



Nicholson Construction Company
12 McClane Street
Cuddy, PA 15031
Telephone: 412-221-4500
Facsimile: 412-221-3127

Pin Piles for Structural Underpinning

by

Seth L. Pearlman, P.E.
Nicholson Construction Company, Cuddy, Pennsylvania

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PIN PILES FOR STRUCTURAL UNDERPINNING

Seth L. Pearlman, P.E. (*)

SUMMARY

Pin Piles are small diameter high capacity drilled and grouted piles also called minipiles or micropiles. They are ideal for building foundations on sites with poor ground conditions, sensitive surroundings, restricted vertical clearance, or difficult access. They are also well suited to foundation underpinning, arresting ground movements, and increasing the capacity of existing foundations. The major factors for selection of Pin Piles are reviewed; drilling, grouting, and design fundamentals are summarized; and a major case history is presented for the underpinning of the 43 story elevator core at the recently opened Mandalay Bay Resort and Casino in Las Vegas, NV.

INTRODUCTION

Major structures are either supported on suitable underlying soils in direct bearing or are built on deep foundation systems such as driven or drilled piles. In bearing cases, the allowable capacity is typically controlled by the amount of movement (settlement) that the building can sustain. Certainly, predictions of bearing capacity may not always match the observed values, and remedial schemes may be necessary. Significant structures, in some cases, may outlast their initially installed deep foundation systems. In other cases, catastrophic events resulting in ground losses can certainly compromise the support of any structure whether in soil bearing or on piling. Or most simply, there are cases where additional foundation capacity is necessary to accommodate new loadings on a structure (e.g. extra stories). It is in these situations; remediation or addition of suitable foundation support is indicated. Pin Piles (micropiles) have been proven to be a reliable and versatile geotechnical construction technique for restoration of support under existing structures.

Pin Piles are drilled in elements typically ranging from 5 to 12 inches in diameter, which typically consist of steel pipe (casing), steel reinforcement, and cement grout. They derive capacity in the ground from side friction and perform very well in both compression and tension. Working load capacities typically range from 50 to 200 tons. They are installed in a wide range of access and ground conditions which makes them ideally suited to working in and around existing structures, as well as when difficult geology is present.

Pin Piles, small diameter drilled and grouted piles, also called minipiles originated in Europe, typically consisting of a central steel core encased with cement grout placed into a small diameter drilled hole. These piles were installed as individual elements or groups with cumulative benefit. One key feature of the European minipiles is that they were typically fully bonded over their entire length, due to the method of installation. That is, a drilled hole (either open or temporarily cased), was filled with grout and a centralized reinforcing element. The

* Vice President, Nicholson Construction Co., Cuddy, PA

temporary casing was removed, thereby providing a pile bonded over its' entire length, and providing ground reinforcement that spans over layers of weaker soil.

In the United States, it was realized that traditional mini or micro piles were particularly limited by their individual structural capacity. That is, the rebar core with grout in the upper portion of the pile had poor lateral support and confinement by the weaker surficial soil surrounding it, and was therefore not very ductile against high compressive loads or any manner of lateral bending or eccentric loading. Additionally, the mindset of those developing the use of Pin Piles in the U.S. was primarily that of an alternative type of discrete structural pile, that serves well in special circumstances. Hence, permanent steel casing pipe, typically 7 inches O.D., is the most common size of Pin Pile that is installed

In cases where restoration of support or underpinning of existing structures is required, it is often neither feasible nor practical to install other deep foundation elements such as driven piles or drilled shafts. The reasons may be physical, geological, or simply an economic combination of several factors.

Physical constraints typically are:

- situations with low overhead clearance,
- tight working conditions inside existing structures,
- sites with limited plan area access, e.g. in hallways or against the face of walls, or
- situations where it is necessary to attach small piling elements directly through the existing foundation elements.

Geotechnical constraints may include conditions such as:

- karstic limestone geology (that may include voids or soil filled solution cavities),
- bouldery ground or glacial till,
- variable and/or random fill,
- underlying existing foundations or man-made obstructions,
- rock formations with variable weathering (e.g. hard zones overlying softer layers), or
- soils under a high water table.

