Piles allow for load transfer from an existing foundation 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 it is common practice to wait anywhere from 5 to 7 days before for the grout to attain sufficient strength before the load is transferred from the existing foundation to the pile.

Low-Cost Mobilization of Equipment

Screw-Piles do not require the mobilization of specialized foundation installation equipment, such as pile hammers or large rotary drill rigs. For confined space work, inside existing structures, as in this project, portable equipment is available. In some situations, small power equipment, such as skid-steers and mini- or micro-excavators can be quickly and easily retrofitted with Screw-Pile installation hydraulics and can still operate inside existing buildings.

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 sometimes difficult to install through large debris fill or large granular materials such as cobbles or boulders. In the current project, the Standard Penetration Test results indicated dense conditions at many locations and in some cases gave very low Recovery. In New England this can be indicative of the presence of cobbles or large gravel. However, in this case, the screw-piles were able to penetrate without great difficulty and were advanced through the fill.

SUMMARY

A case of underpinning a single-family wood frame residence using helical Screw-Piles has been described. The case is not a new application of helical technology but represents a very typical application of helical Screw-Piles for successful underpinning of lightly loaded structures. Engineers need a variety of solutions to solve problems with soils that often develop after construction. Screw-Piles represent another alternative that Engineers can consider as a viable economic option. Every geotechnical project is different and every project requires a unique solution. Screw-Piles present an option for the Engineer to consider. Working with an experienced Contractor who has an understanding of the issues and who can work with the Engineer to develop a solution provides the Owner with an end product that best suits the problem.

REFERENCES

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