10841 Hickory Ridge Street
Littleton, CO 80126
(303) 627-3791 – phone / fax
ryan@hardestyconsulting.com
www.hardestyconsulting.com

Helical Piers vs. Drilled Concrete Piers in Highly Expansive Soil Areas

by Ryan J. Hardesty, P.E.

It is well known along the front range of Colorado that extensive structural damage to lightly loaded structures can occur in areas underlain by expansive soils. In addition to the damages incurred by such structures, especially residential homes, there is a considerable amount of risk that is shared amongst the community when dealing with expansive soils. For example, the risk of building on such soils affects the builders who construct the homes, the engineers who design the foundations, the warranty companies who provide structural warranties on the homes, the insurance companies who insure the warranty companies for such homes, and more importantly, the people who own the homes. In order to mitigate the risk among parties, proper design and construction should be attained and viable foundation alternatives sought out.

In the Rocky Mountain region, drilled concrete pier foundations have been utilized since the early 1950's to minimize the damage caused by the structural movement of homes built on expansive soils. Drilled concrete piers are a means of transferring structural loads from an upper layer of undesirable material to a lower layer of more desirable material. (CAGE, 1999) The load-carrying capacity of a drilled concrete pier depends not only upon its end-bearing value but also to a great extent on the skin friction value between the concrete and the surrounding soil. Concrete piers are generally drilled into bedrock or other competent material in a zone unaffected by moisture change. Within this zone, the skin friction between the concrete and soil generates the withholding force along the pier shaft. Above this zone, the soil is prone to swell along the pier shaft, producing an uplifting force along the top portion of the pier. The uplifting force is to be resisted by both the withholding force along the bottom portion of the pier and the amount of dead load pressure applied to the top of the pier from the superstructure of the home. The theory that leads to the rational method of designing drilled concrete pier foundations in expansive soils assumes that the sources of soil wetting are derived from the surface and gradually penetrate into the subsoil.

One major problem with using drilled concrete piers in highly expansive soil is the extreme embedment depths that are required to anchor the pier and resist vertical movement. Penetration into a zone of soil that is not expected to undergo significant moisture variations should be deep enough to develop enough friction between the shaft and the soil to offset the tendency for the expanding soil to lift the shaft. It may not be feasible and/or possible to construct drilled concrete piers in highly expansive areas due to current drilling constraints. Drilling rigs within the Denver area are currently capable

of drilling concrete pier holes to a depth of 38 to 40 feet. This depth constraint may hinder the ability of the drilled pier to resist the uplifting forces along the pier shaft. Due to the large surface areas of drilled piers, the pier shafts would need to penetrate beyond the possible 38 to 40 feet in order to resist such uplifting forces. Additionally, installing pier reinforcement and placing concrete at greater depths would also become a problem.

A viable alternative to drilled concrete piers is slender, steel shaft helical piers. These helical piers, or anchors, consist of a single plate or multiple plates that are formed into the shape of a helix, which resembles a pitch of a typical screw thread. The helix plate is attached to the lead section of the helical pier shaft, which is usually square or circular in cross section. Shaft extensions are installed as the lead section extends to deeper depths. Installation is accomplished by applying torque to the anchor and screwing it into the soil. The effort to install the anchor is supplied by a torque motor which can be attached to a variety of equipment such as backhoes, mini-excavators, trackhoes, hydraulic excavators, skidsteers, guided masts and hand-held equipment.

Helical piers have been successfully used in the application of underpinning distressed homes that have experienced drilled concrete pier movement. An advantage of using helical pier shafts compared to drilled concrete pier shafts is the small shaft surface area of the helical pier shaft, which allows less uplifting force to be applied to the shaft along the zone affected by moisture. The drilled concrete pier shaft surface area is approximately 377 square inches per foot of shaft length for a typical 10-inch diameter pier compared to only 72 square inches per foot of shaft length for a typical 1-1/2-inch square helical shaft and 108 square inches per foot of shaft length for a typical 2-7/8-inch diameter helical shaft.

