Step 5 – Lateral Capacity

Introduction

The primary function of a deep foundation is to resist axial loads. In some cases, they will be subjected to horizontal, or lateral loads. Lateral loads may be from wind, seismic events, live loads, water flow, etc. The resistance to lateral loads is in part a function of the near surface soil type and strength, and the effective projected area of the structure bearing against these soils. This section of the design manual presents a summarized description of the methods and procedures available to determine the lateral capacity of helical screw foundations in soil. The analysis of deep foundations under lateral loading is complicated because the soil reaction (resistance) at any point along the shaft is a function of the deflection, which in turn is dependent on the soil resistance. Therefore, solving for the response of a deep foundation under lateral loading is one type of soil-structure-interaction problem best suited for numerical methods on a desktop computer.

Lateral Resistance – Methods Used

It is obvious that helical screw foundations have slender shafts – which offer limited resistance to lateral loads that are applied perpendicular to its shaft. However, a large number of load tests have validated the concept that vertical pile foundations are capable of resisting lateral loads via shear and bending. Two commonly used methods to analyze the lateral capacity of pile foundations in soil is the finite difference method and the "Broms" method as outlined by Bengt B. Broms (1963).

Figure 5.1a
Shaft Resistance

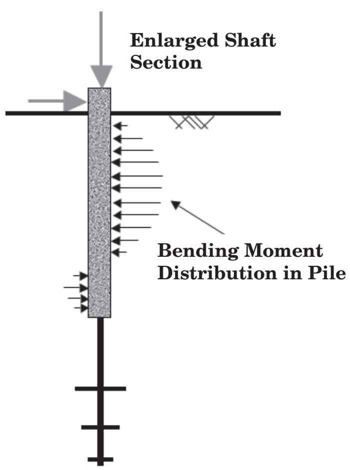


Figure 5.1b
Passive Earth Pressure Resistance

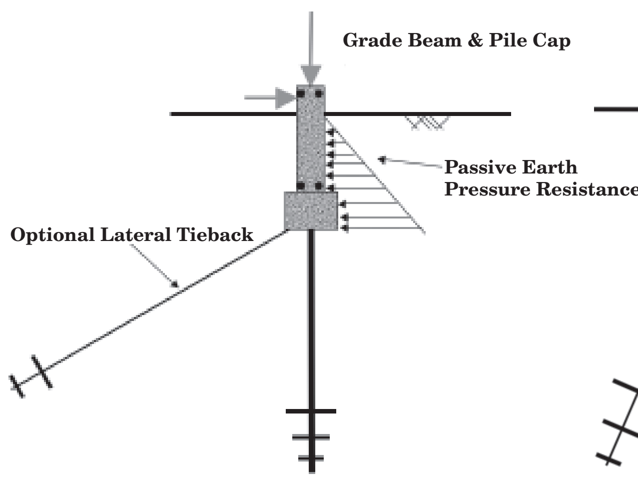
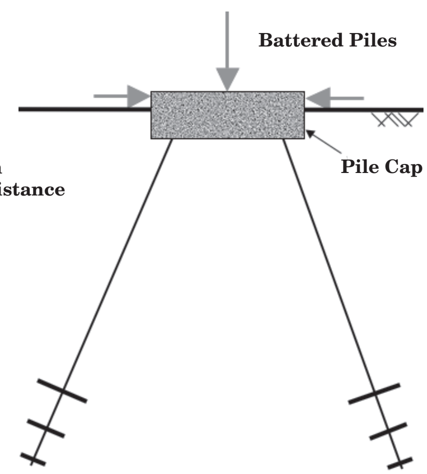


Figure 5.1c
Battered Piles



Lateral resistance can also be provided by *passive earth pressure* against the structural elements of the foundation. The resisting elements of the structure include the pile cap, grade beams, and stem walls. The passive earth pressure against the structural elements can be calculated using the Rankine method.

