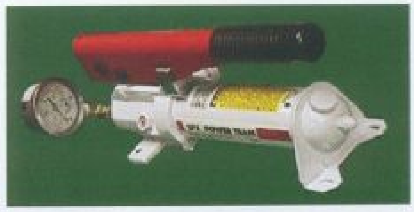
*New School Tricks*

# AN OVERVIEW OF NEW TECHNOLOGIES IN PILE DRIVING



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This article highlights some of the most notable advances in driven pile technology over the last decade. Specific topics include the use of pile foundations for heating and cooling, advances in quality assurance and quality control, and new developments in testing and installation equipment. New strategies for dealing with environmental concerns, such as noise and vibration, are also discussed, including a new concept referred to as "intelligent pile-driving" whereby the hammer energy can be automatically controlled based on measured sound, vibration and pile stresses. Other new technologies and trends in piling equipment will also be discussed.

## USE OF DRIVEN PILES FOR HEATING AND COOLING

A relatively new addition to the list of advantages of driven piles is their potential use as a geothermal heating and cooling system. The features of geothermal systems are well known, but what is not well known is that pile foundations can be easily integrated into a geothermal heating and cooling system. In fact, under the right circumstances a building's pile foundations can provide 100 per cent of that building's heating and cooling needs. Using the pile foundations as the interface with the ground greatly reduces the payback period for the geothermal system. These types of systems have been in use in Central and Western Europe for more than 20 years, but have only recently appeared in North America. Circulating pipes for the geothermal system can be pre-installed in either pre-cast concrete piles or installed after driving in closed-end pipe piles. These types of piles are sometimes called "absorber piles" or "energy piles".

## NEW TOOLS FOR QUALITY

In pile driving, 'QA' and 'QC' typically consist of pile installation records that log the number of blows per unit of penetration, and the final tip elevation for each pile. Very often, however, the performance of the pile hammer is not logged on the pile installation record, or more disturbing, the pile hammer may appear to be operating at the desired impact energy, while in fact it is not. This can lead to a potentially dangerous situation, whereby piles are believed to have more capacity than they actually do.

Historically, the most common problem with diesel hammers has been the phenomenon of "pre-ignition". Pre-ignition occurs when the hammer becomes very hot and combustion begins prior to the impact of the ram. Unfortunately, a diesel hammer that is experiencing pre-ignition may not show any visible signs of a problem. The combustion pressure may still be sufficient to "run" the hammer with the desired stroke, yet the impact energy may be reduced because of the increased gas pressure beneath the falling ram prior to impact.

Diesel hammers that operate using a fuel injection system do not experience pre-ignition. This can be verified using an instrumentation port that allows for monitoring the impact velocity of the ram using magnetic proximity switches. Typically, two proximity switches located on the body of the hammer sense the position of a particular machined "feature" of the ram. Knowing the distance between these two proximity switches and the difference in time between switching signals the velocity of the ram just prior to impact can be calculated. Testing has shown that fuel injected hammers do not experience a loss in impact velocity as the hammer temperature increases.

Further development of the velocity monitoring system included the addition of other features for greater QA and QC in pile driving. In 1990, a device was introduced called a Pile Driving Monitor (PDM) that included a depth logger and blow counter, calculated impacf energy, pile number, cut-off elevation, date, time, project name, splice location,and various other pertinent information. Early versions of these energy monitoring devices included on-board printers for record-keeping, but these have been replaced with newer PDMs that include USB ports for connection to a computer or direct connection to a USB memory key for downloading of data.

On modern construction sites there is a new emphasis on quality assurance and quality control. In pile driving, 'QA' and 'QC' typically consist of pile installation records that log the number of blows per unit of penetration, and the final tip elevation for each pile. Very often, however, the performance of the pile hammer is not logged on the pile installation record, or more disturbing, the pile hammer may appear to be operating at the desired impact energy, while in fact it is not. This can lead to a potentially dangerous situation, whereby piles are believed to have more capacity than they actually do.

This innovation has lead to further development of the velocity monitoring system to include other features for greater QA and QC in pile driving. In 1990, a device was introduced called a Pile Driving Monitor (PDM) that included a depth logger and blow counter, calculated impact energy, pile number, cut-off elevation, date, time, project name, splice location, and various other pertinent information. The unit also had a small printer for a hard-copy of the electronic pile driving log. Updated versions of the PDM are seeing increased usage in the U.S. market, although the printer has been replaced by internal flash-memory, downloadable to a computer.

## INTELLIGENT PILE DRIVING

Developments on the horizon for driven piles include "intelligent" pile driving, whereby the hammer energy is controlled in real-time by any number of measured variables, such as measured vibration, measured sound levels, or any number of parameters coming from dynamic testing equipment such as pile stress (tension or compression) or required capacity. Prototypes exist for this type of system and should be on the market within the next few years.