Also, the surface of the steel helical pier typically exhibits a somewhat lower adhesion value than concrete, thus decreasing the amount of uplifting force applied to the shaft from the expansive soil. The helical pier is able to exhibit larger withholding forces with increasing torque rather than penetrating deeper into the embedment zone as with drilled concrete piers. Unlike drilled piers, the bearing capacity and withholding capacity of a helical pier is a function of the torque applied to the pier shaft. Full-scale load testing has proven that in cohesive and most granular soils helical screw piles typically have the same capacity in tension as in compression. As in any deep foundation system, the helix or helices must extend beyond the active zone into stable material.

In order to compare the two foundation systems, assume a 10-inch-diameter concrete drilled pier embedded 18 feet in expansive soil having a swelling pressure of 20,000 psf. Assuming that the upper 10 feet of the soil becomes wetted, the total uplifting force exerted on the pier is: (Chen, 1988)

$$U = 2\ \pi\ r\ f\ u\ (D - d)$$

$$U = 2\ \pi\ (5"/12)\ (0.15)\ (20000\ psf)\ (18' - 8')$$

$$U = 78,540\ lbs.$$

Assuming the drilled concrete pier is located at the end of a counterfort which exhibits virtually no dead load pressure onto the pier and the skin friction surrounding the pier below the active zone is 2,000 psf, the total withholding force exerted on the pier is: (Chen, 1988)

$$W = \pi\ r^2\ DL\ +\ 2\ \pi\ r\ s\ d$$

$$W = (0\ psf)\ +\ 2\ \pi\ (5"/12)\ (2000\ psf)\ (8')$$

$$W = 41,888\ lbs.$$

Typically by equating the total uplifting force and the total withholding force acting on a pier (Factor of Safety = 1.0), the drilled concrete pier should be adequate to prevent vertical movement from the expansive soils. In the above example, the uplifting force exceeds the withholding forces by 36,522 lbs. resulting in a factor of safety of 0.53, which will cause the pier to heave and possibly damage the superstructure.

Utilizing a 1-1/2-inch-square solid steel shaft helical pier embedded 18 feet in expansive soils having a swelling pressure of 20,000 psf. Assuming that the upper 10 feet of the soil becomes wetted, the total uplifting force exerted on the pier is assumed to be:

$$U = 4\ w_s\ f\ u\ (D-d)$$

$$U = 4\ (1.5"/12)\ (0.15)\ (20,000\ psf)\ (18'-8')$$

$$U = 15,000\ lbs.$$

❖ Conservative Assumption: Due to the lack of testing, the coefficient of uplift between concrete and soil is equal to the coefficient of uplift between steel and soil.

Assuming the helical pier is located at the end of a counterfort which exhibits virtually no dead load pressure onto the pier and the helical pier is installed with 4,000 ft-lbs. of torque, then the total withholding force exerted on the pier is:

$$W = w_s^2\ DL +\ (torque)\ (10\ ft^{-1})$$

$$W = (0\ psf)\ +\ (4,000\ ft\text{-}lbs.)\ (10\ ft^{-1})$$

$$W = 40,000\ lbs.$$

In the above helical pier example, the withholding force exceeds the uplifting force by 25,000 lbs. resulting in a factor of safety of 2.67.

Utilizing a 2-7/8-inch-diameter hollow steel pipe shaft helical pier embedded 18 feet in expansive soils having a swelling pressure of 20,000 psf. Assuming that the upper 10

feet of the soil becomes wetted, the total uplifting force exerted on the pier is assumed to be:

$$U = 2 \pi r f u (D - d)$$

$$U = 2 \pi (1\text{-}7/16''/12) (0.15) (20000 \text{ psf}) (18' - 8')$$

$$U = 22,580 \text{ lbs.}$$

> ❖ Conservative Assumption: Due to the lack of testing, the coefficient of uplift between concrete and soil is equal to the coefficient of uplift between steel and soil.