Pin Piles are an ideal choice then in the following underpinning situations:

- to provide additional foundation capacity to footings or mats with too little bearing capacity (e.g. when building movement or ground consolidation is excessive),
- when supporting foundations to allow an excavation to proceed adjacent to or right below it – (e.g. as a substitution for hand dug underpinning pits),
- to provide both vertical underpinning and lateral earth retention (e.g. as soldier piles),
- to provide support for structures that are distressed or undermined due to a catastrophic event (e.g. erosion, landslides, burst pipes, mine subsidence, etc.), or
- for adding load capacity to an existing foundation system to accommodate a seismic retrofit or addition of new structure, building stories, etc.

Pin Piles are economical and offer the following advantages in these situations:

- small and powerful equipment is used to negotiate tight physical spaces,
- drilling is quiet, vibration free, and causes little or no loss of ground around each pile installation,
- drill spoil can be diverted from the hole location to provide a very clean environment within operating facilities,
- the drilling equipment is used to conveniently install tie-down anchors that provide the primary uplift resistance for vertical pile load testing,
- larger casing pipes can be used in the upper portions of the piles to obtain significant lateral load resistance, and
- many variations of drilling, grouting, and structural configurations make for a fully customized and optimal solution.

Pin Piles derive primary load carrying capacity in the ground using frictional bond in soil or rock. Properly configured, high capacity is available in both compression and tension. In compression, Pin Piles typically range in working load from 50 to 200 tons. In tension, their capacity is nearly the same geotechnically, however it is mainly limited by the amount and detailing of the core reinforcement, casing sections, and the type of casing splice used.

When subjected to lateral loadings, the piles derive resistance from the horizontal response of the adjacent soils and can sustain significant lateral deflection within the available structural pile capacity. Where very large bending capacity is required, the pipe casing is sized accordingly by increasing diameter and/or the thickness of the pipe. For earth retention applications, where cuts are significant, piles in the 9 to 10-inch diameter range are often used.

INSTALLATION METHODS

The ability to install Pin Piles in the most difficult and problematic geotechnical situations is a major advantage in their use for building foundations and underpinning. This capability is gained principally by the optimal selection of drilling and grouting techniques. The specialty contractor is often most adept at choosing the best installation technique to meet the intended result, while respecting the concerns of the owner and his engineer particularly regarding tolerable ground disturbance during drilling.

Pin Piles are installed using rotary drilling techniques similar to those used in the oil and gas industry. The piles develop their geotechnical capacity through grout to ground adhesion in the bond zone. In soils this bond is typically developed using pressure grouting and in rock, tremie grouting. The principle types of drilling and grouting techniques used by the writers' company are described below.

DRILLING METHODS:

Positive Circulation or External Flush Drilling: This method entails rotating a pipe or drill casing into the ground while applying a vertical load or down pressure. The soil inside the casing is cleaned or flushed out by a drilling fluid. The drilling fluid is injected into the casing at the drill

head and returns upward along the outside of the drill casing. Water is the most commonly used drilling fluid, although compressed air and drilling mud are also used in some circumstances. External flush drilling is the easiest and most cost-effective drilling method for installing Pin Piles in soil and is generally used when obstructions are not present and some temporary ground loss can be tolerated.

Duplex Drilling: Duplex drilling is a method of progressing and cleaning out the drill casing where the outer drill casing is advanced simultaneously along with an inner drill rod tipped with a roller bit. The drilling fluid is circulated down through the center of the inner drill rod and returns upward through the annular space between the drill rod and drill casing. Water is again the most common drilling fluid used for this technique. One of the major advantages of duplex drilling is that intimate contact is maintained between the drill casing and the soil during drilling. This is important for situations where ground loss is a concern, or where the soil is so open, that fluid return is not possible with external flush. Duplex drilling is also used to penetrate through obstructions or to maintain an open hole in fractured rock formations. Disadvantages of this method are that it is slower and more labor intensive than external flush drilling and therefore more costly.