The next logical step in the advancement of technology for diesel hammers was the invention of a hammer energy control system. By combining the functions of the PDM and the remote hydraulic throttle and adding basic control-system programming, the first ever diesel hammer energy control system was created (ECS).

The ECS contains a small hydraulic accumulator that provides a source of hydraulic flow to operate the throttle. The accumulator is "pumped-up" at the beginning of the day, and stores enough oil to operate the system for several hours, depending on the amount of "throttling" the system performs. The control box houses the programming and provides the control for two electronically activated valves that either let more oil into the throttle line (for more hammer energy), or release oil to a tank (to decrease the hammer energy).

Using the ECS requires no modifications to the diesel hammer and requires no additional control lines going to the hammer. The ECS simply makes use of the existing hydraulic throttle line in combination with the cable carrying the data from the proximity switches.

The control box operates on either 120-V AC, or 12-V battery power. The ECS allows the user to set an allowable maximum impact energy – this could be determined by a test pile with PDA testing, or determined theoretically. The ECS also allows the user to select a target impact energy for the hammer to operate at and automatically tries to achieve that energy regardless of the driving resistance (of course the preset energy is not always attainable, especially near the beginning of driving or at other times when the driving is "soft").

The ECS used on the following project represents the first attempt (known to this author) to automate the operation of a diesel pile driving hammer.

## ADDRESSING ENVIRONMENTAL CONCERNS AND ADVANCES IN EQUIPMENT

A broad view of foundation equipment market over the last 10-years in North America shows a strong European influence. While North American foundation contractors have traditionally opted for crane-mounted equipment, recent trends show a clear infiltration of European-made foundation 'rigs' with fixed leaders and operating specifications geared specifically for foundation construction. High torque and high 'pull-out' capabilities driven by a more competitive foundation market make these dedicated foundation rigs an attractive option for foundation contractors. Manufacturers of these rigs have experienced an extremely high global demand for their products, which has resulted in high prices and long deliveries for contractors wishing to make the investment. Part of the attraction to these rigs comes from their ability to perform several different foundation functions. For instance, a typical foundation rig might be capable of installing drilled shafts, augercast piles, sheet piles or performing other foundation applications such as soil mixing.

The penetration of dedicated foundation rigs into the North American market has not gone unnoticed by crane manufacturers. Several large crane manufactures have developed what are called "duty-cycle" cranes that are better suited to foundation applications. Some crane manufactures have always had these cranes while others have designed new crane models geared specifically toward the foundation market. The European-style foundation rigs have a very strong presence in the drilling market, but in the overall foundation market crane-mounted foundation equipment still holds the largest market-share in North America.

Another broad development in the industry is the advent of instrumentation and computerized monitoring systems. With these systems, the overall quality control and quality assurance in foundations has greatly improved. While most dedicated foundation rigs come equipped with a computer-system for monitoring and recording relevant construction parameters (such as depth, verticality, concrete volume, torque, etc...), there is also a strong demand for "after-market" instrumentation packages for retrofitting older foundation rigs or crane-mounted foundation equipment. Of course once this data is recorded it can be easily moved to a computer in the job-site trailer and included in detailed quality reports that would have been impossible just a decade ago.

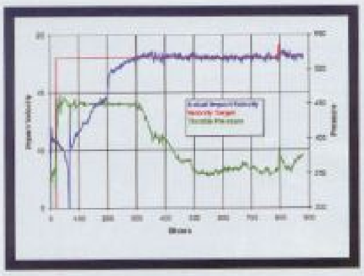
## ADVANCES IN VIBRATORY HAMMERS

Like drills, vibratory pile-driving hammers have also increased in size. While the specifications of some of the newer, larger hammers are impressive, more notable is the advent of a new type of vibratory hammer called a "variable-eccentric moment" hammer. This new type of vibratory hammer allows the driving amplitude of the hammer to be adjusted independently of the rotational speed of the eccentric masses inside the hammer. This means that the hammer can be started and stopped without passing through any resonant frequencies of the crane-boom that typically produces a short occurrence of violent shaking. More importantly, because these new types of vibratory hammers can control their amplitude and frequency, they can control the amount of vibrations felt at adjacent structures. These new variable-moment hammers have extended the use of vibratory hammers into areas where normal vibratory hammers would have been forbidden.

Another area to watch in the development of vibratory hammers is the advent of a new sonic or resonant-frequency vibratory hammer. While not on the market yet, there is a good chance this new technology will start appearing in the next few years.

