

2.1 History

Commonly referred to as push piers, jacked piles, resistance piers, or hydraulically driven piers, these systems were developed to stabilize existing buildings against further settlement and/or to provide additional foundation support. Push pier systems have patent history dating back to the late 1800s and had their early beginnings in the populated areas of the northeast United States (US). Several inventors from New York were the pioneers of these systems, and utilized a common methodology of pushing hollow, tubular iron columns in sections to a suitable load bearing stratum. They are considered retrofit systems since they require an existing structure to provide the reaction necessary to push or drive the piers to competent soils. These early pier systems were typically installed beneath opposing sides of a building wall (staggered or in pairs), or directly beneath the center of the wall.

Jules Breuchard patented the first push pier system in the US (Patent No. 563,130) on June 30, 1896, which specified removal of portions of brick foundation walls to allow for placement of structural "headers" (stone or steel) and setup of the drive equipment (*Figure 2.1*).

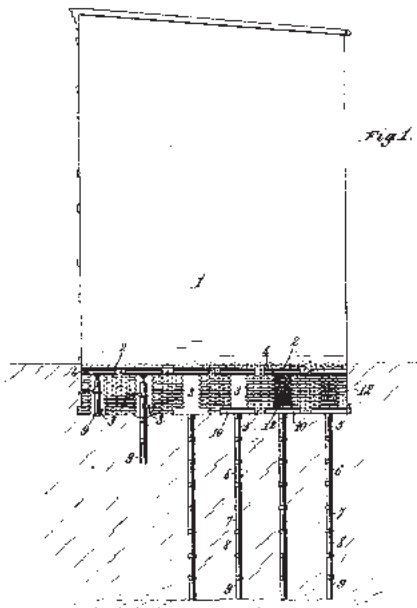


Figure 2.1 Breuchard patented system (1896)

The drive equipment (or "ram") would push steel piling sections against the upper header beam using the weight of the structure until the desired resistance was achieved. The top of the pier would then be shimmed with brick or other structural elements to another header beam located across the bottom of the foundation opening. The space between the structural headers would then be refilled with brick and mortar. The first application of this system was in New York City in 1896. The piers supported a 4-story building during the excavation and construction of the basement level of the new Commercial Cable Building on the adjacent property. Nine piers were installed along a 57-foot long wall to allow excavation to a depth of about 10 feet below the underpinned structure. The piers were manufactured from 10-inch outside diameter (O.D.) pipe with a $\frac{5}{8}$ -inch wall thickness. Five-foot lengths of pipe were pushed to depths of about 33 feet using a 60-ton hydraulic ram to its full capacity. External couplings were used to maintain direct bearing of the pier sections. An internal coupling was first patented by Francis Pruyn (US Patent No. 1,188,485) on June 27, 1916. This internal coupling concept allowed for a premanufactured connection with the same diameter as the pier pipe (*Figure 2.2*).

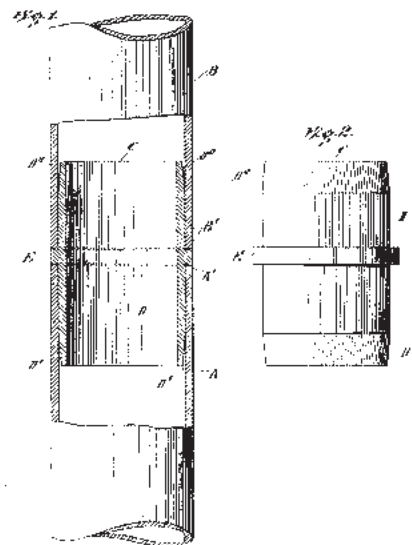


Figure 2.2 Pruyn patented internal coupling (1916)

The Breuchard system did not specify a factor of safety to be applied to the service loads and some problems resulted from underperformance of the piers after construction. The first patented push pier system to recommend a factor of safety was registered by Lazarus White (US Patent No. 1,217,128) on February 20, 1917. Specifically, the language in the patent recommends a final drive load about 50 percent greater than the service load applied to the pier, which equates to a factor of safety of 1.5 against pier settlement. This patent also describes using a pressure gauge within the hydraulic system to monitor final drive and lock-off pressures. The White patent detailed geotechnical considerations, including pier rebound, and provided a drawing of the assumed pressure bulb formed under the pier tip upon loading (*Figure 2.3*). In a later patent registered on October 20, 1931 (US Patent No. 1,827,921), Lazarus White recommended application of the drive force to each pier individually and then simultaneous loading of all piers to evenly distribute structural loads during lock-off procedures. Mr. White also suggested that previous performance problems with push pier systems may have been due to overlap of the assumed stress bulbs for closely spaced piers, which he believed could be mitigated by using simultaneous loading during lock off.

Figure 2.3 Assumed stress bulb under push pier tip (White, 1917)

An eccentrically loaded flush-mount bracket system was presented in the Henry Revesz and Jack Steinsberger Patent (US Patent No. 2,982,103) registered on May 2,

1961. This system had many similarities to current flush-mount pier systems, including attachment of a flush-mount pier bracket to a foundation wall and using a drive stand and hydraulic ram to provide the final drive and lock-off forces. This patent also recommended applying a factor of safety of 1.5 to the service load to determine the required final drive load. The components and setup of this system are shown in *Figure 2.4*.

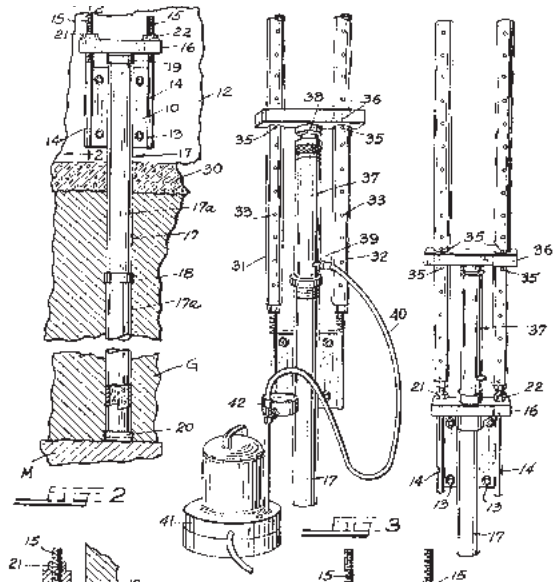


Figure 2.4 Revesz and Steinsberger flush-mount push pier system (1961)

The first patent for a side-load, under-footing bracket with vertical and horizontal bearing plates positioned against and below a footing was issued on September 2, 1975 to George Langenbach (US Patent No. 3,902,326). The system was further refined in subsequent patents to resemble the eccentric push pier systems common today. The ingenuity of these early inventors paved the way for the development of numerous push pier systems and an industry that has grown dramatically since the 1970s. Manufacturers and installers of underpinning systems continue to provide innovative solutions capable of ever-increasing load capacities and improved system performance. Systems designed by reputable manufacturers, installed by experienced foundation repair contractors, and with a proven record of performance have become widely accepted throughout the engineering community.

2.2 Summary Description

Foundation Supportworks push pier systems utilize high-strength round steel tubes and a load transfer bracket (retrofit foundation repair bracket) to stabilize and/or lift sinking or settling foundations, or to provide additional capacity to existing foundation systems. The foundation bracket is secured against and below the existing footing (under-footing bracket), directly beneath the footing and foundation wall (concentric bracket), to the side of the footing or foundation wall (flush-mount bracket), or below existing slabs (slab pier bracket). Pier sections are then hydraulically driven through the bracket and into the soil below using the combined structural weight and any contributory soil load as drive resistance. The one exception to this typical installation process is the concentric pier system. Concentric pier sections are driven without the foundation bracket in place. When the pier has met termination criteria, the drive stand is removed and the concentric pier bracket is set over the installed pier.

Pier sections are added and driven until a suitable load bearing stratum is encountered. At that point, the structure either begins to lift or the target pressure/load is achieved. The weight of the structure is then transferred to the foundation brackets, through the piers, and to firm load bearing soil or bedrock. Typical under-footing, concentric, flush-mount, and slab pier brackets are shown in *Figure 2.5*. A Model PP288 push pier installation is shown in *Figure 2.6*.



Figure 2.5 Left to right; typical under-footing, flush-mount, concentric pier, and slab pier brackets (no relative scale)

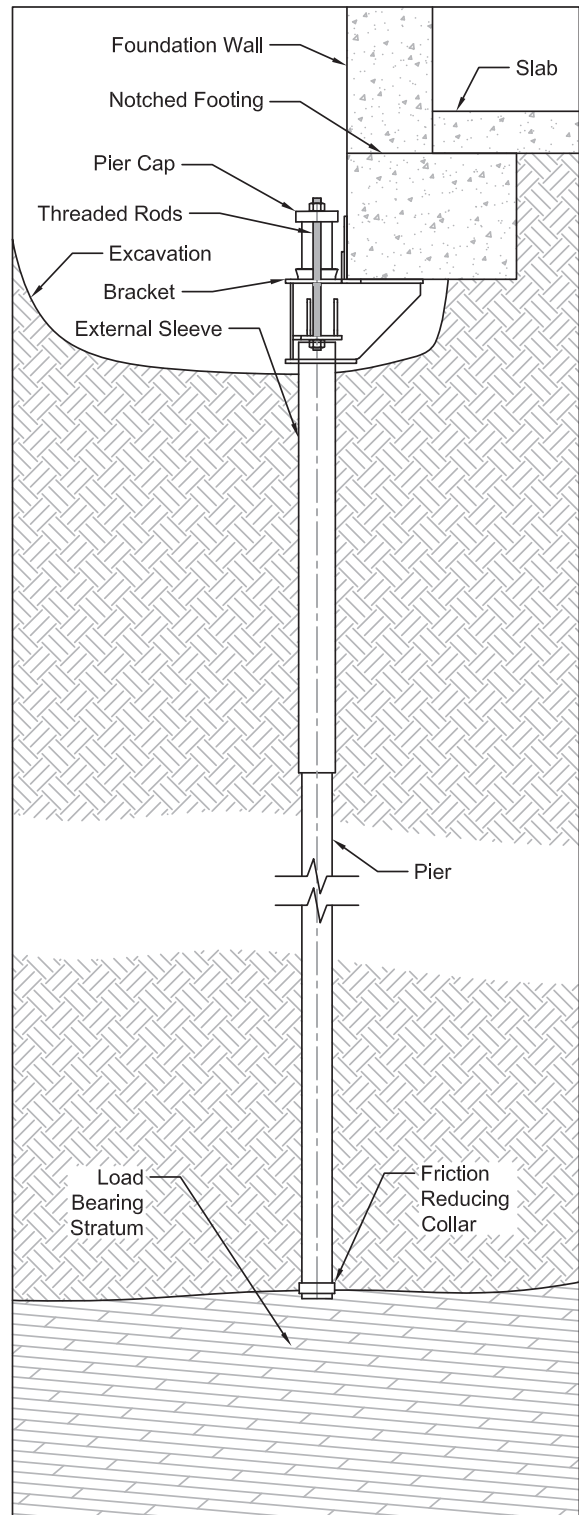


Figure 2.6 Foundation Supportworks PP288 push pier system with an under-footing bracket

2.2.1 Applications

Push pier systems are typically used for underpinning existing structures in the following applications:

- To stabilize settled foundations or slabs
- To stabilize and lift settled foundations or slabs
- To provide increased capacity (additional support) for existing foundations or slabs
- To provide foundation support while adjacent excavations are made

2.3 Push Pier System Components

Foundation Supportworks push pier system components are manufactured to high quality control standards using American Society for Testing and Materials (ASTM) grade steel and certified welding processes. The product line includes Models PP237, PP288, and PP350, corresponding to shaft sizes of 2.375-inch, 2.875-inch, and 3.50-inch O.D., respectively. Various external sleeve and bracket options are available. Push pier system capacities and specifications are provided in *Appendix 2A*. Refer to Sections 2.3.1 thru 2.3.3 for additional discussion regarding push pier system components.