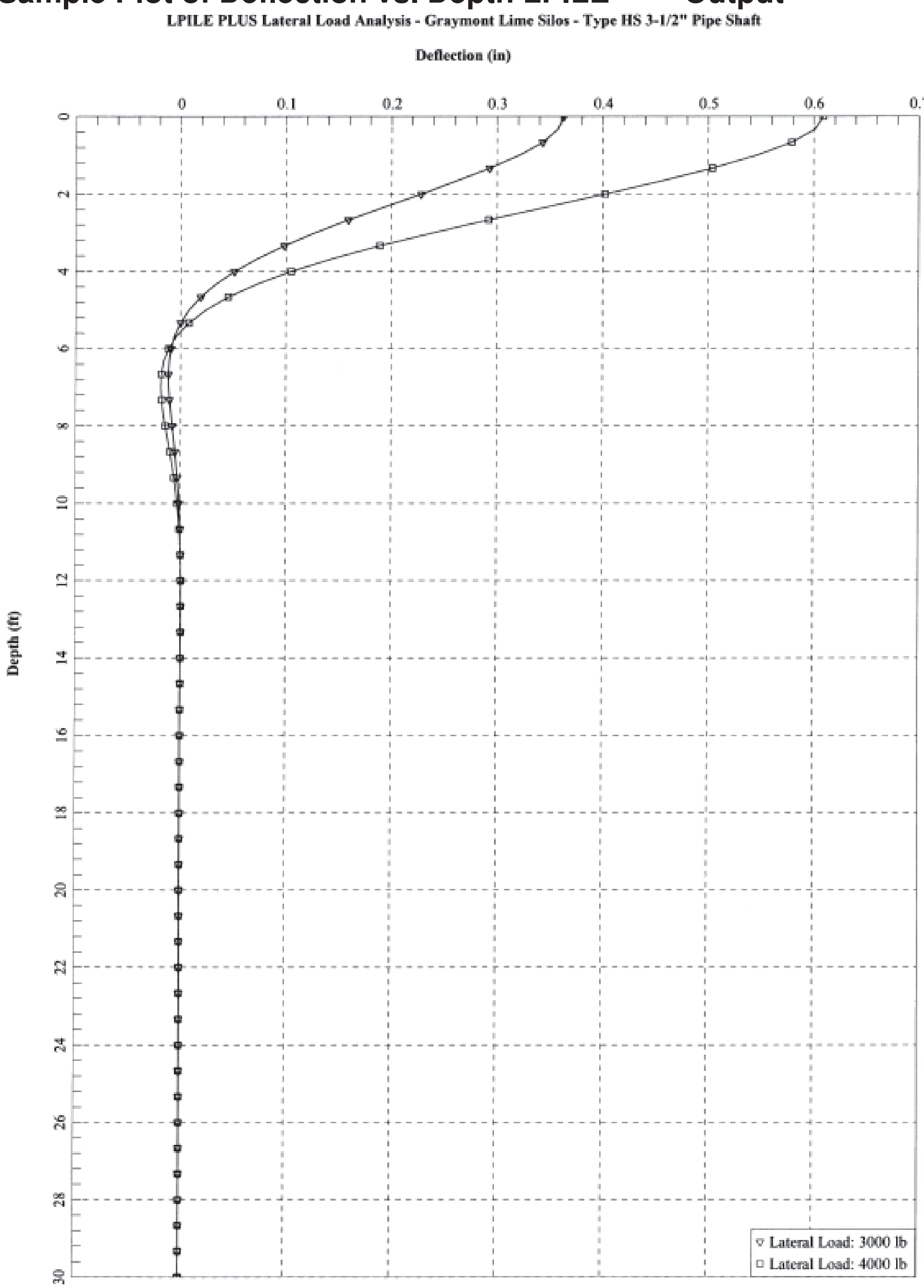
Battered screw foundations can be used to resist lateral loads by assuming that the horizontal load on the structure is resisted by components of the axial load. The implicit assumption in this is the battered foundations do not deflect laterally, which is not true. Therefore, it is better practice to use vertically installed screw foundations to resist only vertical loads and battered screw foundations to resist only lateral loads.

Friction resistance along the bottom of a footing, especially in the case of a continuous strip footing or large pile cap, can be significant. The friction component in a sandy soil is simply the structure's dead weight multiplied by the tangent of the angle of internal friction. In the case of clay, cohesion times the area of the footing may be used for the friction component. When battered piles are used to prevent lateral movement, the friction may be included in the computation. The designer is advised to use caution when using friction for lateral resistance. Some building codes do not permit friction resistance under pile supported footings and pile caps due to the possibility the soil will settle away from the footing or pile cap. Shrink-swell soils, compressible strata, and liquefiable soil can result in a void under footings and pile caps.

