Axial Capacity of Hydraulically-Jacked, Steel-Pipe Micropiles Used for Underpinning

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June 14, 2002

Abstract

A review of the axial capacity of hydraulically-jacked, steel-pipe micropiles used for underpinning is presented. A procedure is suggested for field verification of underpinning pile capacity. Theoretical calculations of pile capacity are compared with measured values for a case study involving a foundation repair performed on a telecommunications building.

Introduction

Push pier, push pile, and resistance pier are some of the trade names often applied to hydraulically-jacked, steel-pipe micropiles used for underpinning. For convenience the term steel push pier will be used herein. There are several different manufacturers of steel push piers including Magnum Piering, RamJack, and Atlas Systems. Although steel push piers can be installed using heavy machinery for construction of new structures, this paper is focused on piers used exclusively for underpinning and repair of existing structures.

Steel push piers essentially consist of short sections of pipe or structural steel tube that are often coupled together by an internal sleeve. Each section of a steel push pier is forced into the ground using a hydraulic ram fastened to the footing, stem wall, or grade beam of an existing structure. In this way, the weight of the structure provides the resistance necessary to force the pier into the ground. A factor of safety is obtained by installing the piers individually and by using more piers than the number required to carry the weight of the structure. An example steel push pier connected to a footing foundation is shown in Fig. 1. A photograph that depicts steel push pier installation is shown in Fig. 2.

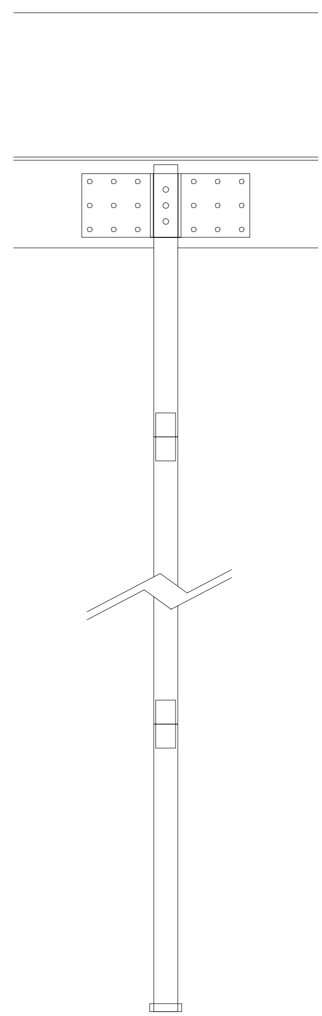

Fig. 1 Example Steel Push Pier

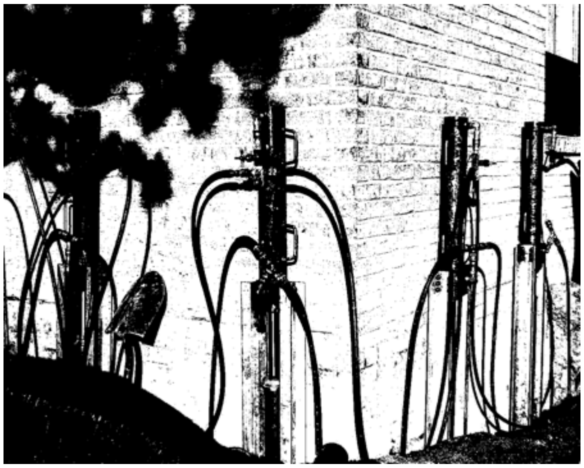

Fig. 2 Example Push Pier Installation

Steel push piers are used to underpin an existing spread footing or slab-on-grade foundation that has undergone excessive total or differential settlement. Once all of the piers are in place, the structure can be lifted to its original grade. This often results in crack closure and provides relief to over-stressed structural members.

The rate of installation of a single steel push pier varies among installers and depends on the subsurface conditions. The typical time required to install a 20 ft long push pier is generally in the range of 4 to 8 hrs. A shear ring with a diameter slightly larger than the pier shaft is usually placed at the bottom of the pier. The purpose of this ring is to reduce friction along the shaft during installation, which permits greater depths to be achieved. Although some of the capacity of a push pier is due to friction of the soil along the sides of the pier, the use of a shear ring effectively produces an end bearing pile.