2.3.1 Bracket Assemblies

Bracket assemblies may include an under-footing bracket, concentric bracket, flush-mount bracket or slab bracket. Under-footing brackets are typically placed against and below the footing and have both vertical and horizontal bearing plates. Under-footing brackets have been designed to allow piers to be driven vertically, or at 2 or 3 degrees from vertical orientation. Two-degree brackets, standard for the PP237 push pier system and used most often with the PP288 push pier system in residential applications, and three-degree brackets which are most often used with the PP350 system for commercial applications, can be positioned beneath foundation walls as much as practical and still provide separation for the drive stand and drive cylinder to miss brick overhangs and window and door trim. Vertical brackets are typically used on opposing sides of column footings and along residential and commercial wall footings where structural details do not obstruct setup of the drive stand and drive cylinder. Independent testing of the PP288 and PP350 push pier systems with the 2-degree, 3-degree and vertical brackets has shown less than 1 percent capacity difference between the canted and vertical brackets. PP288 concentric brackets are positioned beneath the centerline of the footing and foundation wall and are pressed up against the bottom of the concrete footing. PP288 flush-mount brackets have a vertical “bearing” plate anchored to the vertical concrete face of the footing, grade beam, or foundation wall with wedge anchors or adhesive anchors. PP288 slab pier brackets are plate assemblies assembled under the concrete floor slab via holes cored in the slab. Pier sections driven through flush-mount and slab pier brackets, or for use with concentric pier brackets, are in a vertical orientation only. The PP350 push pier system utilizes either a 3-degree or vertical under-footing bracket. The Foundation Supportworks bracket assemblies generally include the bracket, pier cap, external sleeve and associated hardware. However, the PP288 concentric pier system and the PP288 slab pier system are designed without external sleeves. See *Appendix 2A* for mechanical ratings of the various push pier systems and bracket assemblies.

2.3.1.1 Eccentric Loading

Pier tubes of push pier systems utilizing under-footing and flush-mount brackets are not located directly under the structure's footing. Therefore, these systems are eccentrically loaded and in turn need to resist the bending forces generated by this loading condition (Figure 2.7). The eccentricity generated by under-footing and flush-mount bracket systems is in reality shared by the pier and the structure.

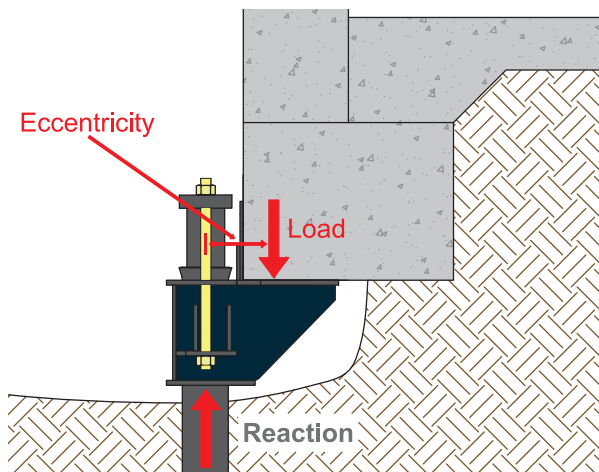


Figure 2.7 Eccentric loading condition for under-footing bracket

In general, the more rigid the pier system and its connection to the foundation, the more the system acts as an extension of that foundation and the more eccentricity must be absorbed by the structure. This bending or twisting imparted to the structure can be resisted by the internal strength of the foundations and connections to the superstructure, by passive resistance of the soil along the opposite face of the footing and/or foundation wall, by bracing with internal structural elements such as floor slabs and shear walls, and by support generated at building corners. When the eccentricity cannot be resisted by such conditions, the piers can be staggered or paired on opposing sides of the foundation. Multiple piers are often needed at column locations simply to balance the load and prevent tipping of the footing. Evaluation of the eccentric loading condition on the structure should

be completed by a qualified design professional on a case-by-case basis.

Overall dimensions of a push pier cross section are 4 inches or less in most applications. These sections are therefore very sensitive to the bending moments introduced by eccentric loading. Additionally, as pier bending moments increase, the pier axial capacity will decrease. This loss of axial capacity due to the addition of bending stresses can be demonstrated with the following example. A given pier section with a 3.50-inch O.D., 0.300-inch wall thickness and a yield strength of 35 ksi has a maximum allowable compressive capacity of 59.3 kips according to the American Institute of Steel Construction (AISC) Allowable Stress Design methodology. When a bending moment of 40 kip-in is applied to the same section, its allowable compressive capacity drops to 24.7 kips. This is a reduction of nearly 60 percent of the section's full axial capacity. Furthermore, this moment would equate to an equivalent eccentricity of only 1.62 inches, which is a seemingly small eccentricity and is still within the envelope of a typical pier cross section. Since, eccentricities for under-footing bracket systems are generally within the range of 3 to 4 inches, the loss of axial capacity due to the resulting bending moments is a significant design consideration.

The bending moment created by eccentric loading is dissipated by passive resistance of the soil against the pier tube within the first few feet of soil support, therefore, the bending moment only needs to be considered for the pier tubes directly below the bracket. One method of providing the necessary bending resistance could involve using larger diameter and/or thicker pier tube sections for the entire length of the pier. The larger/thicker pier sections would resist bending, yet still have sufficient axial capacity in reserve. Although a seemingly reasonable approach, it is not an economical one since the extra steel is only useful within the region of bending, i.e., the first few

feet below the bracket where the bending moment is dissipated into the surrounding soil. Another method used by many manufacturers is to utilize internal or external pier reinforcement after the pier has been exposed to the final drive force. Internal reinforcement is simply smaller diameter pipe or tube sections set inside the pier, generally spanning between the internal couplers of the pier shaft. Internal reinforcement can be of inconsistent length and may not be placed at the optimal location, i.e., not extending through and below the bracket, since the final coupler location cannot be estimated or predetermined. Also, internal reinforcement is not generally placed until after the final drive load has been applied, when the maximum

bending moment may have already caused the pier shaft to deform or buckle. There is little chance for success when trying to insert a straight pipe section through a bent pier tube. External reinforcement typically consists of larger round or square hollow sections driven or placed around the pier, again after the pier has been exposed to the final drive force. Similar challenges exist with placement of straight external reinforcement elements over a bent pier.

Foundation Supportworks engineers developed a unique approach to address the issue of eccentric loading on retrofit push pier systems... the external sleeve.

2.3.1.2 External Sleeve

The PP237, PP288 and PP350 push pier systems incorporate a 48-inch long external sleeve to resist the bending forces generated by the eccentric loading condition on the under-footing and flush-mount brackets, thereby preserving the axial capacity of the pier sections (Figure 2.8). The external sleeve is hydraulically driven with and around the pier starter tube section to extend through and below the bracket. The effect of the sleeve essentially creates a bracket that is 48 inches tall without any additional excavation. A 30-inch long external sleeve is available for the PP237 and PP288 push pier systems for use in limited headroom and crawl space applications.

pier system, but also by the passive pressure of the soil surrounding the external sleeve and pier. Therefore, the capacity and performance of the pier system is in part governed by the stiffness of the confining soils.

The moment or bending force is localized within a relatively short distance below the bracket. Although the bending force is dissipated quickly by the pier bearing against the confining soil, it is significant and cannot be ignored. The depth or length of sleeve and pier over which the bending force dissipates is a function of the soil stiffness. The depth is greater in soft clay and loose sand, and less in stiff clay and dense sand. Finite element analysis software was used to analyze how the external sleeve and the pier interact with soils of various properties. Bracket rotation is resisted not only by the rigidity of the

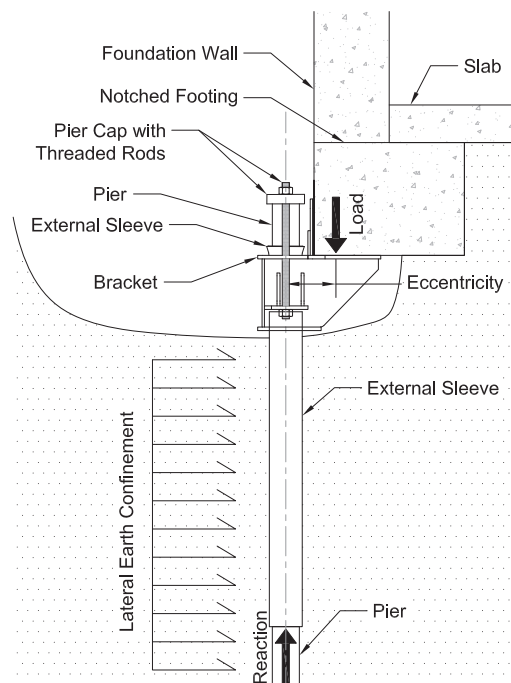


Figure 2.8 External sleeve and pier bear against confining soil when system is under load

Benefits/advantages of an external sleeve:

- The sleeved system separates bending forces from axial compression forces.
- The sleeve resists most of the bending forces and behaves purely as a beam.
- The pier tube is protected from the bending forces preserving its axial capacity so it can behave more like a column.
- The sleeve is easy to install. It's driven at the same time as the starter tube.
- There is no cumbersome reinforcement to install after driving pier tubes.
- The extra steel is where it needs to be. Much more efficient than using thicker pier tube sections for the entire length. It's a local solution to a local issue.
- The sleeve is in place during the system's maximum load (while driving pier tubes).
- The sleeve relieves friction between the pier bracket and pier tube. Drive and lift pressures more accurately reflect the load on the pier system.
- The final pier tube is protected from bending during application of the final drive force, allowing easy removal for cutting to the proper length and reinstallation.