Rotary Eccentric Percussive Duplex Drilling: This method is similar to the duplex method except that the roller bit on the inner drill rod is replaced with a down the hole hammer. The hammer bit is fabricated in two pieces, a pilot and a reamer. The reamer bit mechanically opens up during drilling to a diameter slightly larger than the outside diameter of the drill casing. This bit provides a slightly oversized hole through obstructions or rock and thereby allows the casing to simultaneously follow it down. Compressed air is used to drive the hammer and also acts as the drilling fluid to lift the cuttings. This drilling method is used in soils containing large amounts of obstructions such as cobbles, boulders or demolition waste, and is also very effective in advancing a drill casing through highly fractured rock zones such as karstic limestone, or variably weathered rock like the mica schist formations in the New York metropolitan area. The drill tooling required is more costly than that required for external flush or normal duplex drilling, but in many situations, the method is very effective.

GROUTING METHODS:

Tremie Grouting: This is a method used to place grout in a wet hole. A grout tube is lowered to the bottom of the drill casing and/or open hole or rock socket. Grout is pumped through the tube as it is slowly removed from the hole. As the grout fills the drill casing or hole, it displaces the drilling fluid. Tremie grouting is primarily used where the Pin Pile bond zone is founded in rock or ideal conditions in granular soils. When working in highly broken or fractured rock or in voided, karstic situations, grout loss is possible and may warrant testing for a sealed bond zone. When this is done it is typical to perform certain tests to verify grout integrity prior to the installation of the final pile reinforcement. Sometimes, an initial grouting, then redrilling and grouting again prior to final pile completion is warranted.

Pressure Grouting: Pressure grouting is a method used to develop enhanced pile capacity in soils. This is done by applying pressure to the top of the fluid grout column through the drill head as

the drill casing is withdrawn from the bond zone. The pressure forces the grout into the surrounding soil to create a “grout bulb”. The pile capacity is derived from the friction and bond developed between the surrounding soil and the grout bulb.

Post Grouting: Post grouting is a technique that uses a tube with drilled holes that are covered with rubber sleeves (one way valves) which allow introduction of controlled quantities of additional grout at pressures that may exceed the in-situ lateral stresses. The sleeved port pipe is generally lowered into the hole with the core reinforcement, and sometimes is part of the reinforcing when steel sleeved pipes are used. After the initial grout has partially cured, a packer is used to place controlled quantities of grout at high pressures through individual sleeve ports. This process breaks the initial grout, allowing the placement of additional grout, and results in higher in-situ lateral stresses around the bond zone while enlarging the bond zone.

STRUCTURAL CONFIGURATIONS:

The elegance of the Pin Pile system is the intelligent mating of the drilling and grouting methods to develop an optimal design for the Piles. The authors’ company typically uses four configurations as described below. The combined drilling and grouting methods for each type are as follows.

Type S1: A steel pipe is rotated into the soil using external flush or either duplex technique. Neat cement grout is tremied from the bottom of the hole to displace the drilling fluid. The central reinforcing element is then placed to the bottom of the hole. As the pipe is withdrawn over the length of the bond zone, additional grout is pumped under sufficient excess pressure to create the bond zone. The pipe is then plunged back into the grouted bond zone for 5 to 10 feet. In granular soils, a certain amount of permeation and replacement of loosened soils takes place. In cohesive soils, a certain amount of lateral displacement or localized improvement of the soil around the bond zone is accomplished with the pressure grouting (See Figure 1). To attain an even greater displacement effect around the bond zone, a special technique called post-grouting as described above is often used with Type S1 Pin Piles.

Type S2: The Type S2 pile may be installed two ways. The first is similar to the methods used for the Type S1 pile, except that the pipe reinforcement must be plunged back down over the full depth of the bond zone.