Steel push piers are fastened to an existing structure by the application of a foundation bracket. The capacity of a steel push pier depends on five factors, given as follows:

1. Integrity of the structure at pier location
2. Connection between bracket and structure
3. Mechanical strength of the bracket
4. Buckling strength of the pier
5. Soil friction and bearing pressure

Although each of these factors is equally important, the topic of this paper is the capacity provided by soil friction and bearing pressure. It is assumed for the remainder of this discussion that the first four factors are adequate to support the required load on the pier.

Capacity Requirements

The required capacity of a steel push pier used for underpinning is computed by the same techniques as those used for other deep foundations with a few special precautions. As with other foundation types, a push pier must have sufficient capacity to support the dead and live loads of the structure. If a structure is to be lifted and re-leveled, it is essential to add the weight of the soil above the footing to the total dead loads computed by conventional means. The cohesion of the soil on the bottom of the footing and/or slab and the friction of the soil along the foundation wall or grade beam also need to be considered.

Demonstrating the ability to lift and re-level the structure is an insufficient verification of push pier capacity. Foundation underpinning must also be capable of supporting live loads such as snow, wind, people, and furnishings that may be added to the structure at a later time. It is imperative that live loads are taken into account in the layout and spacing of push piers.

Total dead and live loads represent the required design capacity of push pier underpinning. In general practice, an appropriate factor of safety must then be applied to derive the required ultimate capacity. Factors of safety used in foundation engineering vary depending on the reliability of soil and subsurface information, the heritage of particular foundation capacity determination methods, and the sensitivity of the structure to movement. A factor of safety of 3 is generally used in conjunction with spread footing foundations. The American Society of Civil Engineers Publication 20 96, "Standard Guidelines for Design and Installation of Pile Foundations", explains that a factor of safety of 1.5 is permissible for driven pile foundations since the method of installation provides a means of capacity determination in the field. Installation of a steel push pier provides an even more direct means of capacity determination as compared to pile driving. The engineer of record should select a factor of safety suitable for each project and site conditions. A factor of safety between 1.5 and 2.0 is often used in practice for steel push pier installation.

Field Verification of Capacity

The installation of steel push piers generally involves the following procedures:

1. An engineer or contractor's technical representative observes the condition of the structure, computes building loads, and plans push pier locations
2. All underground structures and utilities in the vicinity of the piers are located and moved or avoided
3. Foundation access holes are excavated at each pier location
4. Existing foundation is modified to allow connection of brackets as close to foundation wall face as possible
5. Piering brackets are mounted to the existing foundation
6. Elevation of the structure at each pier location is measured and a building monitoring program is established
7. Hydraulic rams are temporarily attached to the brackets on the existing structure
8. Steel push piers are jacked into the ground individually until the load used for driving the pier equals or exceeds the required ultimate capacity
9. Ram pressure is measured and recorded at 3 feet intervals of push pier depth
10. Local building official or building owner's representative observes pier loading and verifies required capacity has been achieved
11. After all piers are installed and inspected, the building is lifted and re-leveled to the extent possible without compromising integrity of the structure
12. The piers are permanently secured to the brackets and the hydraulic rams are removed
13. Final building elevation is recorded
14. Access holes are backfilled and landscaping materials are restored

To date, no standard method exists for completion of installation steps 7 and 8 which involve field verification of push pier capacity. The American Society for Testing and Materials specification D1143 - 81, "Standard Test Method for Piles Under Static Axial Compressive Load" explains routine methods to determine if a pile has adequate bearing capacity. Based in large part on this standard, the following procedure for verifying the capacity of a steel push pier is suggested.

1. The bracket and ram assembly shall be such that loads are applied vertically

and directly to the central longitudinal axis of the push pier with a minimum of eccentric loading