Design Assistance

If required, the application engineers at Hubbell Power Systems/Chance can provide project specific lateral load response analysis - given sufficient data relating to the applied loads and the soil profile. If you need engineering assistance, please contact the Hubbell/Chance Civil Construction Distributor in your area. Contact information for Hubbell/Chance Civil Construction Distributors can be found at www.abchance.com. These professionals will help you to collect the data required to perform lateral capacity analysis.

Figure 5.2a
Sample Plot of Deflection vs. Depth LPILE PLUS Output

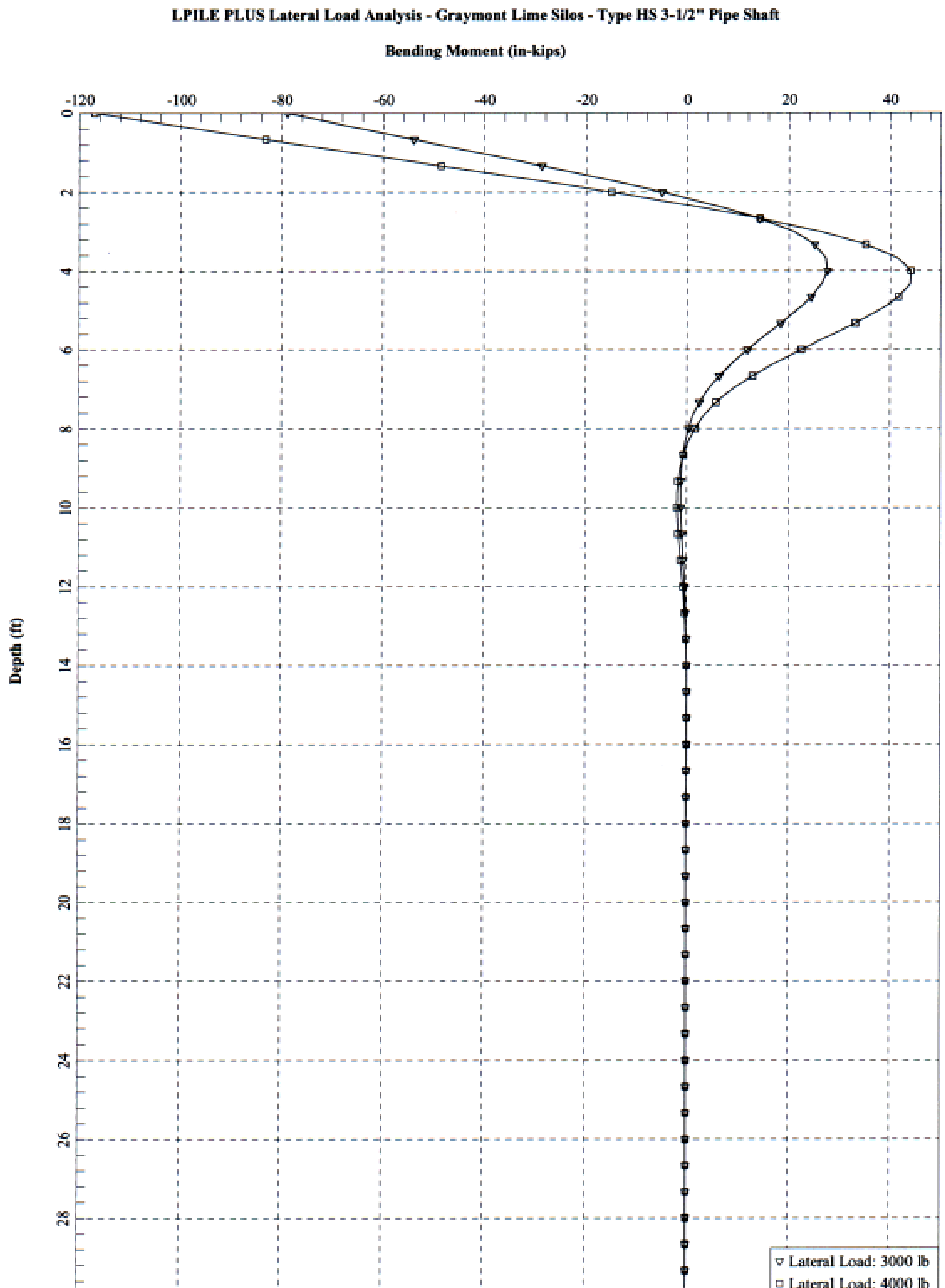


Lateral Analysis by Finite Differences

Several computer programs, such as LPILE^{PLUS} (ENSOFT, Austin, TX), are subsequent revisions of the COM624 program (Matlock and Reese) and its predecessor Beam-Column 28 (Matlock and Haliburton), which both use the p-y concept, i.e. soil resistance is a non-linear function of pile deflection, which was further developed by Poulos (1973). This method is versatile and provides a practical means for design. This method is made possible with computers for solving the governing nonlinear, fourth-order differential equation, which is explained in greater detail in Step 6. Lateral load analysis software gives the designer the tools necessary to evaluate the force-deflection behavior of a helical screw foundation embedded in soil.

Figure 5.2a and b are sample LPILE^{PLUS} output plots of lateral shaft deflection and bending moment vs. depth where the top of the pile is fixed against rotation. From results like this, the designer can quickly determine the lateral response at various horizontal loads up to the structural limit of the pile – which is typically bending. Many geotechnical consultants use LPILE^{PLUS} or other soil-structure-interaction programs to predict soil-pile response to lateral loads.