A second approach for soils with sufficient cohesion has been developed using external flush and maintaining an open borehole. Grout is first tremied inside the pipe, then pumped from the filled center of the pipe and forced to flow up the annulus. This encapsulates and bonds the pipe to the soil. There is no pressure grouting here, just tremie flow; however, the entire pipe is engaged in frictional bond.

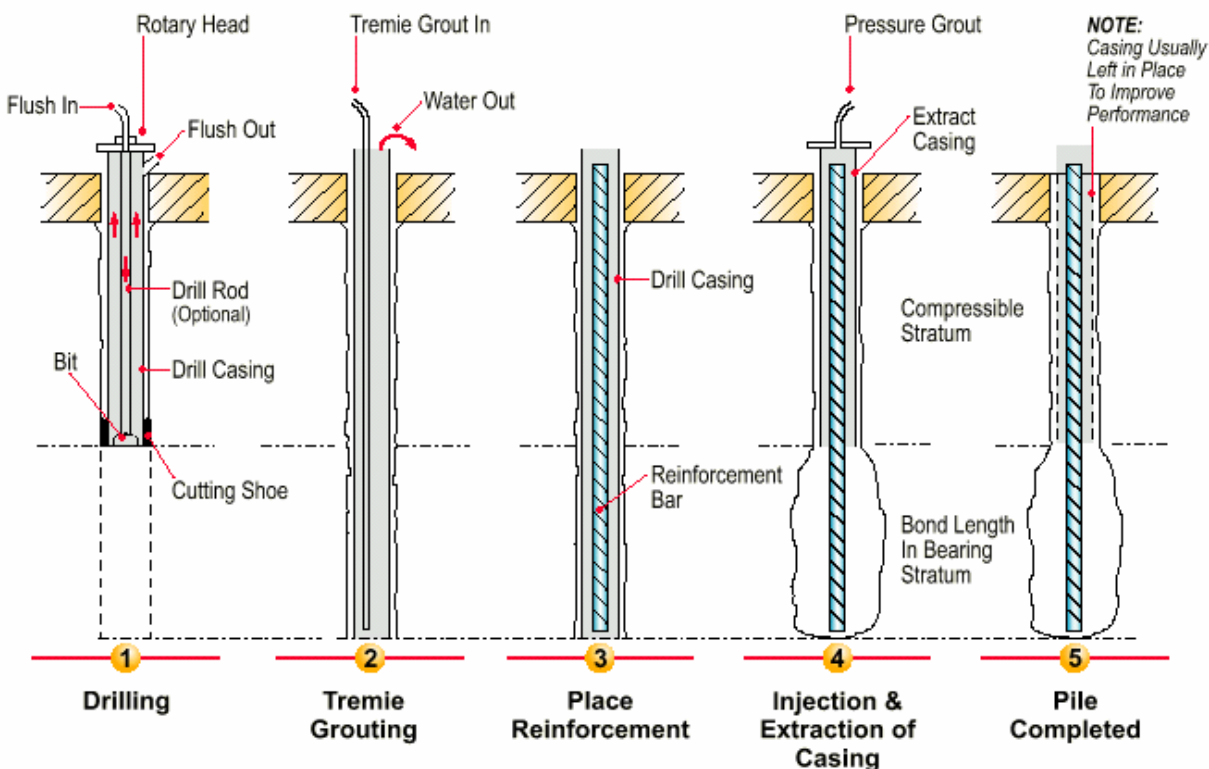


Figure 1. Typical Drilling and Grouting Sequence for a Type S1 Pin Pile

Type R1 - The Type R1 pile uses the same techniques for advancing a steel pipe as described for Type S1, except that the depth of penetration is limited to the top of the rock bond zone. Once the pipe is seated into the rock, a smaller diameter drill string is advanced through the center of the pipe to drill the rock bond zone to a diameter slightly less than the inside diameter of the pipe. Once cleaned out, neat cement grout is tremied from the bottom, and a reinforcing element is placed in the rock bond zone to complete the pile installation. A minimum transfer/development length is required for the reinforcing to develop inside the pipe (typically 5 to 10 feet).