2.3.2 Starter Tube

The starter tube is the first pier section pushed into the ground and is installed at the same time as the external sleeve, where applicable. Under-footing, concentric and flush-mount bracket systems utilize a friction reduction collar at the bearing end of the starter tube. The friction reduction collar will be discussed in more detail in the following section. Models PP237 and PP288 starter tubes come in standard lengths of 17, 32 and 50 inches. The PP288 concentric pier uses 17-inch long starter tubes and 18-inch long pier tubes to fit within the system's unique drive stand assembly. The 32-inch starter tubes are used in limited access and low headroom applications, such as within a crawl space, along with a modified (shorter) drive stand, shorter drive cylinder, a 30-inch long external sleeve and 18-inch long pier tubes. The PP350 system uses a 50-inch long starter tube only, to coincide with the standard 48-inch long external sleeve. The PP350 is a higher capacity system and generally not ideal for crawl space applications. The PP288 slab pier system does not utilize a starter tube with a friction reduction collar. The first section advanced consists of a field-modified standard pier section (*Section 2.12*).

2.3.2.1 Friction Reduction Collar



Figure 2.9 PP288 starter tubes with pressed fit and welded friction reduction collars

A friction reduction collar is included at the bearing end of push pier system starter tubes (*Figure 2.9*). This collar consists of a 1-inch long slice of a slightly larger round shaft section slid over and welded to the end of the starter tube, or a machined ring with a pressed fit. These friction reduction collars have outside diameters $\frac{1}{2}$ -inch larger than their respective pier sections and serve to either create annular space or remold the soil around the pier shaft as it is advanced through the soil. The reduction in frictional resistance on the outside surface of the pier results in a driven pier that generates most of its capacity in end bearing. With reduced skin friction and high bearing pressures generated at the pier tip, push pier systems with friction reduction collars also generally penetrate deeper into the ground (than a frictional pier) and advance through weak or marginal soils to bear on competent material below.

It is common to think of push piers as being advanced through overburden soils to bear on bedrock. This may or may not be the case. For residential and light commercial projects with light to moderate pier loads, adequate resistance may be achieved within very stiff to hard clay soils or medium dense to dense sand and gravel. Allowable pier capacities of 15 to 20 kips, with a factor of safety of 1.5, may be achieved in soils having standard penetration test N-values around 30 blows per foot. Higher strength soils or rock would therefore be required to develop higher pier capacities.

The soils displaced or remolded by the friction reduction collar “heal” back around and against the shaft over time, generating an additional frictional component to the pier’s capacity. This effect is often referred to as pile “setup” when driving larger, higher capacity pipe piles or H-piles. Setup can occur within a matter of hours, days or weeks, and is the reason piercing contractors generally try to start and finish installation of a push pier the same day and, in some unique conditions, before a work break is taken. Although this frictional capacity can be significant, it is conservatively ignored in most cases in the determination of the pier’s factor of safety against settlement. The final drive force is measured and documented prior to development of the soils ultimate frictional resistance. Push pier system factors of safety are further discussed in *Section 2.8.1*.

2.3.3 Pier Tube

Pier tubes follow the starter tube during installation and have a crimped, slip-fit internal coupling at the leading end (*Section 2.3.3.1*). The push pier tubes and couplings are manufactured from hollow round structural steel sections. Models PP237 and PP288 push pier tubes are available in standard lengths of 18 and 36 inches. The 18-inch long pier tubes are again used for concentric piers and limited headroom or crawl space applications. Model PP350 pier tubes are available in standard lengths of 36 inches only.

2.3.3.1 Coupling

Pier tube sections are coupled with an internal slip-fit connection (*Figure 2.10*). A hollow round shaft section with an outside diameter smaller than the inside diameter of the respective pier tube is crimped (button punched) or plug welded to the leading end. The internal coupler extends one-half its length inside the pier tube and one-half its length beyond the end to maintain direct bearing of the pier sections. The coupling is not pinned or bolted and is therefore generally considered and utilized for compression applications only.



Figure 2.10 Push pier tube coupling

2.4 Benefits

Some of the benefits of hydraulically driven steel push pier systems versus other underpinning systems may include:

- Premanufactured components increase the quality control of the installed system
- Components available with zinc coating for additional corrosion resistance
- Laboratory testing of the push pier system and components verifies the system capacity
- Eccentricity between the shaft and bearing area is minimized to reduce the bending moment transferred to the pier system, allowing superior performance when stabilizing or lifting the structure
- Drive and lock-off forces easily determined using hydraulic pumps and cylinders
- Documentation of the final drive force and lock-off force is used to verify a factor of safety at each pier location
- Essentially, a proof load test is completed for each pier installation
- End-bearing pier is driven deep through problem soils
- Additional skin friction develops after installation, increasing the factor of safety against pier settlement
- Steel reinforcement and grout added within hollow pier sections improves lateral capacity and pier stiffness
- Installs with portable hydraulic equipment
- Can be installed within areas of limited or difficult access
- Can be installed in areas of low overhead clearance (crawl spaces)
- Easy to install
- No vibration
- Installs quickly from inside or outside the structure
- Cost-effective solution

2.5 Limitations

The use of push pier systems is limited to structures that have sufficient structural load and/or contributory soil load to provide adequate resistance to advance the piers to a competent bearing stratum. Push pier systems are generally considered for compression-only applications and are not considered for lateral capacity. Foundation Supportworks' published system capacities are based on the following assumptions:

- The systems should be used on structures that are fixed from translation or braced in some manner to prevent translation of the foundation.
- Concrete bearing assumes a minimum compressive strength (f'_c) of 2,500 psi. Local concrete bending and other local design checks should be evaluated on a case-by-case basis.
- The surrounding soils provide continuous lateral support with SPT N-values greater than or equal to 4 blows per foot. Piers with exposed unbraced lengths or piers placed in weaker or fluid soils should be evaluated on a case-by-case basis.
- The maximum recommended drive load is not exceeded during installation.

2.6 Corrosion Protection

Foundation Supportworks' hydraulically driven steel push pier systems have been designed following the guidelines of ICC-ES AC358 and ICC-ES AC406 for corrosion loss rates and design period (50 years).

The starter and pier tube sections used for Models PP288 and PP350 push pier systems are manufactured with a triple-layer, in-line galvanized coating. The triple-layer coating process consists of a uniform galvanized zinc coating, an intermediate conversion coating to inhibit the formation of white rust and enhance corrosion resistance, and a clear organic polymer top coating which interacts with the intermediate coating to further enhance the corrosion protection and durability. The insides of the PP288 and PP350 starter and pier tubes also have a zinc-rich coating. Although the triple-layer coating offers significant corrosion resistance, the process is not specifically recognized within AC358 and AC406. The PP288 and PP350 push pier system capacities provided in *Appendix 2A* are therefore conservatively based on corrosion losses for plain steel. The starter and pier tube sections for the PP237 push pier system are available in either plain steel or with a hot-dip galvanized coating in accordance with ASTM A123.

The Foundation Supportworks' push pier system brackets, external sleeves, and pier caps are also available as either plain steel or hot-dip galvanized (ASTM A123). The bracket hardware is electro-plated in accordance with ASTM B633.

Additional corrosion protection may be achieved by filling the pier tubes with a fluid grout or concrete mix following installation. With a dry hole and using a neat or sand mix, the grout may be gravity fed from the top of the pier. In a wet hole, to prevent segregation of aggregate, or to prevent bridging effects, the grout may be placed by tremie tube from the bottom of the pier toward the surface. Pier tubes can also be filled with concrete or grout at intervals during the installation, i.e., piers are gravity filled from the top after advancement of every one or two sections.

2.7 Push Pier Installation Equipment

The equipment needed to first drive the piers individually and then transfer the structural load to the multiple pier locations consists of hydraulic cylinders, a hydraulic pump, a remote valve assembly (or other control device), hoses and fittings, drive stands and lift cylinder assemblies.

Safety precautions must be followed when using high-pressure hydraulics. The pressure rating of each system component must be verified prior to use to ensure that all components meet the maximum pressure rating required during the installation. Hoses and fittings should be checked periodically for damage and replaced when in question. Failure to follow manufacturer's specifications may result in equipment failure and/or personal injury.

2.7.1 Drive & Lift Cylinders

Hydraulic drive cylinders (also commonly referred to as “rams”) are used to push (drive) pier sections below the existing footing or slab until the target ultimate pressure or load is achieved or until the structure begins to mobilize (lift response). Hydraulic lift cylinders are then used at each of the multiple pier locations to provide the final lock-off load for stabilization or to lift the structure, if required. Foundation Supportworks offers five drive cylinder (FS425DC, FS35CSDC, FS35DC, CP288DC, and CP238DC) and two lift cylinder (FS256LC and FS35LC) options. The FS35CSDC drive cylinder is a shorter version of FS35DC for use in limited headroom and crawl space applications. The CP288DC and CP238DC are used for concentric pier installations. Drive and lift cylinders are shown in *Figure 2.11* and *Figure 2.12*.

Drive and lift cylinder specifications are provided in *Appendix 2B* (Drive Stand Specifications) and *Appendix 2C* (Lift Assembly Specifications), respectively.



Figure 2.11 Foundation Supportworks FS35DCA drive cylinder assembly



Figure 2.12 Foundation Supportworks FS35LCA lift cylinder assembly

2.7.2 Hydraulic Pumps

Hydraulic pumps used to drive pier tube can be electric or gasoline powered. The selection of the pump unit should take into consideration the maximum drive pressure (ultimate pier capacity) required and the rate of pier installation desired. The flow rate of the hydraulic pump will affect how fast piers can be advanced with higher flow units allowing faster pier installation. That said, gasoline pumps generally provide greater flow than electric pumps and are therefore preferred for deep foundation pier installation. Electric pumps, or gas pumps with slower proportional control, are often used for the stabilization/lift operation of foundation pier installation and for both the driving and stabilization/lift operations of slab pier installation. With lower flow rates, these pumps install piers slower and provide greater control to reduce potential overstressing of the concrete slab or footing should sudden spikes in pressure/load occur. Foundation Supportworks offers models of both electric and gas pumps.

The effective area of the hydraulic drive cylinder used will also have an effect on installation speed. Foundation Supportworks drive cylinders FS35DC and FS35CSDC have effective areas of 9.62 in² while operating in extension mode and 6.48 in² while operating in retraction mode. Foundation Supportworks drive cylinder FS425DC has effective areas of 14.18 in² and 11.04 in² for the extension and retraction modes, respectively. With different effective areas, the drive cylinders will have different extension and retraction rates at similar flow rates, as shown in *Figure 2.13*. Cylinders with less effective area will have faster extension or retraction rates than cylinders with more effective area at similar flow rates. The effective area of the cylinder in retraction mode is less than the effective area in extension mode due to the presence of the internal drive rod.