Assuming the helical pier is located at the end of a counterfort which exhibits virtually no dead load pressure onto the pier and the helical pier is installed with 4,000 ft-lbs. of torque, then the total withholding force exerted on the pier is:

$$W = w_s^2 \text{ DL} + (\text{torque}) (9 \text{ ft}^{-1})$$

$$W = (0 \text{ psf}) + (4,000 \text{ ft-lbs.}) (9 \text{ ft}^{-1})$$

$$W = 36,000 \text{ lbs.}$$

In the above helical pier example, the withholding force exceeds the uplifting force by 13,420 lbs. resulting in a factor of safety of 1.59.
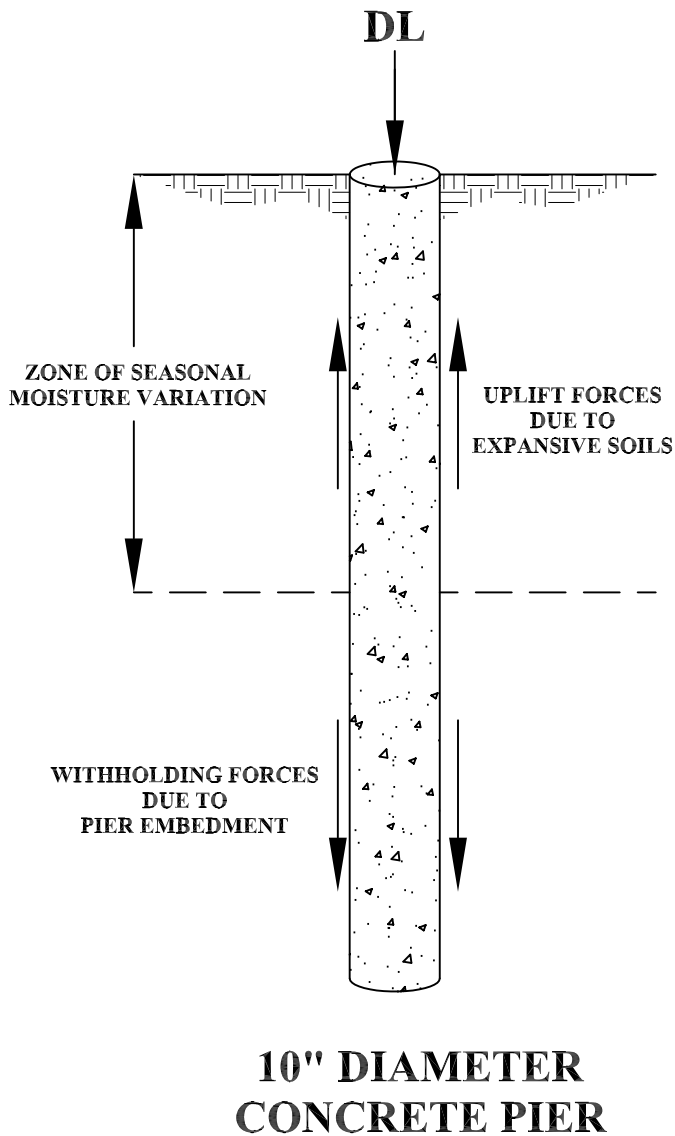
Assuming the same site conditions for both the helical piers and the drilled concrete pier, it is apparent that the helical piers are the better choice in this example. Drilled concrete piers have been found to be a feasible foundation system in low to moderately swelling soils. However, it has been shown in the above referenced calculation that drilled concrete piers would not perform adequately in such highly expansive soils.

References:

Chen, F.H. (1988). Foundations on Expansive Soils. American Elsevier Science Publication, New York, NY.

Colorado Association of Geotechnical Engineers (1999), "Commentary on Geotechnical Practices – Drilled Pier Design Criteria for Lightly Loaded Structures in the Denver Metropolitan Area," Denver, CO.

CONCRETE PIER ANALYSIS (EXPANSIVE SOILS)

DL

ZONE OF SEASONAL
MOISTURE VARIATION

UPLIFT FORCES
DUE TO
EXPANSIVE SOILS

WITHHOLDING FORCES
DUE TO
PIER EMBEDMENT

10" DIAMETER CONCRETE PIER

GIVEN:

10" DIAMETER CONCRETE PIER.