Figure 5.2b
Sample Output of Bending Moment vs. Depth LPILE^{PLUS} Output

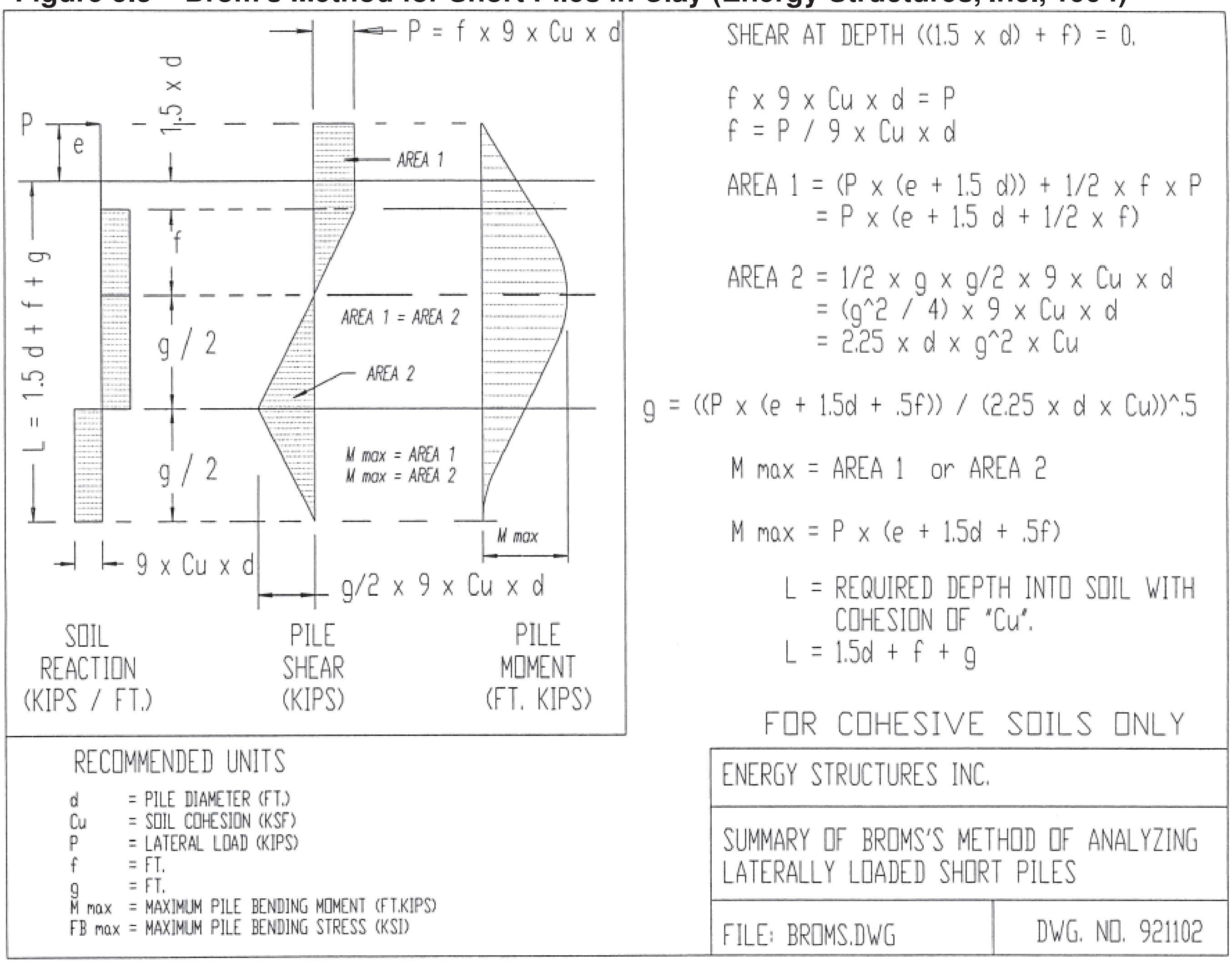


Lateral Analysis by Brom's Method

The Broms' method is best suited for applications where the top section of the helical screw foundation is a greater diameter than the bottom section. Enlarged top sections are commonly used to increase the lateral capacity of the foundation shaft. Design Example 5.1 gives an example of this. It uses the Broms' method for short piers in cohesive soil. A "short" pier is one that is rigid enough that it will move in the direction the load is tending by rotation or translation. A "long" pier is one that the top will rotate or translate without moving the bottom of the foundation, i.e. a plastic hinge will form.

Broms developed lateral capacity methods for both short and long piles in cohesive and non-cohesive soil. Broms' theorized that a short free-headed pier rotates about a center, above the lower end of the foundation, without substantial deformation along its axis. The resistance is the sum of the net of the earth pressures above and the passive earth pressure below the center of rotation. The end bearing influence or effect is neglected. Likewise, the passive earth pressure on the uppermost 1.5 diameters of shaft and the active earth pressure on the back of the pile are neglected. Figure 5.3 is a reaction/shear/moment diagram that demonstrates the Broms theory for laterally loaded short piles in cohesive soils. A simple static solution of these diagrams will yield the required embedment depth and shaft