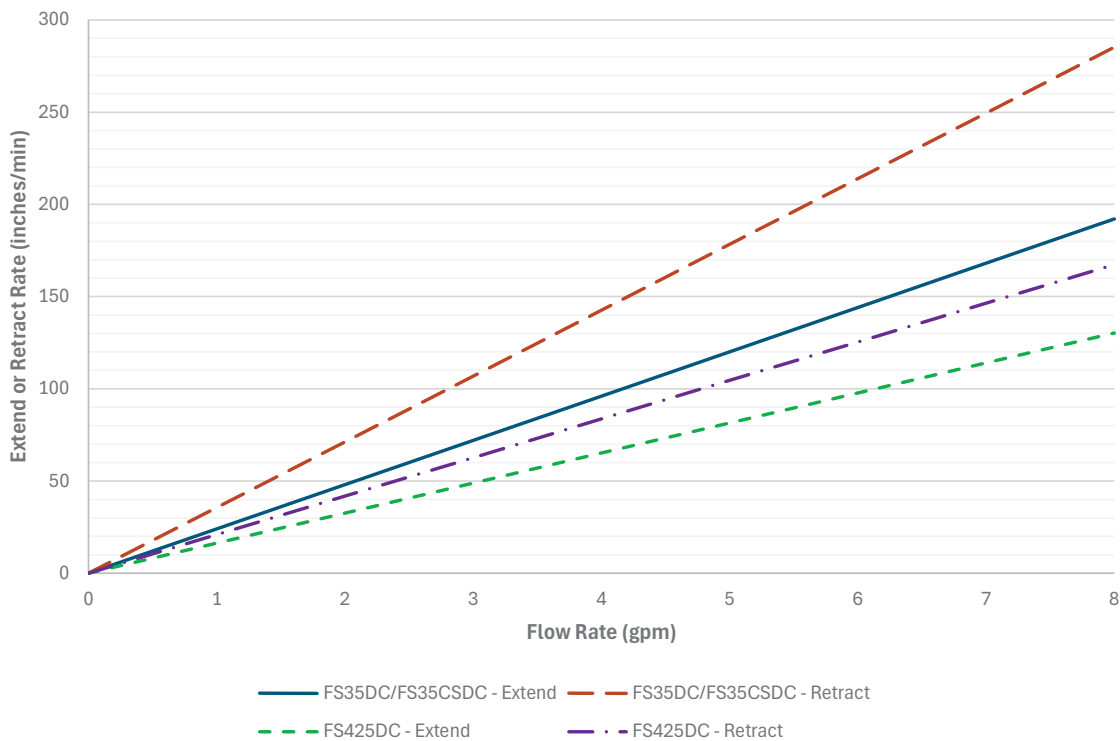


Figure 2.13 Foundation Supportworks drive cylinder extend and retract rates

2.7.2.1 Gasoline Powered Hydraulic Pumps

FSGP5A is a single-stage gear pump driven by a variable speed, 11 HP, 4-cycle gasoline engine. Per manufacturer specifications, the pump unit is capable of a 629 in³/min (2.7 gpm) flow rate at the maximum rated output pressure of 4,000 psi and a speed of 3,600 rpm. FSRGP5K is a dual-stage piston pump driven by a variable speed, 23.5 HP, 4-cycle gasoline engine. In the first stage of operation, with an output pressure up to about 3,000 psi, the pump produces hydraulic flow of at least 1,850 in³/min (8.0 gpm). The flow rate then drops through the second stage of operation to 1,150 in³/min (5.0 gpm) at the maximum rated output pressure of 5,000 psi. Pump performance is affected by the output pressure and pump speed. The output pressure may also be limited by the pressure relief

valve setting. The pump output flow versus pressure curves for both motors are illustrated in *Figure 2.14*.

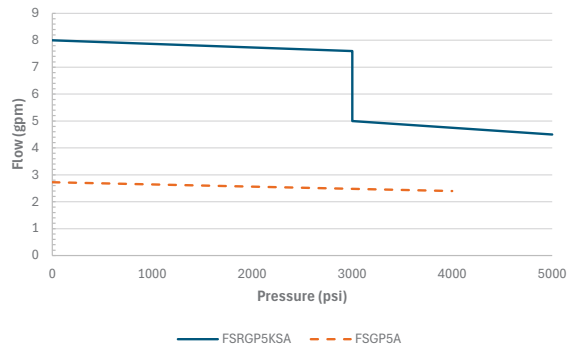


Figure 2.14 Foundation Supportworks gasoline powered hydraulic pump curves

Safety precautions must be followed when using gasoline-powered equipment. Ignition sources must be kept away from the gasoline tank and any gasoline vapor or fluid leakage must be stopped. Exhaust fumes from operation of gasoline engines require proper ventilation, particularly when used indoors or in confined spaces.

2.7.2.2 Electric-Powered Hydraulic Pump Units

The FSEPZU4A hydraulic pump is driven by a single speed, 1.125 HP, 110 volt electrical motor capable of a 60 in³/min (0.26 gpm) flow rate at the maximum rated output pressure of 10,000 psi. The pump performance curve can be seen in *Figure 2.15*. Again, pump performance is affected by the output pressure and pump speed and the output pressure may be limited by the pressure relief valve setting.

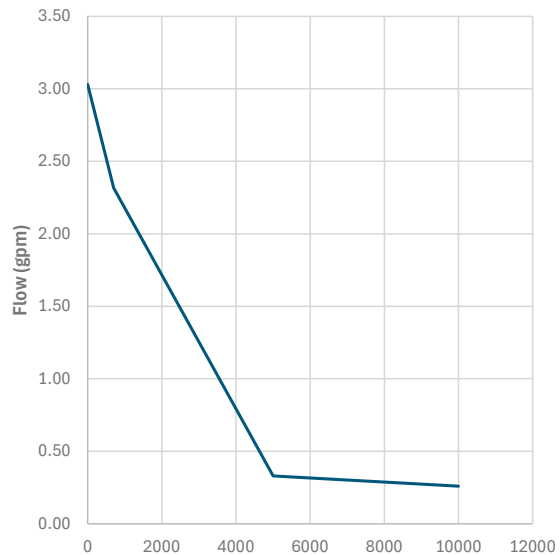


Figure 2.15 FSEPZU4A Hydraulic Pump Curve

2.7.3 Gas Hydraulic Pump Control

The FSGP5A controls the hydraulic flow and pressure to the hydraulic cylinders via a remote valve assembly. It includes a proportional control joystick giving it the precise control needed to be suitable for both pier driving and pier lifting operations. The remote valve assembly is typically attached to the drive cylinder to provide greater control and response during the driving operation. The remote valve assembly is shown in *Figure 2.16*. The FSRGP5K also provides proportional control, but via a wired or wireless remote. The remote communicates with an electrically powered Hawe valve that is mounted to the pump. The wired remote is shown in *Figure 2.17*.



Figure 2.16 Remote valve assembly



Figure 2.17 Wired Remote

2.7.4 Hoses & Fittings

Hoses and fittings should be designed for the maximum system pressure. Hose lengths of 10, 50 and 100 feet are available to accommodate either sequential connection of lift cylinder assemblies or connection through a manifold system. Foundation Supportworks offers both flush face and threaded fittings for the cylinder and pump connections.

2.7.5 Drive Stands

Drive stands provide the means for advancing pier tubes through foundation and slab brackets. The drive stand is positioned over and then secured to the bracket. Hydraulic drive cylinders or rams are then set within the top fixture of the drive stands. Lengths of the drive stand legs have been specifically designed for the Foundation Supportworks standard pier tube lengths of 36 inches. The drive stands used for PP237 and PP288 installation within a crawl space have shorter legs designed for 18-inch long pier sections. There are several drive stand assembly options available for the multiple pier sizes and bracket details. *Figure 2.18* shows standard and crawl space drive stand assemblies for the the PP237 and the PP288 systems. The drive stand assembly specifications, along with general dimensioning, are included in *Appendix 2B*.



Figure 2.18 Standard and crawl space drive stand assemblies

2.7.6 Lift Cylinder Assemblies

Lift cylinder assemblies are connected to the thread rod or coil rod of the bracket assembly after the pier cap has been placed (*Figure 2.12*). The lift cylinder assemblies provide the final application of force to first stabilize and then lift the structure. After the stabilization or lift force has been applied, the top nuts on the thread or coil rods of the bracket assembly are tightened down to the pier cap, thereby locking off the load. See *Appendix 2C* for lift assembly specifications.

2.8 Push Pier Capacity & Spacing

Foundation Supportworks offers multiple pier sizes and bracket assembly combinations to provide solutions for varying applications and design loads. A main design consideration for eccentrically loaded retrofit systems is minimizing bracket rotation. This is accomplished not only by designing a stiffer pier system, but also by the system's interaction with the surrounding soil and the structure. *Section 2.3.1.1* and *Section 2.3.1.2* discuss the bending forces that are generated by the

eccentric loading condition and how the Foundation Supportworks external sleeve resists the bending force below the bracket. The near-surface soils surrounding the bracket, the external sleeve and the upper sections of pier tube therefore act to resist and dissipate the bending. Finite element analysis software was used to analyze how the external sleeve and pier interact with various soil types and strengths. The standard 48-inch long external sleeve was thereby selected to provide

an efficient use of additional steel to resist most, if not all, of the bending force when piers are installed within somewhat typical near-surface soil conditions, i.e., loose sands and medium stiff clays, or stronger. Although laboratory testing cannot exactly duplicate actual installed field conditions with all possible soil types and strengths, the results from the standard test method utilized (ICC-ES AC406) generally confirmed these calculated capacities.

Retrofit bracket testing in accordance with AC406 also considers interaction of the bracket with a concrete block of known compressive strength (2,500 psi). Testing pier systems against concrete is completely logical as it includes concrete failure as a potential failure mechanism of the “system.” Bracket testing within a rigid steel frame does little to simulate field behaviors and failure conditions, and these capacities could rarely be duplicated in the field without first buckling the pier and/or breaking the concrete footing.

Push pier system ultimate capacities may be limited by the ability of the structure and surrounding soil to provide the necessary reaction to drive the piers. Light structures or structures with shallow footings may start to mobilize before the target drive load is achieved. In such cases, it may prove beneficial to excavate small, shallow holes at the pier locations, instead of a full excavation, to allow as much soil load as practical to remain around and above the footing. The soil load can contribute significantly to “hold” a light structure down in order to achieve target pressures/loads. When a structure experiences early lift, the project engineer should evaluate if the drive pressure/load is adequate, if adjustments can be made to the proposed piercing plan, or if a change to retrofit helical piers should be considered. Helical piers are installed by the application of torque with machines independent of the structure. Helical piers are discussed in *Chapter 1*.

A structural assessment should be performed prior to installation to determine if the existing footing, stem wall or floor slab can resist the estimated final drive

force without structural damage. Overstressing the concrete can be prevented or at least minimized by following proper techniques and best practices for footing preparation and pier installation. The contractor should carefully monitor the installation and release the load at the first sign of foundation or slab distress.

Stone or cobble foundations, brick foundations, or foundations that are severely broken or deteriorated may not be good candidates for retrofit foundation piers. Foundations and slabs must be able to span between pier locations for the system to be effective. Pier locations and pier spacing are often determined by the spanning capability of unreinforced or under-reinforced footings, foundation walls and floor slabs, and not by the pier’s capacity. Monolithic footings, footings with short stem walls or footings with masonry stem walls may require closer pier spacing and/or additional support at the bracket locations. Spanning capability of a footing may be improved by using structural steel angles, plate, tube, etc., sandwiched between the bottom of the footing and the horizontal bearing plate of an under-footing bracket. In more severe cases, such as stone, cobble, brick, and highly deteriorated foundations, the footings can be temporarily undermined in short sections to construct a continuously reinforced concrete grade beam. The grade beam would then provide adequate spanning capability for the installation of the retrofit piers.