2. The structure to which the bracket and ram assembly is attached shall have sufficient integrity and weight to allow for application of loads to the push pier without excessive lifting and without causing damage to the structure
3. If the structure is of insufficient weight to permit the required push pier loading, then an earth anchor, ballast weight, or battered pile must be used to provide the necessary reaction
4. The hydraulic ram used to load the pier shall be fitted with a pressure gauge, shall be capable of delivering the prescribed loads with a sensitivity of at least 2% of the required ultimate capacity of the pier, and shall be calibrated at least annually
5. Push piers shall have a minimum spacing of 2 feet or at least 10% of their average depth
6. After the pier is installed and is ready to be proof loaded, the loading procedure shall consist of applying the design ultimate load to the pier, which shall be at least 150% of the design allowable load
7. Push pier movement relative to a fixed frame of reference shall be measured optically or through the use of a dial gauge
8. The proof load shall be maintained until the rate of settlement is not greater than 1/16 in/h but not less than 1 h
9. A field report shall be prepared that at least shall contain pier location, applied loads, load duration, and final pier depth

<u>Theoretical Capacity</u>

In practice, the theoretical capacity of a steel push pier is seldom computed due to the measurement and verification of capacity in the field. However, on certain occasions it may be desirable to determine theoretical capacity in order to evaluate the suitability of a particular bearing stratum or to approximate push pier depth.

A case history is presented for a two-story, 12,000 sf, telecommunications office structure in Cincinnati, OH. The south sides of the building had experienced excessive settlement. A plan view of the structure is shown in Fig. 3. Exploratory borings were drilled at the three locations shown. Graphic logs of these borings are provided in Fig. 4. As can be seen from the boring logs, the subsurface conditions consisted of 0 to 3 feet of fill over sandy clays and highly weathered shale underlain by hard shale and limestone bedrock at depths between 14 and 19 feet.

In most cases, underpinning the entire structure with steel push piers is the recommended course of action. In this particular case study, the north ends of the building were underlain directly by the hard shale and limestone bedrock. It was decided that the north sides of the building were adequately supported and did not require underpinning. A total of 24 steel push piers were located and installed along the south sides of the building, as shown in Fig. 3. The depth of pier installations varied from 3 to 21 feet. All of the piers were installed individually and proof loaded to at least 45 kips. Hydraulic ram pressure was measured and recorded at installation depth intervals of 3 ft. Ram pressure and corresponding load is shown in Table 1 for the three piers located closest to the exploratory soil borings.

Table 1. Records of Push Pier Installation

		Pier Location					
		3		14		20	
		Hydraulic Ram Pressure (psi) - Applied Load (lbs)					
Depth	3	500	4,125	200	1,650	100	825
	6	500	4,125	500	4,125	100	825
	9	1,000	8,250	1,500	12,375	1,000	8,250
	12	5,500	45,375	5,500	45,375	3,000	24,750
	15					5,500	45,375
	18						