TOTAL PIER LENGTH = 18'.

EMBEDMENT INTO
COMPETENT BEDROCK.

DEPTH OF WETTING = 10 FEET.

SWELL PRESSURE = 20,000 PSF.

SIDE SKIN FRICTION = 2000 PSF.

DEAD LOAD PRESSURE = 0 (COUNTERFORT).

FIND:

UPLIFTING FORCE ?

$U = 2(\pi)(r)(f)(u)(D-d)$
$U = 2(\pi)(5"/12)(0.15)(20,000\ PSF)(18'-8')$
$U = 78,540\ LBS.$

WITHHOLDING FORCE ?

$W = \pi(r^2)(DL) + 2(\pi)(r)(s)(d)$
$W = 0 + 2(\pi)(5"/12)(2000\ PSF)(8')$
$W = 41,888\ LBS.$

FACTOR OF SAFETY AGAINST UPLIFT ?

F.S. = 0.53 - NO GOOD.

DRILLED PIER ANALYSIS

FIGURE NO.:

1

HELIX PIER ANALYSIS
(EXPANSIVE SOILS)

DL

ZONE OF SEASONAL
MOISTURE VARIATION

UPLIFT FORCES
DUE TO
EXPANSIVE SOILS

WITHHOLDING FORCES
DUE TO
PIER EMBEDMENT
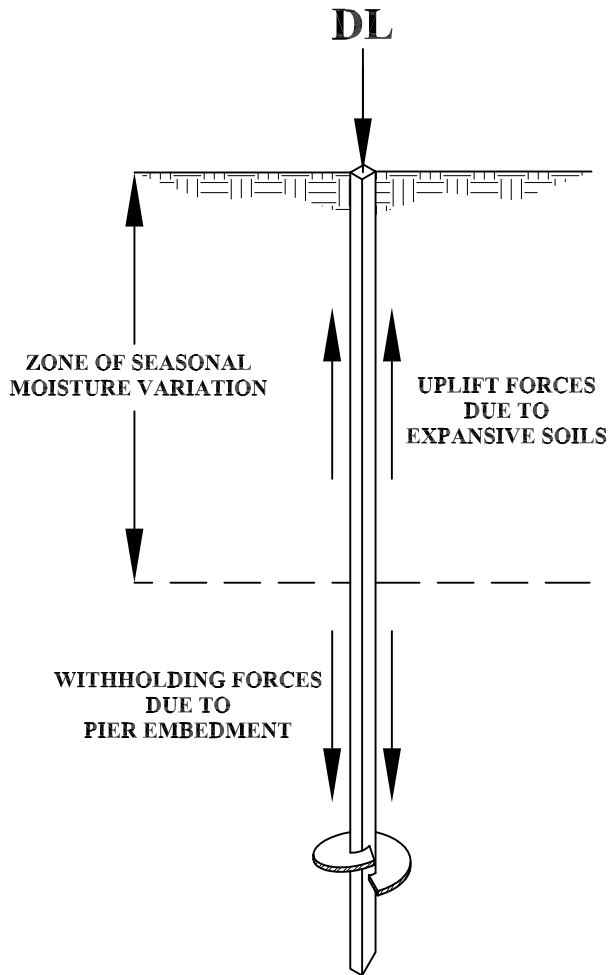
1-1/2" SQUARE SHAFT
HELIX PIER

GIVEN:

1 1/2" SQUARE SHAFT
WITH SINGLE 8" HELIX.

TOTAL PIER LENGTH = 18'.

EMBEDMENT INTO
COMPETENT BEDROCK.

INSTALLATION TORQUE = 4000 FT-LBS.

DEPTH OF WETTING = 10 FEET.

SWELL PRESSURE = 20,000 PSF.

DEAD LOAD PRESSURE = 0 (COUNTERFORT).

FIND:

UPLIFTING FORCE ?

$U = 4 (Ws) (f) (u) (D - d)$
$U = 4 (1.5" / 12) (0.15) (20,000 \ PSF) (18' - 8')$
$U = 15,000 \ LBS.$

WITHHOLDING FORCE ?