Expansive soils are prevalent in many regions of the United States and Canada with varying degrees of shrink/swell potential. Volumetric changes (shrink/swell) occur in expansive soils from seasonal fluctuations of the natural moisture content. The depth of soil that is affected by changes in seasonal moisture is commonly referred to as the “active zone” or the “depth of wetting”. Below this depth, the soil moisture content is presumed to remain relatively constant, thereby limiting any volumetric changes within the deeper strata. The geotechnical investigation may identify layers of expansive soils and swell testing may

be performed on soil samples to determine the potential vertical rise (PVR) and swell pressure of the expansive zone upon wetting. When push piers are installed in expansive soil profiles, it is important to advance the piers to depths below the active zone to limit pier and structure movement.

If expansive soils are found at the project site, swell pressures determined from testing can be used to estimate the uplift force on the foundation. This potential uplift pressure, or force, must be considered when designing push pier systems. Many times, the dead load from the structure on the foundation and the installed piers is enough resistance to counteract uplift forces from swelling soils. However, in highly expansive soil profiles, the design engineer and contractor may decide to first support and level the existing structure with push piers, and then excavate the soil beneath the concrete footings. This provides a gap that would allow the soil to expand upon wetting without inducing an uplift force on the foundation system.

Push pier systems are designed for compression loading and typically do not provide tension resistance. Slip fit connections, therefore, are a common coupling detail for the pier sections. With this detail, the effect of coupling movement due to soil adhesion and swelling along the shaft in the active zone must be considered. If expansive soils are a concern, at a minimum, the geotechnical engineer should provide guidance regarding the depth of wetting, PVR and swell pressures that may be applied to the foundation. Any resulting uplift forces should be considered in the push pier design, and additional appropriate measures taken.

With all the discussion above, a push pier system can still only provide support for the structure if competent soils are encountered at the pier tip. Typically, SPT N-values of 35 to 40 blows per foot for clay soils and 30 to 35 blows per foot for granular soils are needed to provide the necessary end-bearing resistance for light to moderate push pier loads. See *Appendix 1E* for additional information regarding geotechnical considerations for push pier systems.

Technical specifications and capacities for Foundation Supportworks push pier systems are provided in *Appendix 2A*.

2.8.1 Factor of Safety

The push pier system develops a factor of safety against pier settlement by the pier installation methods used and the sequence with which multiple piers are driven and then reloaded. Piers are first driven individually using the maximum weight of the structure and any contributory soil load as the reaction. The pier gathers load from adjacent sections of the foundation, not just in the immediate area of the pier. The more rigid the structure, the more load can be transferred to the pier during the drive process. It is for this reason, along with consideration of contributory soil load against the foundation, that piers can be driven to loads greater than the calculated service loads.

The drive or installation force on the piers is determined by calculating the structural load (dead plus live) and the soil load on each pier, then multiplying by a factor of safety. Factors of safety of 1.5 to 2.0 are commonly used for push pier systems since the drive and lock-off loads are easily measured and verified using hydraulic cylinders, pumps and gauges. Foundation Supportworks engineers do not recommend the use of bottle jacks for the drive or

lift operations of a push pier installation. Loads applied with bottle jacks are unknown and not easily determined. Higher factors of safety may be considered at the discretion of the project engineer or as dictated by local codes.

Piers are driven to the calculated “ultimate” load, or until lift of the structure occurs. After all of the piers are driven, the piers are connected in series with hydraulic lift cylinders and reloaded to either the design service load to stabilize the structure, or until the desired lift is achieved. The total reaction load is then distributed over the multiple pier locations. The final factor of safety against pier settlement at each pier location is calculated by dividing the drive load by the lock-off load.

As discussed in *Section 2.3.2.1*, additional skin friction develops over time as the soils heal around the pier shaft. The factor of safety generally increases with an increase in frictional capacity.

2.8.2 Bolting the Under-Footing Bracket to the Foundation

Foundation Supportworks engineers neither require, nor recommend bolting of under-footing brackets to a concrete foundation with expansion or adhesive anchors. Experience has shown that bolting to unreinforced or under-reinforced concrete routinely causes concrete to crack and spall during installation of the expansion or adhesive anchors, or during the repeated loading and unloading procedure of driving piers. At best, bolting provides little benefit to the pier capacity and stability while introducing the potential to weaken the system by damaging the footing. Holes are included in the brackets to be used at the discretion of the installer or if a project engineer or building official requires that the piercing system be positively attached to the structure.

Actually, the manner in which a push pier system is loaded and supported would tend to cause the bracket to push against the structure, not pull away from it. At the same time, however, while the bracket is pushing against the structure, it also tends to rotate toward the structure. If the pier system does not have adequate stiffness, then the tendency for excessive bracket rotation will be evidenced by the bearing plate being pried away from beneath the structure. This phenomenon does not mean that the overall pier system is translating away from the structure. Instead, it means the pier needs to be much stiffer. The stiffness of Foundation Supportworks' push pier systems greatly reduces this rotational tendency and precludes the need to positively attach the bracket to the structure. When such an attachment is made due to preference or local requirements, Foundation Supportworks engineers recommend the expansion or adhesive anchors be installed after completion of the piercing operations. Anchors were not used when the pier systems were tested in accordance with AC406.

2.9 Under-Footing Push Pier Installation

The steps for under-footing push pier installation include footing preparation, bracket mounting/support, drive stand and drive cylinder attachment, pier tube driving, application of the final drive force, attachment of the lift cylinder assembly, structural lift (if applicable) and load transfer and lock off.

Safety precautions must be followed prior to and during excavation activities. Locate underground utilities prior to excavation and perform excavations at a distance away from utilities as mandated by the utility owner. Follow Occupational Safety and Health Administration (OSHA) guidelines for trench safety.

Step 1: Footing Preparation

Excavation is required in most cases to expose the concrete footing and prepare it for under-footing bracket placement. The footing may be accessed from either inside or outside the structure using isolated "pocket" or continuous excavations. For structures with basements, it may be advantageous to access the footing from within the basement of the structure by first removing sections of the basement floor slab. General steps for footing preparation include:

1. For shallow pocket excavations, soil should be hand or machine-excavated from against the footing and foundation wall within an area approximately 3 feet square and to a depth approximately 9 to 13 inches below the bottom of footing. These excavations are made at each pier location. Alternatively, soil could be removed completely with a trench excavation. Trench excavations are more common when a lift is required.
2. The soil under the footing and foundation wall is removed to a distance that allows bracket placement (*Figure 2.19*).



Figure 2.19 Removing soil from beneath the footing with a chisel attachment

3. Notch spread footings 16 to 22 inches wide (depending upon the width of the retrofit bracket) and approximately flush with the face of the foundation wall. Notching of footings may not be necessary depending upon the footing geometry, strength, steel reinforcement and the proposed piercing plan. Notching of the footing reduces the eccentricity between the applied load and the pier section. The proposed pier plan may consider pier installation on opposing sides of the footing to provide balanced support of the loads. Installing piers on opposing sides of the footing in pairs or in a staggered configuration can be an acceptable alternative to notching. The design professional of record should approve the notching, particularly when notching will cut steel reinforcement. The outline of the notch is typically first made by drilling a series of closely spaced holes with a concrete drill bit. After the notch outline has been made, a chipping hammer or jack hammer can be used to impart energy to the perforated section, causing it to separate from the rest of the footing. Drilling the holes prior to using the chipping hammer or jack hammer also reduces the likelihood of concrete spalling from under the footing.



Figure 2.20 Smoothing the vertical and horizontal bearing surfaces with a chipping hammer



Figure 2.21 Checking underside of footing for proper preparation

4. Smooth the concrete surfaces with a chipping hammer or other tool to produce similar results. The vertical and horizontal surfaces of the footing and foundation wall must be smooth and clean to allow full contact with the vertical and horizontal bearing plates of the under-footing bracket (*Figure 2.20* and *Figure 2.21*). Footing preparation should be completed to provide proper bracket/pier alignment (*Figure 2.22*).

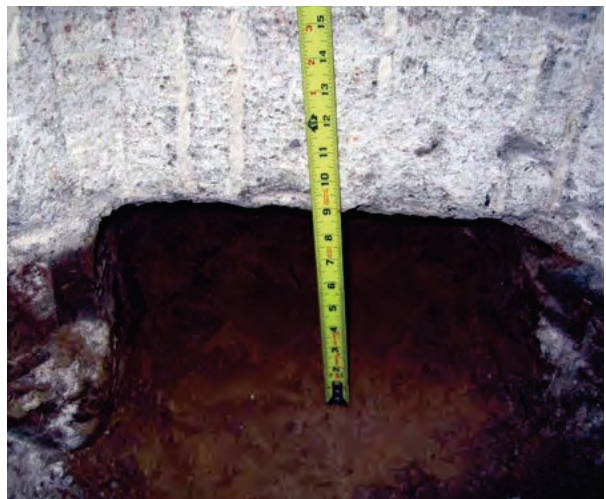


Figure 2.22 Completed footing excavation and preparation; ready to position bracket

Step 2: Positioning the Bracket

The bracket is placed under the footing and raised into position with the horizontal and vertical bearing plates in full contact with the concrete surfaces. The bracket may be temporarily held in place using wood cribbing (*Figure 2.23*). Alternatively, a bracket RAYser™ is available from Foundation Supportworks for the more commonly used brackets. The bracket RAYser consists simply of a U-shaped plate with bottle jacks or scissor jacks to position the bracket and hold it snug against the concrete during the initial pier installation process (*Figure 2.24*).

Foundation Supportworks' under-footing brackets do not require mechanical anchorage to the concrete foundation. The published capacities are based on testing and analyses without anchors. There are bolt holes that may be used to mount the bracket to the concrete with expansion or adhesive anchors, if needed to meet the project specifications. It should be noted, however, that the use of anchors to mount the under-footing bracket may cause concrete spalling and cracking from the repeated loading and unloading process during pier installation and lock off. Additionally, drilling the anchor holes could compromise the integrity of steel reinforcement. If mounting of the under-footing bracket with anchors is required, Foundation Supportworks engineers recommend anchoring the bracket after the system has been locked off. See *Section 2.8.2* for more information regarding bolting of the bracket to the foundation.



Figure 2.23 Temporary bracket support with wood cribbing



Figure 2.24 Bracket RAYser support system

Step 3: Mounting the Drive Stand & Hydraulic Drive Cylinder

1. Slide the external sleeve over the starter tube and insert the sleeve and starter tube together through the bracket (*Figure 2.25* and *Figure 2.26*). Care must be taken that the sleeve and starter tube are properly aligned and extend past both the top and bottom plates of the bracket. The sleeve and starter tube could also be placed after mounting the drive stand to the bracket. Installers may find it easier, however, to set the sleeve and starter tube without being restricted by the drive stand legs.