diameter of the top section required to resist the specified lateral load. It is recommended the designer obtain and review Broms' technical papers (Reference items 2 and 3) to familiarize themselves with the various solution methods in both cohesive and non-cohesive soils.

Figure 5.3 – Brom's Method for Short Piles in Clay (Energy Structures, Inc., 1994)



Design Example 5.1 – Broms' Method

A Type SS175 1¾" square shaft helical screw foundation is proposed for a pedestrian bridge abutment. The top section of the shaft is to be encased in a 6" nominal steel pipe and grout to provide lateral resistance. The top 10 feet of the soil profile is medium-stiff clay with cohesion of 1000 psf. Determine what length of 6" diameter steel case is required to resist 4400 lb of lateral load using the Broms' method.

Assumptions:

1. The 1¾" square shaft below the 6" cased section provides no lateral resistance.
2. The solution method used is as shown in Figure 5.3.
3. Eccentricity is assumed to be 1 ft.

The Broms' method is typically an iterative process best solved with a computer spreadsheet program. But for this example, the solution is straightforward.

Solution:

P = Applied Horizontal Shear Load: Use 4400 lb, Include a Factor of Safety of 2 in the calculations, thus double the Horizontal Shear Load: P = 2 x 4400 = 8800 lb

C_u = Cohesion of Clay, use C_u = 1000 psf

D = Diameter of Foundation; Use D = 6.625" (6" nominal pipe size)

e = Eccentricity; Distance Above Grade to Resolved Load: Use e = 1 ft

L = Minimum Length of Foundation Based on Above Criteria.