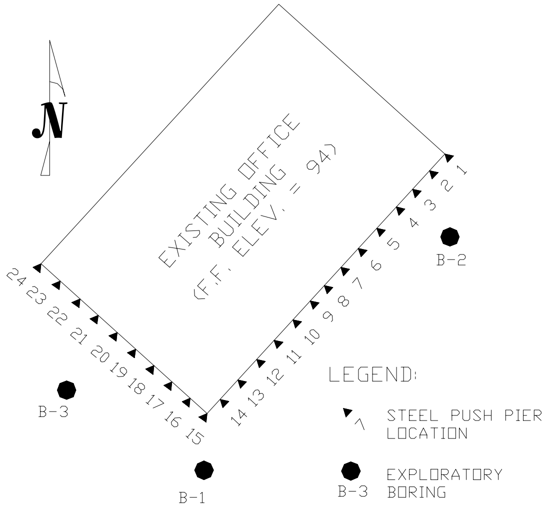

Fig. 3 Case History Site Plan

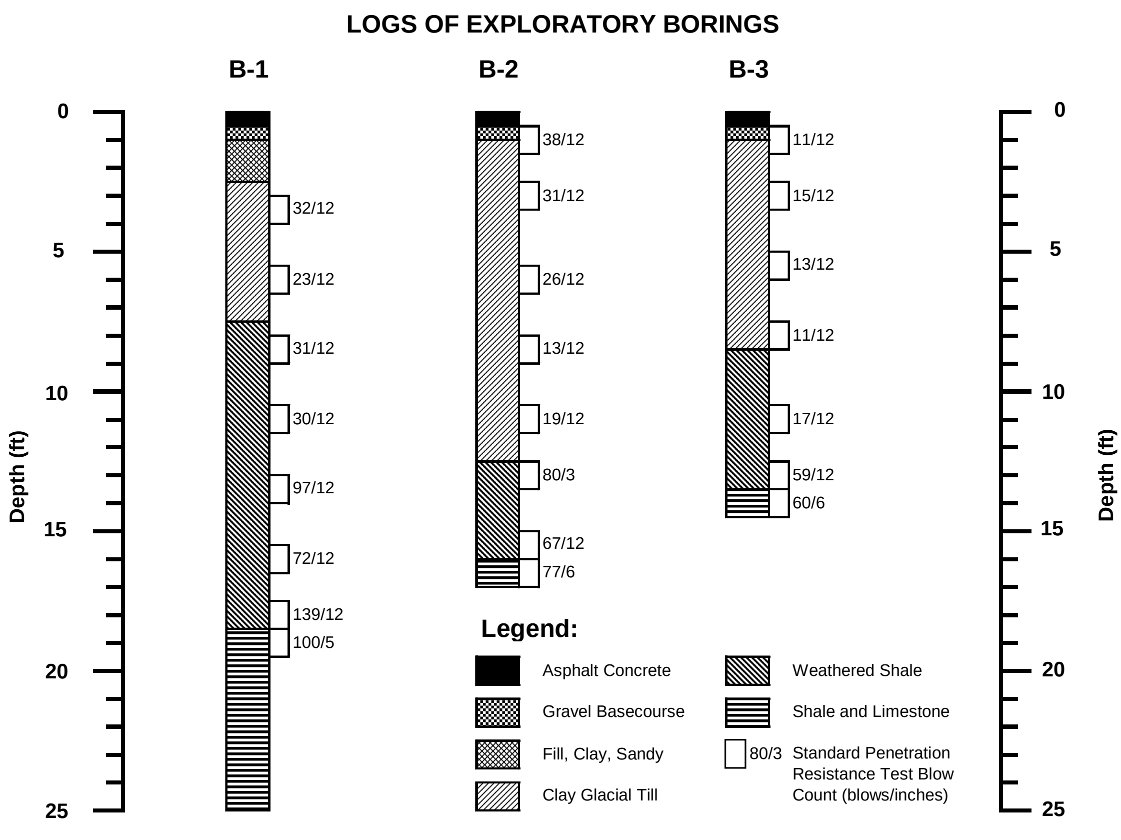

Fig. 4 Logs of Exploratory Borings

Due to the use of a shear ring, a steel push pier should be treated essentially as an end bearing pile. According to Meyerhof (1956, 1976), ultimate static pile point capacity can be related directly to Standard Penetration Resistance test blow count by

$$P_{ptu} = 840AN\frac{L}{D}$$

where A = pile tip area (ft^2);
N = SPT blow count (blows/ft);
L = penetration length (ft),
and D = pile diameter (ft).

Meyerhof also specified the criterion that

$$\frac{L}{D} \leq 10$$

It has been shown (Miller and Lutenegger, 1997) that open-ended piles exhibiting a plugged condition develop end bearing similar to that of a closed-ended pile. It has also been calculated that plugged conditions are achieved at depths between 10 and 20 pile diameters (Paikowsky and Whitman, 1990). This is consistent with the authors observation that push piers typically develop a plugged condition within the completion of the first 3' section of pier pipe installed. Hence, in almost all practical cases, the pile tip area, A, should include the area of the plugged end. Pile tip area should also include the additional diameter provided by the shear ring (if used).

The steel push pier diameter, D, used for the case history presented above was 3". The shear ring diameter was 4". The standard penetration resistance blow count used in the above equation should be taken as the average value from 3 D below the pile tip to about 8 D above the pile tip. Since Meyerhof's equation is for tip capacity, it should be recognized that the penetration length, L, is not associated with friction along the pile shaft; rather, it is an indication of the effective vertical pressures that govern the N_q term in the traditional bearing capacity equation. As such, it is reasonable to use a fraction of the push pile depth.

In applying Meyerhof's equation to the data available for the case history, it was assumed that the penetration length, L, is equal to 25% of the depth of the pier minus 1.5 ft to account for disturbed soil at the ground surface. In terms of mathematical symbols, L is given by

$$L = 25\% \times (L_T - 1.5)$$

where L_T = total depth of the pier (ft).