Figure 2.25 Exterior sleeve slid over the starter tube



Figure 2.26 Sleeve and starter inserted together through the bracket

- The drive stand is fitted to the bracket and secured with L-pins (PP237 and PP288 systems) or quick release hitch pins (PP350 system). *Figure 2.27* and *Figure 2.28* show setting of the drive stand for the PP288 push pier system and securing it to the bracket with L-pins.



Figure 2.27 Drive stand for PP288 push pier system fitted to the bracket



Figure 2.28 PP288 drive stand secured to the bracket with L-pins

- Slide the hydraulic drive cylinder into the top fixture of the drive stand and lock it in position with the coil rod and nuts (*Figure 2.29* and *Figure 2.30*).



Figure 2.29 Hydraulic drive cylinder placed within top fixture of drive stand



Figure 2.30 Drive cylinder locked in position with coil rod and nuts

4. Connect the hydraulic hoses to the inlet and outlet of the drive cylinder and the inlet and outlet of the remote valve assembly (Figure 2.31).



Figure 2.31 Connecting hydraulic hoses to the remote valve assembly

5. Align the drive stand by activating the hydraulics and extending the drive cylinder rod to make slight contact with the starter tube. Use a digital level, protractor or other device to check alignment of the drive stand, sleeve, starter tube and bracket (Figure 2.32). Adjust the alignment as necessary for the bracket system being utilized; i.e., 2-degree, 3-degree, or vertical brackets. Proper footing preparation is critical for setting the bracket and system at the correct installation angle. Temporary cribbing may be used between the drive stand and the foundation wall to set the correct installation angle while advancing the starter tube and external sleeve (Figure 2.33).



Figure 2.32 Checking drive stand alignment with digital level



Figure 2.33 Adjustable cribbing tool used to set installation angle

Step 4: Pier Tube Installation

1. Drive the external sleeve and starter tube together until the welded collar or trumpeted end of the sleeve is seated at the top of the bracket. Pier tubes are then coupled (*Figure 2.10*) and pushed through the external sleeve (*Figure 2.34*). The standard length for pier tubes is 36 inches for all of the Foundation Supportworks side-load, under-footing, pier systems. Drive cylinders FS35DC and FS425DC have 22-inch strokes. The PP237 and PP288 crawl space pier tubes have lengths of 18 inches and are generally pushed with Foundation Supportworks drive cylinder FS35CSDC, which has a 13-inch stroke. Therefore, the drive process for the sleeve and starter tube, the standard 36-inch pier tubes, and the 18-inch crawl space pier tubes requires a two-stage process with the use of a driving tool (drive tube). When the maximum cylinder stroke has been reached, the cylinder is retracted, the drive tube is set in place, and the push is completed to the top of the bracket or external sleeve (*Figure 2.35*).



Figure 2.34 Installing PP288 push pier tube



Figure 2.35 Driving tube tool set in place for second stage of push

- Record the drive pressure at final stroke of each pier tube section (*Figure 2.36*).

Safety precautions must be followed when driving pier tube sections to ensure that body and clothing are away from pinch points. Take caution and avoid over-stroking the cylinder rod which may result in a rapid increase in pressure, possibly resulting in cylinder damage or personal injury.

- Once the predetermined drive pressure is achieved or the structure starts to lift, the pressure is released from the hydraulic system and the drive stand and drive cylinder are removed from the bracket. The drive process is repeated at each of the proposed pier locations.



Figure 2.36 Pressure readings are recorded for each pier tube

Step 5: Assembling the Bracket & Mounting Lift Cylinders

- The final pier tube extending up from the bracket will often have to be cut to the desired elevation. To accomplish this, the final pier tube is removed from within the external sleeve and placed in a chop saw to achieve a square cut (*Figure 2.37*). Alternatively, a tube cutting guide can be positioned over the in-place pier section and a cut can be made with a reciprocating saw or portable band saw. The last pier tube section is typically cut to a length to extend above the external sleeve approximately 4½ inches. The cutoff length may vary depending upon the amount of structural lift anticipated. The removed pier section is replaced after the cut is made.



Figure 2.37 Cutting pier tube to desired length with a chop saw

2. The pier cap is set on the pier tube and two threaded rods or coil rods are fed through the holes of the pier cap and bracket. The pier cap is connected to the bracket with nuts on each end of the rods (Figure 2.38). There should be adequate thread left above the top nuts above the pier cap to allow coupling of the lift cylinder assembly to the rods (Figure 2.39).



Figure 2.38 Installation of pier cap plate with coil rods and nuts



Figure 2.39 PP288 bracket ready for lift cylinder assembly

3. Lift cylinder assembly rods are coupled to the bracket assembly rods as shown in Figure 2.40. Adjacent lift cylinders (on adjacent piers) are connected in series to provide uniform application of load (Figure 2.41).

Note: The hydraulic system shown in the figures is technically a “parallel” system. However, it is common to say that the piers are connected in “series,” which simply means hydraulic lines run between adjacent pier locations and they are often all connected together with one setup.



Figure 2.40 Connection of lift cylinder assembly



Figure 2.41 Hydraulic system connected to provide uniform application of load

Step 6: Structural Lift and/or Lock Off

1. Hydraulic pressure is applied to the system to either lift the structure to the proper elevation or provide the required lock-off pressure/load. The lock-off pressure/load is generally the service load or design working load per pier. It may be necessary to remove the soil from above the footing if pocket excavations were initially made. Removal of as much soil load as possible around the foundation will increase the potential to achieve a desired lift.
2. The system is first equalized by opening the valves at each cylinder in sequence and adjusting the system pressure. The system should be equalized to a pressure on the order of 1,000 psi.
3. Slowly raise the pump pressure to raise the foundation. Monitor the lift at each pier location and after achieving proper lift, close the valve to the top of the cylinder. If the piers are for stabilization only, close the valves as soon as noticeable movement occurs.
4. When the structure has been lifted to the proper elevation or the piers have been reloaded to the required lock-off load (typically the design working load), the load is locked off to the piers by tightening the two nuts down to the top of the pier cap.
5. The pressure is released from the hydraulic system and the lift cylinder assembly is removed from the bracket (*Figure 2.42*). The pier system installation is essentially complete. Permanent benchmarks may be established within and beyond the work area, if approved by the owner or client. These monitoring points would allow relative movements to be measured in the future, if necessary (*Figure 2.43*).



Figure 2.42 System locked off; pier installation complete

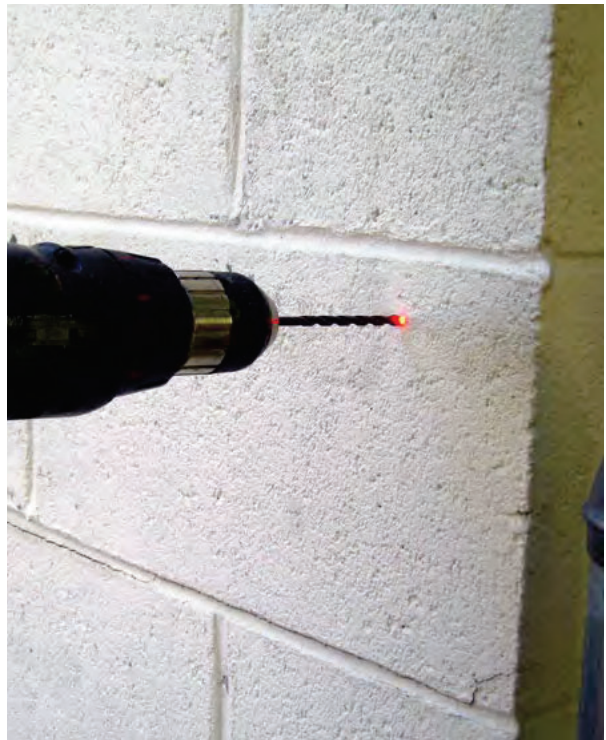


Figure 2.43 Benchmark established with a shallow hole drilled into the concrete block

Step 7: Backfill & Clean Up Work Area

1. Backfill excavations and properly compact with a mechanical tamper (*Figure 2.44*). This may also be an ideal time to improve the drainage system around structures with below grade living areas or working space. New drain pipe can be installed along with free-draining granular backfill provided the drain pipe is connected to an interior sump system or drained by gravity to daylight discharge points. Interior pier installation may require concrete patching and finishing after soil compaction (*Figure 2.45*).



Figure 2.44 Backfill excavations and compact soil



Figure 2.45 Concrete placement at interior pier locations

2.10 PP288 Flush-Mount Push Pier Installation

The PP288 flush-mount bracket system may be used for applications where poured concrete elements such as a foundation wall, column, pile cap, or grade beam have adequate strength, thickness, and vertical dimensions to allow proper attachment of the bracket. PP288 flush-mount system capacities are provided in *Appendix 2A* for systems using either expansion or adhesive anchors.

Step 1: Concrete Preparation

Excavation may be necessary to expose the vertical face of the concrete. If the bracket is mounted on a foundation wall or column above a spread footing, the concrete footing would have to be cored through or removed entirely to allow for advancement of the pier tube sections. The vertical face of the concrete to receive the bracket should be smooth of surface irregularities and free of structural cracks. If necessary, a thin layer of leveling compound may be used to create a smooth flat surface prior to mounting the bracket.

Safety precautions must be followed prior to and during excavation. Locate underground utilities prior to excavation activities and perform excavations at a distance away from utilities as mandated by the utility owner. Follow OSHA guidelines for trench safety during excavation and installation activities.

Step 2: Mounting the Bracket

The flush-mount bracket is secured to the concrete vertical face using eight (8) $\frac{3}{4}$ -inch diameter anchors (*Figure 2.46*). Rather than attempting to position and hold the bracket in place, a template of the bracket bolt holes could be considered to mark the anchor locations.

Steps 3 - 7

The remaining steps for flush-mount push pier installation are similar to those for the under-footing system described in *Section 2.9*.



Figure 2.46 Flush-mount bracket installation

2.11 Concentric Push Pier Installation

The concentric push pier system is used to stabilize and lift settled foundations. Unlike the typical “side-load” retrofit brackets, these systems are installed directly beneath foundation walls or point loads and, therefore, are not exposed to bending forces generated from off-set, eccentric loading conditions (*Figure 2.47*). Concentric piers are commonly used in confined spaces such as crawl spaces or tunnels, on pier-and-beam foundations, on post-tensioned slab interior grade beams, and under shallow exterior wall footings with limited soil cover.



Figure 2.47 Concentric pier installation

Step 1: Excavation

1. Excavate a 3-foot square hole to an approximate depth of 40 inches below the bottom of footing.
2. Excavate the soil from beneath the footing back an adequate horizontal distance so that the drive stand assembly can be located directly below the center of the foundation wall.
3. Remove all soil that may be adhered to the bottom of the footing.
4. Bottom of excavation and footing should be flat. Use chipping hammer as necessary (*Figure 2.48*).