Alternatively, in poor quality rock formations, such as karst, the rotary eccentric percussive drilling tool is used to advance the casing into rock until the hammer response indicates that rock of sufficient quality is penetrated. Then the casing is withdrawn over the length of the bond zone, the pile is grouted, and the reinforcement is placed.

Type R2 - The Type R2 pile differs from the R1 pile in that it uses a full length steel pipe. Centralized reinforcement is optional. In order to advance the pipe through both the overburden and the rock, a permanent drill bit is used on the end of the pipe with a diameter somewhat greater than that of the outside diameter, or the eccentric percussive system is used as described above. Once the hole is advanced to the desired depth, grout is tremied from the bottom, and additional grout is pumped to assure full grouting of the rock bond zone. This grout may not flow completely

to the surface in some conditions. However, once the level inside the pile has stabilized, the final grout level on the outside of the pile is verified.

DESIGN

MATERIALS:

Pin Piles are typically constructed using steel casing with special machined flush jointed threads. The casing meets the physical properties of ASTM A-252 Grade 3, except that the minimum yield strength is typically 80 ksi. This material is most often mill secondary drill casing manufactured under oilfield specifications. Material certifications are usually not available; hence physical properties are confirmed by cut coupons from representative pieces of casing.

The core reinforcing steel is normally Grade 60, 75, or 80 reinforcing bar (ASTM A615, A616 or A617) or occasionally Grade 150 pre-stressing bar (ASTM A722). The Grade 150 may be useful in piles subjected to very high tension loads, however, in compression, the 60 to 80 ksi yield core steels are most compatible with the strain levels in the grout as well as the 80 ksi steel casing.

The grout typically consists of neat cement and water mixed with a high shear colloidal type mixer. This grout has a fluid consistency, a water/cement ratio of about 0.45, and a typical minimum unconfined compressive strength (from cubes) of 4,000 psi in 28 days.

STRUCTURAL DESIGN:

The structural design of Pin Piles for building foundations is not yet addressed in many building codes. However, based on our experience and practice in various areas, the following equation is used.

$$P_{all} = (0.40 \text{ to } 0.50)F_y A_s + (0.35 \text{ to } 0.45)f'_c A_c$$

where: F_y = Yield Stress of either the casing or rebar
 A_s = Cross-sectional area of casing or rebar
 f'_c = Unconfined Compressive Strength of the grout at 28 days
 A_c = Cross-sectional area of the grout

The factors that are most appropriate depend upon the experience of the contractor, the experience of the structural engineer, and the observed performance of the test piles. One factor that deserves additional study is the superior performance that is observed with respect to pile stiffness, and perceived strain level in the grout when steel strains are allowed to approach yield levels. The equation above is conservative as long as the pile is structurally configured to take advantage of confinement. That is, in soft soils, the grout needs to be confined inside the pipe casing, and in dense soil or rock bond zones, the grout receives lateral confinement from the ground. This effect has been confirmed many times through load test performance at ultimate loading, with back-calculated stresses far in excess of typical values. More research and

modeling is needed in this area to further quantify this benefit so that a more complete understanding of the designs is possible which could lead to added economies.

GEOTECHNICAL DESIGN:

The bond length is determined by experience and by previous load tests in similar ground. The bond zone capacity is calculated as a typical friction pile. Tip resistance is usually neglected. The following calculation is used.

$$P_{all} = \sigma \pi d L$$

where: σ = Allowable bond stress of soil/rock in bond zone
d = Diameter of bond zone
L = Length of bond zone

LOAD TESTS:

All projects of any significance justify full scale testing (ASTM D1143) of at least one pile unless there is significant confidence and prior experience with the founding stratum. If the ground conditions vary considerably across a site, then more than one or two load tests should be planned. The purpose of the testing is to verify both the geotechnical capacity of the bond zone and the structural performance of the pile. Many tests have been run on the Pin Pile configurations. As more highly loaded Pin Piles are installed and tested, the experience and confidence with this technique expands.