$W = (Ws \wedge 2) (DL) + (TORQUE) (10 \ ft\text{-}1)$
$W = 0 + (4000 \ FT\text{-}LBS) (10 \ ft\text{-}1)$
$W = 40,000 \ LBS.$

FACTOR OF SAFETY AGAINST UPLIFT ?

F.S. = 2.67 - OK.

HELICAL PIER ANALYSIS

FIGURE NO.:

2

HELIX PIER ANALYSIS
(EXPANSIVE SOILS)

DL

ZONE OF SEASONAL
MOISTURE VARIATION

UPLIFT FORCES
DUE TO
EXPANSIVE SOILS

WITHHOLDING FORCES
DUE TO
PIER EMBEDMENT
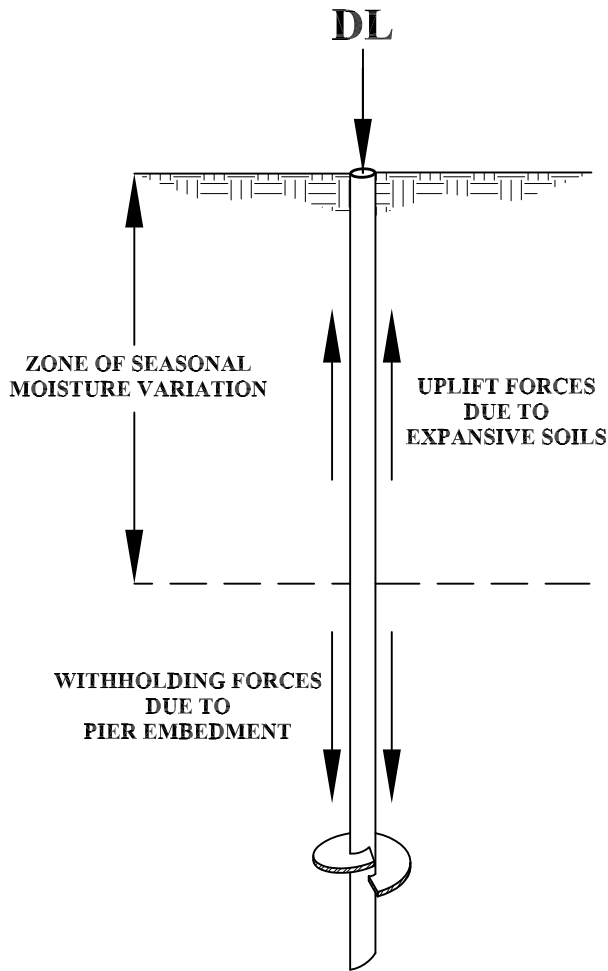
2-7/8" O.D. SHAFT
HELIX PIER

GIVEN:

2-7/8" O.D. ROUND SHAFT
WITH SINGLE 8" HELIX.

TOTAL PIER LENGTH = 18'.

EMBEDMENT INTO
COMPETENT BEDROCK.

INSTALLATION TORQUE = 4000 FT-LBS.

DEPTH OF WETTING = 10 FEET.

SWELL PRESSURE = 20,000 PSF.

DEAD LOAD PRESSURE = 0 (COUNTERFORT).

FIND:

UPLIFTING FORCE ?

$U = 2 (\pi) (r) (f) (u) (D - d)$
$U = 2 (\pi) (1\text{-}7/16" / 12) (0.15) (20{,}000 \text{ PSF}) (18' - 8')$
$U = 22{,}580 \text{ LBS.}$

WITHHOLDING FORCE ?

$W = \pi (r \wedge 2) (DL) + (TORQUE) (9 \text{ ft-1})$
$W = 0 + (4000 \text{ FT-LBS}) (9 \text{ ft-1})$
$W = 36{,}000 \text{ LBS.}$

FACTOR OF SAFETY AGAINST UPLIFT ?

F.S. = 1.59 - OK.

HELICAL PIER ANALYSIS

FIGURE NO.:

3