$f = P/9(C_u)D$ — Equation 5.1

$f = 8800\text{ lb.}/9(1000\text{ psf})(6.625''/12) = 1.771\text{ ft}$

$M^{POS}{}_{MAX} = P[e + 1.5(D) + 0.5(f)]$ — Equation 5.2

$M^{POS}{}_{MAX} = 8800\text{ lb}[1\text{ ft} + 1.5(6.625''/12) + 0.5(1.771\text{ ft.})] = 23{,}880\text{ ft-lb}$

$M^{POS}{}_{MAX} = 2.25(D)g^2(C_u)$ — Equation 5.3

$23{,}880\text{ ft-lb} = 2.25(6.625''/12)g^2(1000\text{ psf})$

$g^2 = 19.22\text{ ft}^2$

$g = \sqrt{19.22} = 4.38\text{ ft}$

$L = 1.5D + f + g$ — Equation 5.4

$L = 1.5(6.625''/12) + 1.771\text{ ft} + 4.38\text{ ft.} = 6.98\text{ ft}$

The 6" nominal steel case should be at least 7'-0 long to resist the 4400 lb lateral load.

The Broms method was probably the most widely used method prior to the finite difference and finite element methods used today and gives fair agreement with field results for short piles.

Lateral Capacity by Battered Helical Screw Foundations and Anchors

Lateral loads are commonly resolved with battered screw foundations and tension anchors. The method is to statically resolve the axial load capacity into its vertical and horizontal components. As stated earlier, it is best to use vertically installed screw foundations to resist only vertical loads and battered screw foundations to resist only lateral loads.

There are some engineers who feel that battered piles in seismic areas "attract seismic forces" during an earthquake, and may therefore rupture. This restriction requires seismic loads to be resisted by means other than battered piles. Other designers allow battered tension devices to elongate elastically and act as a damper, but do not consider the tension anchor capable of resisting compression. Chance helical screw foundations have been supplied to the seismic prone areas of the west coast of the United States and Canada for over 20 years for civil construction projects. In tension applications, they have been in service for over 40 years. They have been subjected to many earthquakes and aftershocks with good experience. Our helical pre-engineered products have been used far more extensively than any other manufacturer's helical product in these areas. To date, there have been no ill effects observed using battered screw anchors and foundations in seismic areas. These foundations, both vertically installed and battered, have been subjected to several earthquakes of magnitude 7+ on the Richter scale with no adverse affects. Anecdotal evidence indicates the structures on screw foundations experienced less earthquake-induced distress than their adjacent structure on conventional foundations. Their performances were documented anecdotally in the technical literature, including Engineering News Record.

Lateral Capacity by Passive Earth Pressure

Passive earth pressure on the projected area of the pile cap, grade beam, or stem wall can be calculated by the Rankine (ca. 1857) method, which assumes no soil cohesion or wall-soil friction. One can use known or assumed soil parameters to determine the sum of the passive earth pressure minus the active earth pressure on the other side of the foundation as shown in Figure 5.4. The following are general equations to calculate active and passive pressures on a wall for the simple case on a frictionless vertical face and a horizontal ground surface. Equations 5.8 and 5.9 are Rankine equations for sand. Equations 5.10 and 5.11 are the addition of the cohesion for clay or cohesive soils. Three basic conditions are required for validity of the equations:

1. The soil material is homogenous.
2. Sufficient movement has occurred so shear strength on failure surface is completely mobilized.
3. Resisting element is vertical, resultant forces are horizontal.

$K_0 = 1 - \sin\phi$ Equation 5.5

$K_a = \tan^2(45 - \phi/2)$ Equation 5.6

$K_p = \tan^2(45 + \phi/2)$ Equation 5.7

For Granular Soil (sand):

$P_a = \frac{1}{2} K_a \gamma H^2$ Equation 5.8

$P_p = \frac{1}{2} K_p \gamma H^2$ Equation 5.9

For Cohesive Soil (clay):

$P_a = \frac{1}{2} K_a \gamma H^2 - 2cH + 2c^2/\gamma$ Equation 5.10

$P_p = \frac{1}{2} K_p \gamma H^2 + 2cH$ Equation 5.11

Where:
K_0 = coefficient of earth pressure at rest
K_a = coefficient of active earth pressure
K_p = coefficient of passive earth pressure
H = height of wall or resisting element
c = cohesion
γ = unit weight of soil
P_a = active earth pressure
P_p = passive earth pressure

NOTE: Equations 5.5 – 5.11 from Reference item 7.