CASE HISTORY – MANDALAY BAY RESORT AND CASINO

PROJECT BACKGROUND:

On the first of July in 1998 the author was referred to consult with the owner and developer of a very large hotel development in Las Vegas, NV to be called the Mandalay Bay Hotel. Circus Circus Enterprises, now named Mandalay Resort Group were building a 3700 room hotel complex consisting of 43 stories, and three radial wings that emanated from the central elevator core at 120-degree intervals. The central elevator core accommodated 28 vertical cars to be constructed inside four large shear wall enclosures. The total dead and live loading on the center core was estimated at about 250,000 kips.

The center core was built on a 10-foot thick mat foundation at about 20 feet below grade. In early July of 1998, after the reinforced concrete structure was topped out, it was recognized that the vertical movements, and particularly differential movements between the tower core and the wings, were unacceptable. The structure, consisted of heavy reinforced concrete columns, that supported relatively flexible post-tensioned concrete floor slabs. If the movements were not arrested, then the potential usability of the structure could be compromised. The center core at this point was sinking at a rate of about ½ to ¾ inches per week and the wings were sinking at a slower rate thereby increasing the differential distortion between column bays. It was imperative to quickly devise and implement a scheme for supporting the structure. Pin Piles, installed with

small equipment, inside the structure and adjacent to the large concrete shear walls that surrounded the elevator shafts were proposed by Nicholson and accepted by the owner and his engineers.



Overall Elevation View of the Mandalay Bay Resort Hotel in the Fall of 1998

A Similar Small Scale Case History: This proposal had many similarities to a structural support solution done by the author in the early 1990's at a power plant in Northern Indiana. In this case, a 14 foot diameter steel pipe carrying intake cooling water from Lake Michigan failed, and in doing so pulled in very large quantities of very loose wind blown dune sand. A new structure that supported process elements sensitive to movements had been undercut on one side, and one corner had dropped at least one inch.

Nicholson Construction Co. proposed the emergency installation of 21 Type S1 Pin Piles which were drilled through cored holes in the mat, and attached using high strength tie down bolts supporting small cross beams. The beams were used to react against jacks so that support could be restored and the structure could be raised. The piles were installed in one week, and the edge was lifted back up.

At Mandalay Bay: Based upon the experience in Indiana, we proposed a much larger scale application of the same solution. That is, the piles would be drilled in through holes cored into the mat and not bonded in the mat. Then structural beam supports would be installed to act as permanent attachments and jacking frames. The entire system had the capacity to lift the center of the tower if that proved to be necessary. In order to support the center core, a layout consisting of 536 Pin Piles was developed by the structural engineer, Lochsa Engineering. Due to the limited plan area and the fact that it would be impractical to delay elevator construction to drill inside the shafts,

all piles were located outside of the shafts. The resulting system was designed to support the core as if it was one very large pile cap. In all, 536 7-inch diameter Pin Piles, were drilled and grouted over their full 200 foot length both outside and inside of the pipe. From July 4th to the start of drilling, 9 feet of fill overlying the mat had to be excavated around numerous utilities, and the utilities had to be relocated. Drilling work began on July 15, 1998 and was completed on October 9, 1998, working around the clock. Prior to full attachment, vertical building movements were reduced. After full attachment and jacking, the movement was stopped.

GEOTECHNICAL CONDITIONS:

The valley of Las Vegas is founded above very deep interbedded layers of alluvial sands, silts and clay. Some layers of caliche and cemented sands and gravels exist at various elevations. Most large structures are built on mats in bearing on these soils. At the Mandalay Bay site, caliche layers several feet in thickness were identified at 20, 25, 65 and 85 feet below the surface. Harder layers of partially to fully cemented materials were also identified at depths of 185 to 200 feet below the mat and another at 300 feet below the mat. All the Pin Piles used to support the hotel core were tipped out in the cemented sands and gravels at a depth of 200 feet. Each was fully bonded with grout to all the silty, clayey, and sandy layers above that.