A comparison between theoretical and measured pier capacity for the three piers given in Table 1 is shown in Fig. 5. These data are for all depth intervals. As can be seen in the figure, Meyerhof's equation and the definition of penetration length given above match the field measurements very well.

Discussion

In saturated low permeable soils, the installation of steel push piers causes high pore water pressures. Subsequently, soil effective stress is reduced substantially. It is standard practice to proof load steel push piers immediately after installation. This procedure is conservative since the capacity of the pier should increase substantially after pore pressures dissipate and effective stresses return to steady state. It is common knowledge amongst installers that push piers must be completely installed in the same day. Even an overnight delay is sufficient to make the obtainment of additional installation depth difficult. In most cases, push pier capacity should increase with time. Groundwater fluctuations and corrosion are exceptions that may adversely affect capacity.

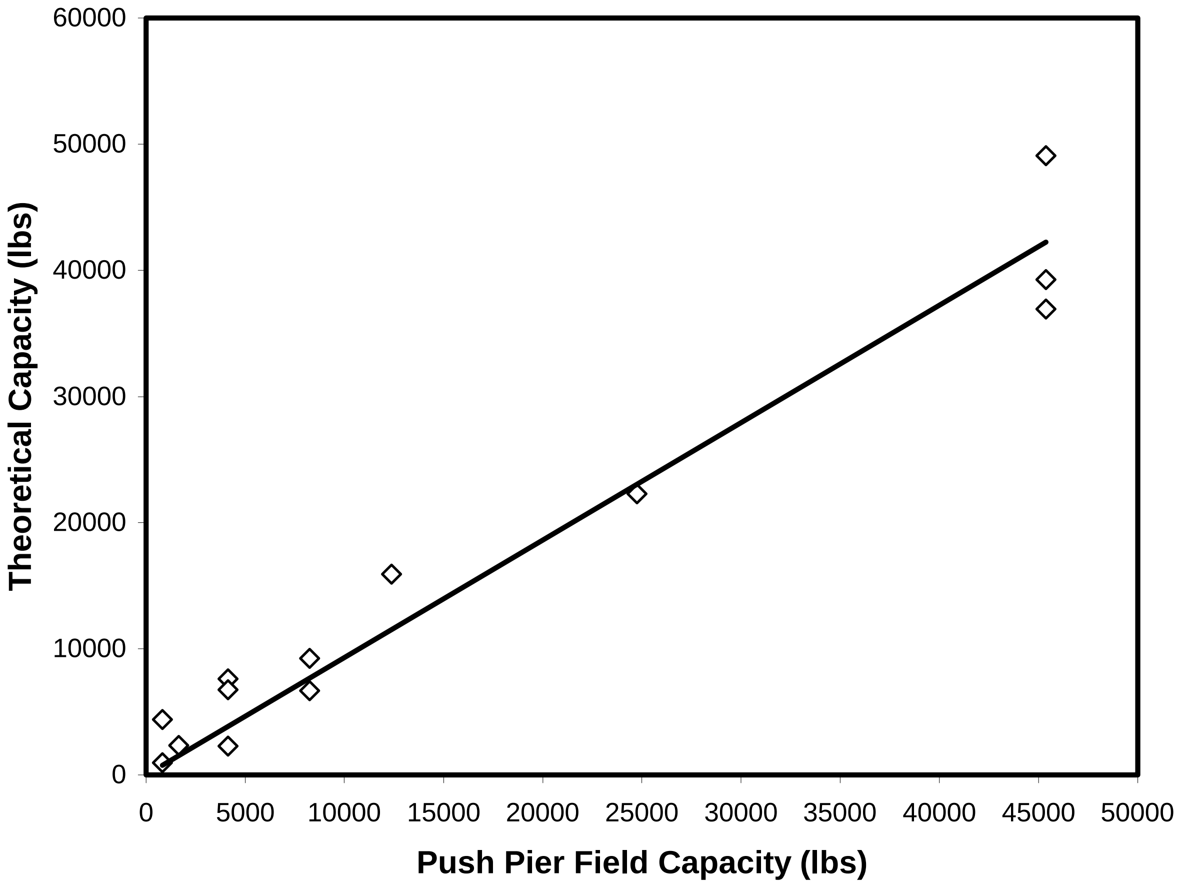

Fig. 5 Theoretical and Measure Push Pier Capacity

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