Table 5.1 is a tabulation of the coefficient for at rest, active, and passive earth pressure for various soil types, relative densities and consistencies.

Table 5.1 Coefficients of Earth Pressure (Das, 1987)

Soil	K_0, drained	K_0, total	K_a, total	K_p, total
Clay, soft*	0.6	1	1	1
Clay, hard*	0.5	0.8	1	1
Sand, loose	0.6	0.53	0.2	3
Sand, dense	0.4	0.35	0.3	4.6

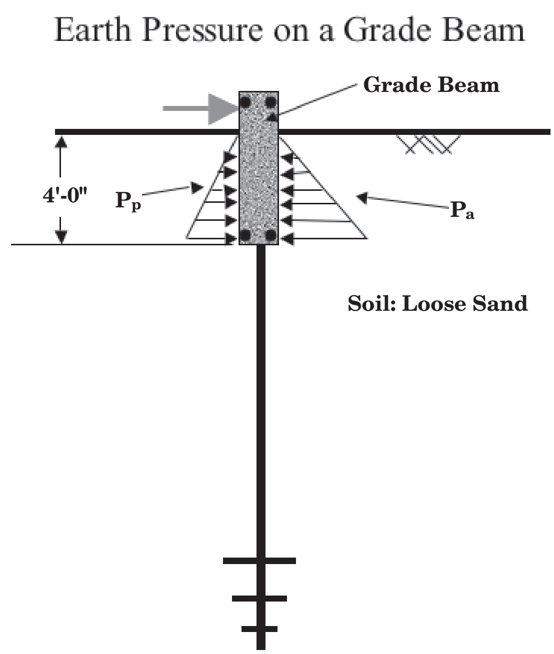
* assume saturated clays

Using the Rankine solution may be an over-simplification of the problem but tends to be conservative since the height of the projected area of the footing or pile cap is not large and the cohesion term will generally be small.

Design Example 5.2
– Earth Pressure Resistance

A Type SS5 $1^1/_2$" square shaft helical screw foundation is proposed as part of a pier and beam foundation for a residential structure. The top of the screw foundation is fixed in a concrete grade beam, which extends 4'-0 below grade. The surface soils are loose sands. Determine the lateral capacity of the grade beam using the Rankine earth pressure method.

Figure 5.4
For Design Example 5.2



<u>Assumptions:</u>

1. The lateral capacity of the $1^1/_2$" square shaft helical foundation is limited based on shaft size. It is generally not assigned any contribution to the lateral capacity of a foundation.
2. The effective length of the grade beam for lateral resistance is 25'-0.
3. Assume a unit weight of 95 pcf.
4. The water table is well below the bottom of the grade beam.
5. There are no surcharge loads.

Solution:

From Table 5.1, $K_a = 0.2$, $K_p = 3$

$P_a = {}^1/_2 K_a \gamma H^2$
$P_a = {}^1/_2 \times 0.2 \times 95 \times 4^2 = 152$ lb/ft

$P_p = {}^1/_2 K_p \gamma H^2$
$P_p = {}^1/_2 \times 3 \times 95 \times 4^2 = 2280$ lb/ft

Pp – Pa = 2280 – 152 = 2128 lb/ft

Total lateral resistance = 2128 x 25'-0 = 53,200 lb

NOTE: In this example, more than 1" of movement will probably be required to fully mobilize the total lateral resistance. Partial mobilization requires less deflection.

Additional Comments

The lateral capacity of pipe shaft foundations is greater than the square shaft foundations because of the larger section size. Typical pipe diameters of $3^1/_2$" and 4" OD are used for Hubbell/A.B. Chance Company helical screw foundations. As shown in Design Example 5.1, enlarged shaft sections are used for certain applications. From a practical standpoint, the largest diameter screw foundation available from Hubbell/Chance is $10^3/_4$" diameter.

There are several other methods used to analyze the lateral capacity of the shaft of the pile, including the early researchers Davis (1961) and Brinch Hansen (1961), with the most commonly used being Broms (1964). The Davis research applied the principles of plane strain to the problem. Other simplifying assumptions made to the Brinch Hansen method are: the shape of the pile has no influence of the pressure magnitude or distribution, the full lateral resistance is mobilized at the movement considered and the distribution of the passive earth pressure is three times the Rankine passive earth pressure.

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