## ADVANCES IN DRIVEN PILING EQUIPMENT

This reliable old foundation type has also benefitted from recent equipment developments. Much like drilling equipment, there is a clear European influence in the driven pile equipment market. The



main shift in the last decade has been towards hydraulic hammers and away from diesel and air hammers. The main attractions of the hydraulic hammer are improved controllability and performance monitoring. Most European-made hydraulic hammers introduced to North America in the last decade come equipped with performance monitoring built-in to the hydraulic power unit that runs the hammer, or the foundation "rig" that the hammer is mounted on. This monitoring system allows engineers to verify that the hammer is producing the required amount of impact energy. Also, unlike a diesel hammer, the energy (or stroke) of a hydraulic hammer can be controlled independently of the pile and soil resistance. This improved controllability is thought to provide an advantage when driving concrete piles that are prone to break in tension if struck too hard. With increasing steel costs and a greater shift to concrete piles, combined with improved systems for "splicing" concrete piles, hydraulic hammers have captured significant market share in the last decade.

Although dedicated piling rigs are common in Europe, their penetration into the driven pile market has been much slower than their penetration into the drilling market. Although the hydraulic hammers have made a significant impact in North American, the driven pile market is still dominated by the hanging or swinging lead and the diesel hammer. Some factors that have kept the diesel hammer alive-and-well in North America have been advances in the use of bio-fuels and oils, as well as cleaner-burning diesel hammers and diesel hammers with built-in performance monitoring. Of course, the biggest factor affecting a contractor's choice of hammer is the capital cost, and the main contributor to the continued presence of the diesel hammer has been the shift to low-cost Chinese-made diesel hammers.

Sound mitigation remains the driven-pile's main area for improvement and several hammer manufactures have taken-up the challenge. Some hammer manufacturers have developed very effective sound enclosures for their hammers that can greatly reduce the measured sound levels. Look for this topic to appear in future developments in driven pile equipment.

Probably the most significant change to the way piles are driven over the last ten years has not been with the installation equipment, but rather the monitoring equipment. Dynamic pile testing methods are now universally accepted. Using this method, pile capacity can be estimated and driving stresses measured. This equipment has greatly improved the quality assurance of the driven pile, and is now available with wireless and even "remote" operation. Even when dynamic testing is not performed, new tools such as acoustic blow-counters and hammer energy monitors all serve to improve the overall quality of the driven pile. New developments using embedded strain gages and accelerometers in concrete piles that transmit wireles signals to data collection devices using Blue-toothTM technology are already in use in some states.

## ADVANCES IN PILE POSITIONING

Another new development in foundation equipment has been the use of GPS or other land-based positioning systems for locating foundations. Sensors on the booms of cranes, masts of foundation rigs, or the tops of leads have now been used to assist in the positioning of foundation elements. In its simplest form, this advancement allows the crane or rig operation to position the foundation according to the specified coordinates thereby minimizing cost of survey staking and the inevitable re-staking. In some cases, such as in marine pile-driving, this new feature can even eliminate the need for a costly positioning "template". Lead and pile positioning systems are sure to gain popularity over the next few years, with some systems even promising to automate the positioning process.

## ADVANCES IN FOUNDATION TESTING

In addition to the increase in popularity of dynamic pile testing (used primarily for driven piles), techniques for determining the integrity of cast-in-place piles have also become more widely used. Sonic-based integrity testing using a small impact event on the pile top, as well as cross-hole sonic logging using embedded tubes in drilled shafts have added greatly to the quality assurance of cast-in-place piles.

Most dramatic in the field of testing has been the proliferation of large capacity load testing using an embedded hydraulic jack in the toe of a pile, called an Osterberg Cell or O-Cell. The largest such test on a drilled shafts now exceeds 31,000 tons and the largest test on an augercast pile now exceeds 5,200 tons. This technology has allowed the design-loads of foundations to increase to previously unheard of levels, going hand-in-hand with developments in rigs and drills.

Another technology that has made a large impact in the last decade has been a type of force-pulse load test called Statnamic. Like the O-Cell, Statnamic is capable of applying large test loads to foundations – the largest Statnamic test to date is 5,000 tons.

Drop-weight testing devices have also been used on drilled shafts producing large test loads using technology similar to what is more typically used on driven piles.

Overall, these advances in testing methods have allowed designers to continue pushing the limits of the ever-increasing capabilities of the drilling and driving equipment.

## SUMMARY

Taken as a whole these equipment improvements or developments have recreated an industry which is populated with machines which are faster, safer, and easier to physically operate. The product is more predictable than ever before, which means that it is of higher quality.

The challenge brought on by these innovations is that the skill and knowledge level required in the field to properly operate and manage these innovations is higher than it has ever been before and has brought on the necessity for in depth training of personnel. While the resources and knowledge are available, the concern is that those involved in these industries must recognize the importance of the necessity of upgrading of personnel. ■