Figure 2.48 Prepare bottom of footing with chipping hammer, as necessary, to create a flat and level surface

Step 2: Drive Stand & Hydraulic Drive Cylinder Placement

1. Place collapsed drive stand under the footing and center below the foundation wall above.
2. Level and plumb the drive stand.
3. Remove hitch pins from the telescoping legs.
4. Raise the top of the drive stand to as close to the bottom of footing as possible.
5. Insert hitch pins into the upper holes on the drive stand legs. If installing a grout plate, place plate with grout on top of drive stand (*Figure 2.49*).
6. Place a starter tube section on top of the floating middle plate.
7. Raise the floating middle plate until the top plate on the drive stand is approximately two inches below the bottom of the footing (*Figure 2.50*).
8. Tighten the coil nuts on both sides of the drive stand.
9. Remove starter tube from the middle plate.
10. Place hydraulic drive cylinder on the middle plate (*Figure 2.51*).
11. Place starter section and small drive tube through the hole in the drive stand bottom plate.
12. Connect hydraulic pump to the cylinder.
13. Slowly extend cylinder until the top of the drive stand engages the bottom of footing (*Figure 2.52*).
14. Tighten the coil nuts on both sides of the drive stand.



Figure 2.49 Grout plate used to create uniform bearing

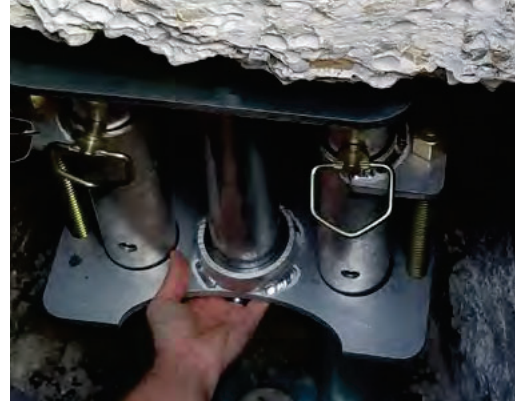


Figure 2.50 Drive stand setup within excavation



Figure 2.51 Placement of hydraulic drive cylinder



Figure 2.52 Extend hydraulic cylinder to engage footing

Step 3: Pier Tube Installation

1. Make sure starter section is plumb and adjust drive stand as necessary (*Figure 2.53*).
2. Fully extend cylinder.
3. Fully retract cylinder.
4. Remove small drive tube.
5. Place medium drive tube onto starter tube.
6. Fully extend cylinder.
7. Fully retract cylinder.
8. Remove medium drive tube.
9. Place large drive tube onto starter tube.
10. Fully extend cylinder.
11. Record final drive pressure for that section.
12. Fully retract cylinder.
13. Remove large drive tube.
14. Place an 18-inch long push pier tube into the starter section.
15. Repeat procedure for rest of the tube sections. Pier advancement is terminated when the target drive pressure is achieved, or the structure starts to mobilize.
16. Occasionally check that the coil nuts are tight and that the drive stand and pier sections are plumb.



Figure 2.53 Check alignment of drive stand and starter section

Step 4: Drive Stand & Hydraulic Drive Cylinder Removal

1. Extend cylinder and loosen coil nuts several inches.
2. Fully retract cylinder and remove from drive stand.
3. Remove hitch pins and lower drive stand to the collapsed position.
4. Place hitch pins into the lower holes on the drive stand legs.
5. Remove drive stand assembly from excavation.

Step 5: Pier Bracket & Hydraulic Lift Cylinder Placement

1. Measure the distance from the bottom of the footing to the top of the last pier tube (Figure 2.54).
2. Subtract 15 inches from the measured dimension and cut a 36-inch long pier tube to this length.
3. Connect the pier cap to the bracket with coil rods and nuts.
4. Insert the cut pier tube through the bottom plate of the bracket and up against the pier cap.
5. Secure the pier tube to the bracket with the Concentric Pier Vice Grip (Figure 2.55).
6. Place bracket assembly onto the last driven pier tube (Figure 2.56).
7. Remove the vice grip.
8. Lift bracket to the bottom of the footing.
9. Tighten the coil nuts.
10. Place hydraulic cylinder on top of the pier cap.
11. Slowly extend the cylinder until the top of the bracket is snug against the bottom of footing (Figure 2.57).
12. Make sure the bracket is plumb and adjust as necessary.
13. Tighten coil rod nuts.



Figure 2.54 Measure from bottom of footing to top of installed pier section

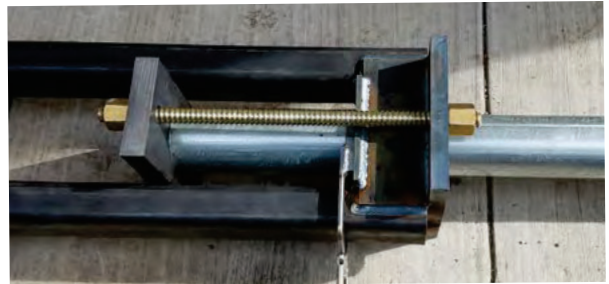


Figure 2.55 Assemble bracket and pier section outside of excavation



Figure 2.56 Place bracket assembly onto last driven pier tube



Figure 2.57 Place hydraulic cylinder and snug bracket against footing

Step 6: Structural Lift and/or Lock Off

Refer to *Section 2.9, Step 6*, for final procedures.

Step 7: Backfill & Clean Up

Completely backfill all excavations and properly compact soil with a mechanical tamper.



Figure 2.58 Completed concentric pier installation

2.11.1 Push Pier SmartJack System

The drive equipment used to install concentric piers can also be used to install push piers that provide a deep foundation for a SmartJack system beneath a main girder. The Foundation Supportworks SmartJack system provides supplemental support to structures within a crawl space and is described in detail in Chapter 4. The push piers will transfer the load from the girders through weak upper soils and into competent load bearing strata below (*Figure 2.59*). Refer to the technical specifications within *Appendix 2* (for concentric piers) and *Appendix 4* (for SmartJacks) for component and system capacities.

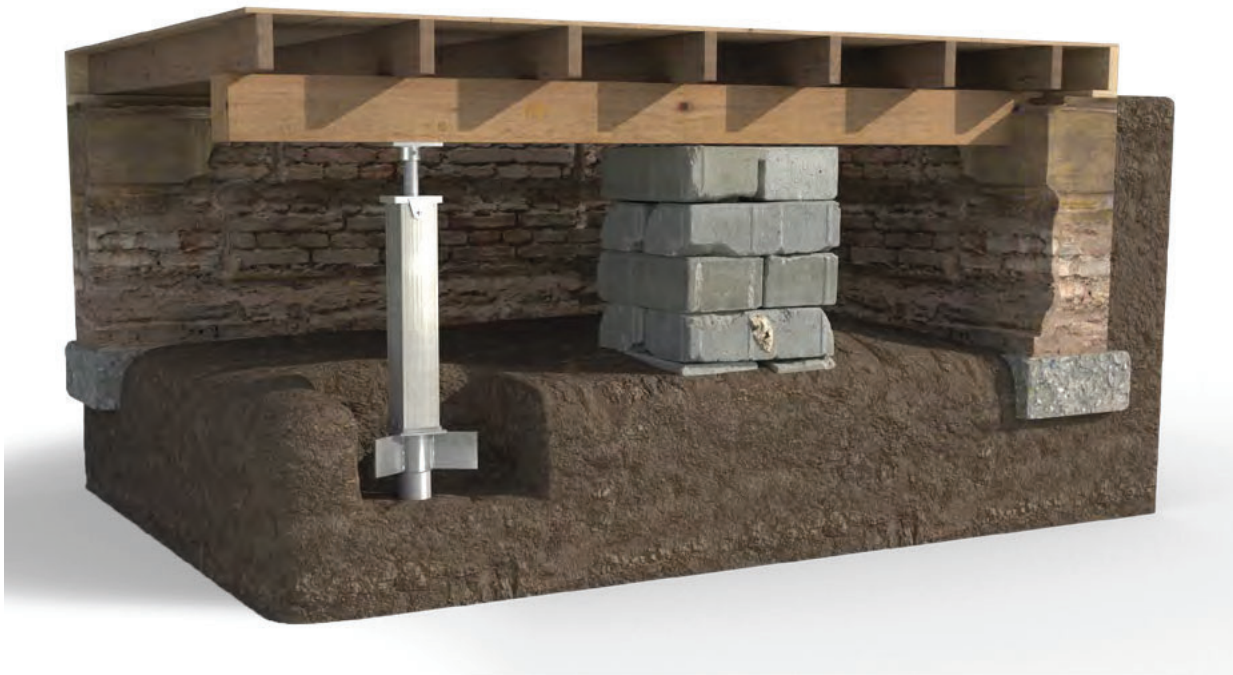


Figure 2.59 Graphic of a Push Pier SmartJack installation. Backfill around base of SmartJack not shown for clarity. Backfill is required.

Step 1: Excavation

1. Excavate an approximate 2-foot square hole to a distance of 40 inches below the bottom of the girder.
2. Bottom of excavation should be flat and level.

Step 2: Pier Installation

Much slower installation should be used to install push piers supporting SmartJacks to reduce the risk of overstressing the supported structure above during the pier driving operations.

See Steps 2, 3, and 4 within the Concentric Push Pier Installation (*Figure 2.60*). The top of the last installed pier tube should be below the ground surface elevation, i.e., below the top of the excavation. Cut tube as necessary.



Figure 2.60 Concentric pier drive stand beneath main girder in crawl space

Step 3: SmartJack Base Plate

1. Place the Push Pier SmartJack Base Plate onto the last installed pier tube (*Figure 2.61*).



Figure 2.61

2. Backfill and compact thoroughly to the top of the base plate (*Figure 2.62*). If the existing soil is excessively wet or dry, or consists of a material type that cannot be reasonably compacted, consideration should be given to bringing in adequate backfill soil, mixing the existing soil with a cement bag mix to improve strength, or backfilling the excavation with concrete.



Figure 2.62

3. Complete Steps 3 through 5 from *Section 4.2*

Step 4: Backfill & Cleanup

Backfill and compact soil to fill the remainder of the excavation. Level out extra spoils, replace concrete, or install a crawl space liner as required.



Figure 2.63 Completed Push Pier SmartJack installation. Model 288 SmartJack shown.

2.12 PP288 Slab Push Pier Installation

The PP288 slab pier system is used to stabilize and/or lift settled concrete floor slabs. Monometer survey equipment, a laser level, a zip level, or other suitable equipment should be used to identify low areas in the slab. Slab piers should be located at these identified low points. Slab piers should also be considered in areas of significant floor cracking, either centered on the crack or located on alternating sides of the crack to ensure an even lift. Voids beneath a stabilized and lifted slab should be filled with suitable material such as a cementitious grout mixture or PolyLevel® polyurethane foam.

Step 1: Slab Preparation

1. Mark the slab pier locations with consideration given to possible underground utilities, overhead obstructions, maximum pier spacing, existing floor cracks and lift requirements.

Slab pier spacing can be estimated using *Figure 2.64*, which gives a recommended grid pattern spacing for various slab thickness and live load combinations. The guide is based on unreinforced concrete slabs having a minimum concrete strength of 2,500 psi.