PILE DESCRIPTION AND INSTALLATION METHOD:

Each identical Pin Pile consisted of 7-inch OD 80 ksi pipe sections drilled down with threaded flush jointed 10-foot long pieces. The lead piece had an 8-1/2 inch diameter roller bit attached to it so that an oversized hole was drilled. External flushing with water and polymer additives assured that the heavier soil particles were lifted around the annulus of the pile and ejected. The external flush drilling also provided very rapid advancement of the casing. Once the casing reached the desired bottom elevation, a flexible tremie pipe was lowered inside the pipe casing to the bottom of the hole. Neat cement grout, mixed in high shear colloidal mixers, with water to cement ratio of 0.45 and a super-plasticizing admixture was then pumped through the tremie pipe. This very fluid grout would often travel a significant distance up the annulus just under the head of the tremie. Finally, full external grouting was completed by attaching the drill head back on the casing, and pumping additional grout through the head of the drill until it was observed to be flowing up from around the outside of the pile. A 10-foot long PVC pipe was inserted over the top of the pile into the mat to act as a bond breaker.

This technique of fully grouting around the pile annulus was developed in order to assure that the potential ground loss that may have been created with the external flush drilling, was immediately restored in each case with the grout filling. In other cases, duplex drilling may have been selected as a lower risk option; however, the increased production obtained with external flushing far outweighed any ground loss risk, particularly given the predominantly clayey sands and sandy clays underlying the mat. Additionally, the fully bonded piles proved to act as reinforcement against ground movement, and improved the situation as the installation progressed.

To connect the mat foundation to the piles, each Pin Pile was constructed with its own reaction frame/transfer beam assembly and its own 350-ton jack. Four steel reaction bars were grouted into the mat around each pile. A small beam was placed on top of the pile, followed by the hydraulic jack and then another beam. The four reaction bars were attached to the top beam with large nuts. When the jack was extended, the force pushed down against the pile and up against the mat. When the desired load was reached, nuts were tightened down on the bottom beam to lock in the load on the pile. Each pile was cyclically load tested with its' own jack to 600 kips and finally locked off at a nominal load of 50 kips. This is by far, a record for the largest number of full-scale pile load tests ever done on one site. No lifting of the core was attempted since floors were being leveled continuously during construction and attachment of the adjacent structures.

To accommodate this forest of attachments, a sub-basement was created below a new steel framed deck and floor at the lower entrance/baggage level of the hotel. All the utilities were restored and snaked through the new sub-basement.



**Overhead
View of Pile
Attachment
Frames**

SUMMARY:

As discussed in the drilling section of the paper, perhaps one major innovation of this project was introduced that allowed the rapid installation of very high capacity piles to act as both ground reinforcement and individual structural supports. Geotechnically, due to the full length bonding, the piles served to slow the rate of ground movement prior to their final attachment to the structure.

The major construction feat was the installation of about 110,00 lineal feet of high capacity piles in a very small plan area, with only about 20 feet of overhead clearance, all in about 2-1/2 months. All of the 536 load tests and attachment frames were completed only about 4 weeks after the last pile was

drilled, at which time the nominal load of 50 kips was applied to all the piles. This entire time, crews worked together in one space performing concrete coring, Pin Pile drilling, frame installation, pile testing/jacking, installation and monitoring of instrumentation, installation of steel decking to form the floor above, and replacement of utilities that were diverted to accommodate the underpinning work.

Because of Nicholson's prompt and efficient response, underpinning of the resort prevented any significant structural damage. The building is performing very much to the satisfaction of the owner, and in fact, even with the all of the additional foundation underpinning work that had to be performed, the hotel opened on schedule in early March of 1999.

OVERALL SUMMARY

The use of Pin Piles for building foundations is rapidly expanding while the technology is refined by gaining higher working loads. As more experience is gained, and disseminated, their usage will become more common. Numerous and successful tests accompanied by major projects have been installed which demonstrate the viability of their use. As the building industry continues to grow, rehabilitate, and expand, the benefits of using Pin Piles will be further realized.

ACKNOWLEDGMENTS

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