		Live Load					
		30 psf	40 psf	50 psf	60 psf	80 psf	
Slab Thickness	3.5"	5'-0"	4'-6"	Typical for Residential	4'-3"	4'-0"	3'-9"
	4.0"	5'-6"	5'-0"		4'-9"	4'-6"	4'-3"
	4.5"	6'-0"	5'-6"		5'-3"	5'-0"	4'-6"
	5.0"	6'-6"	6'-0"	5'-9"	5'-6"	5'-0"	
	6.0"	7'-3"	7'-0"	6'-6"	6'-3"	5'-9"	
	8.0"	8'-9"	8'-6"	8'-3"	7'-9"	7'-3"	

Figure 2.64 Slab Pier Spacing Guide

2. Core 8-inch diameter holes in the concrete slab (*Figure 2.65*). Adjust slab pier locations and spacings based on the actual concrete thickness determined at the first cored hole. Remove the concrete cores and use a hand probe to check for underground obstructions (*Figure 2.66*). Using a small hand tool, excavate all material beneath the slab to at least 4 inches below the bottom of the slab and extending at least 3 inches beyond the edges of the cored hole (*Figure 2.67*). Check with your hand to confirm that the bottom of slab is relatively smooth and free of subgrade material.

Safety precautions must be followed during concrete coring to ensure the core drill is securely mounted to the floor slab and proper safety equipment including eye and ear protection is worn during coring operations. Immediately remove any water from the floor when coring to reduce potential for electrical shock. Keep body parts, clothing and other objects away from core bit during operation.



Figure 2.65 Concrete coring

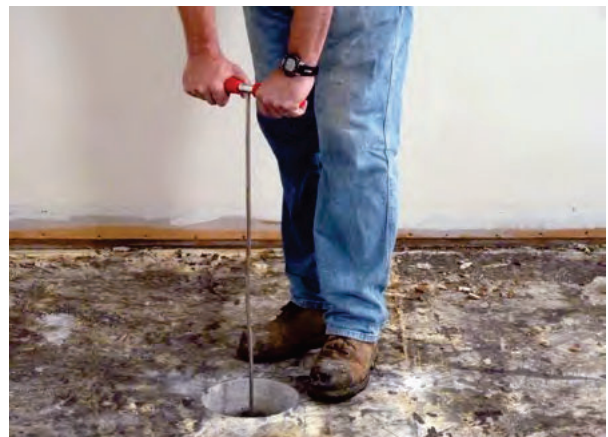


Figure 2.66 Probing for utilities or obstructions



Figure 2.67 Excavating beneath the slab

Step 2: Assembling the Bracket Below the Slab

1. The PP288 slab pier bracket assembly consists of one (1) main plate, two (2) wing plates, two (2) 14-inch long $\frac{5}{8}$ -inch diameter threaded rods, four (4) $\frac{5}{8}$ -inch hex nuts, and one (1) pier cap. Set the main plate (first) and the wing plates (second) through the cored hole. Cover the welded nuts on the bottom of the main plate with duct tape prior to placement through the cored hole to ensure clean threads for later insertion of the threaded rods. Locate the wing plates above the main plate so that the wing plate holes line up with the holes in the main plate (*Figure 2.68*). Align the straight edges of the two wing plates to be essentially parallel with each other.
2. Install hex nuts on one end of the threaded rods leaving about 2½ inches of thread below the nuts. Insert the threaded rods through the wing plate holes and thread them into the weld nuts below the main plate. Turn the rods by hand until the nuts on the threaded rods are seated against the top surface of the wing plates. Continue to tighten the nuts with a deep well socket to fasten the wing plates firmly to the main plate (*Figure 2.69*).



Figure 2.68 Main plate and wing plates positioned and aligned beneath the slab



Figure 2.69 Threaded rods installed

Step 3: Mounting the Drive Stand & Drive Cylinder

1. Cut the coupler extension off a standard 36-inch long pier tube to use as your starter tube (*Figure 2.70*). Insert the "coupler" end of the starter tube through the hole of the main plate.
2. Place the slab pier drive adaptor over the pier tube and allow the $\frac{5}{8}$ -inch threaded rods from the bracket to extend through the holes within the drive adaptor (*Figure 2.71*). The pier tube assists with alignment of the bracket main plate with the slab pier drive adaptor. Alternatively, the pier tube could also be placed through the bracket after positioning of the drive adaptor, but before the threaded rods are tightened.
3. Pull up on the threaded rods while tightening the hex nuts to bring the bracket wing plates snug against the bottom of the slab. Slide the PP288 drive stand onto the slab pier drive adaptor and secure with L-pins (*Figure 2.72*). Set the hydraulic drive cylinder into the top fixture of the drive stand and lock it in position with the coil rod and nuts (*Figure 2.73*). Connect the hydraulic hoses.



Figure 2.70 Starter tube made by cutting coupler end of standard pier tube



Figure 2.72 PP288 drive stand mounted to slab pier drive adaptor



Figure 2.71 Slab pier drive adaptor installed



Figure 2.73 Drive cylinder set into top fixture of drive stand

Step 4: Pier Tube Installation

1. Much slower installation speeds should be used to install slab piers to reduce the risk of overstressing the concrete slab during pier driving operations.
2. Pier tubes are driven using similar procedures as outlined in *Section 2.9* (Step 4), including recording of drive pressures at the end of each driven tube section. The drive stand should self-align when force is applied by the drive cylinder to the pier tubes; therefore, no cribbing or alignment of the drive stand should be necessary if the floor slab was prepared properly.

Safety precautions must be followed when driving pier tube sections to ensure that body and clothing are away from pinch points. Take caution and avoid over-stroking the cylinder rod which may result in a rapid increase in pressure, possibly resulting in cylinder damage or personal injury.

3. Drive pier tubes until the required termination drive force is achieved or slab movement (flexing) in excess of about ¼ inch occurs. Care should be taken by the installer to slowly release hydraulic pressure at the end of each cylinder stroke. Once the predetermined termination drive force is achieved or the slab starts to lift, the pressure is released from the hydraulic system and the drive stand and drive cylinder are removed from the slab pier drive adaptor. The drive adaptor is then disconnected from the threaded rods of the slab pier bracket.

Step 5: Mounting the Lift Cylinder

1. The last pier tube section is pulled from the hole, cut to desired length in a chop saw and replaced. The desired top-of-pier elevation relative to the top of the slab depends upon the slab thickness and the maximum amount of lift anticipated. If the slab will be stabilized without lifting, the top of pier tube can be approximately two inches below the top of the floor slab. It is imperative that the pier tube is cut correctly to ensure that the pier cap, threaded rod, and nuts are below the top of the slab after lift and/or lock-off operations.
2. Place the pier cap over the threaded rods and lightly tighten it against the top of the pier tube with two 5/8-inch hex nuts (Figure 2.74 and Figure 2.75). Set the lift cylinder assembly onto the pier cap (Figure 2.76). Couple the threaded rods of the lift cylinder plate assembly to the threaded rods of the slab bracket to hold the lift cylinder in place (Figure 2.77).

Note: The 3/4-inch threaded rods of the standard Model 288 lift cylinder assembly are larger than the 5/8-inch rods of the slab pier bracket and are not used in this application.



Figure 2.74 Pier tube cut to length; pier cap placed



Figure 2.76 Lift cylinder assembly set on pier cap



Figure 2.75 Lightly tighten pier cap down onto pier tube



Figure 2.77 Lift plate assembly coupled to threaded rods of slab pier bracket

Step 6: Slab Lift and/or Lock off

1. Connect hydraulic hoses to the top and bottom fittings on the lift cylinders (Figure 2.78). The lift cylinders are all hydraulically connected as a system (Figure 2.79) in order to provide simultaneous lift pressure at each cylinder. The system is first equalized by opening the valves at each cylinder in sequence and adjusting the system pressure. The system should be equalized to pressures on the order of 100 to 300 psi.
2. Slowly raise the pump pressure to raise the slab. Monitor the slab for lift at each pier location. After achieving the desired lift, close the valve to the top of the cylinder. If the piers are for stabilization only, close the valves as soon as noticeable slab movement occurs. Once all the cylinder valves are closed, the piers are locked off by tightening the $\frac{5}{8}$ -inch hex nuts to the tops of the pier caps (Figure 2.80).

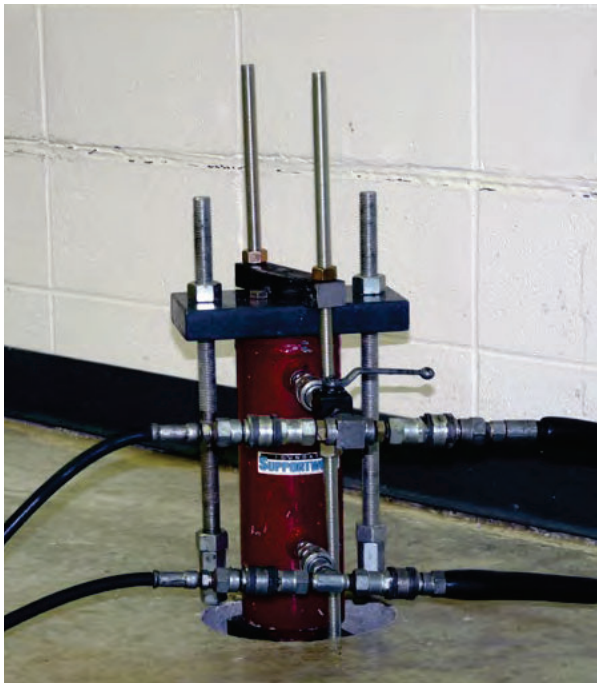


Figure 2.78 Hydraulic connections at lift cylinder



Figure 2.79 Lift cylinders connected for simultaneous loading



Figure 2.80 Pier load locked off by tightening nuts on top of pier cap

3. The system pressure is released and the lift cylinder assemblies are removed. Cut the threaded rods flush with the tops of the hex nuts with a grinder or saw (Figure 2.81). The tops of the nuts must be below the surface elevation of the slab.



Figure 2.81 Cutting the threaded rods

Step 7: Void Fill & Finish Surface

Place concrete and trowel finish at each pier location (*Figure 2.82* and *Figure 2.83*). Voids under the slab should be filled completely with a suitable grout mixture or PolyLevel® polyurethane foam. Void filling is typically completed before patching the core holes with concrete, but can be done either before or after the concrete is placed. Concrete patches should be allowed to cure before void filling.



Figure 2.82 Patching holes at pier locations



Figure 2.83 Finishing concrete

2.13 Push Pier Load Testing

The push pier installation process is essentially equivalent to performing a proof load test at each push pier location; therefore, “official” load testing of push pier systems is not commonly required. The piers are advanced to a final drive pressure or ultimate load, then reloaded to the specified lock-off load (typically at or near the service load) or until the desired lift is achieved. The drive and lock-off loads are easily calculated from the effective area of the hydraulic cylinder and the pressure gauge reading at the hydraulic pump.

If it is determined that a proof test is necessary, then the production pier can be loaded incrementally with deflections measured using the procedure outlined in Evaluation Report ER-289.