ADVANCES IN DYNAMIC FOUNDATION TESTING TECHNOLOGY

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ABSTRACT

While dynamic pile testing is not new, and is included in many worldwide codes and specifications, dramatic changes from traditional testing methods and common practice have occurred in recent years. Traditionally, the sensors send their signals through a cable to the data acquisition equipment. Experience has shown that some poor data is caused by damage to these cables. New equipment now transmits sensor data from the pile wirelessly to receiving antennas on the data collection equipment. "Wireless" technology eliminates the cables and improves data quality. Sensors which remember their calibration sensitivity and transmit that information eliminate another common problem in data quality, namely having the wrong calibration assigned. Methods of protecting the sensors during installation allow attaching sensors prior to lifting the pile into the hammer leads, and hence speeding up the testing process, and promote safety. The most radical change in the data acquisition process is "remote" dynamic testing, which has revolutionized dynamic testing in some parts of the world. In remote testing, the data acquisition equipment is operated on site by an inspector or the pile crew, and sends the data over the internet to the test engineer in his office. Wireless and remote procedures are described and example experiences indicate the benefits, and areas of caution, of the new technology.

INTRODUCTION

Dynamic pile testing is not new. The original research began over 50 years ago at Case Western Reserve University (Eiber, 1958). Dynamic testing with the Pile

Driving Analyzer® (Analyzer) is included in many worldwide codes and specifications (Beim, 2008), so it is now routine standard practice. In fact, the Analyzer has become the most common measurement tool for assessing deep foundation performance.

For the first few decades, the routine dynamic test consisted of the engineer arriving on site with the test equipment, attaching the sensors to the pile and entering sensor calibrations and pile properties into the Analyzer. Upon hammer impact, the signals from the sensors were sent via a cable to the Analyzer. The engineer evaluated data on site blow by blow in real time by the Case Method. After field tests, critical data from end of drive or restrike was analyzed by CAPWAP® signal matching to obtain ultimate capacity, resistance distribution, and damping constants.

NEW POSSIBILITIES

Continual improvement in communication electronics has allowed alternate modes of operation that provide distinct advantages.

Data quality is of primary importance. Calibration of the sensors is obviously critical since the derived result is directly affected by signal sensitivity. There is an industry trend for the sensor to know and transmit its sensitivity to the parent data collection system using memory chips now installed in the sensors. Automatic detection of unusual signals further warns the engineer of suspect data quality.

Experience has shown that sometimes the cause of poor data is damage to or fatigue of the cables transmitting the signal from the pile to the Analyzer. The system can be equipped for "wireless" Bluetooth data transmission (Figure 1, 2), eliminating the main signal transmission cable entirely. A small battery powered transmitter transmits the data to the receiving Analyzer, located up to 100 meters from the pile.

FIG. 1. Wireless sensors and transmitter.

FIG.2. Wireless Analyzer in operation.

The sensors and transmitters can be protected by hard foam pads, allowing instrumentation to be attached to the pile on the ground prior to lifting the pile into the leads. For full length pile monitoring, this reduces testing time and improves safety because climbing the leads to attach the sensors is eliminated.

Wireless technology can send data from the jobsite to any worldwide destination using the internet. "Remote" testing was conceived and first enabled over 10 years ago through serial data transmission on TAPI cell phone systems (Gravare 2000).

In remote testing, the equipment is on site with the pile crew and a neutral observer to answer any questions from the test engineer. The sensors are attached to the pile by the pile crew, who already often attach the sensors even when the test engineer is on site. During remote testing, the test engineer may be anywhere in the world, but typically is in his office location, usually hours from the jobsite. Connection was made from the site equipment to the engineer's office computer. Data was then sent serially, although typically slow transmission rates resulted in a real time sample of about every sixth blow in continuous operation, or a short delay in time if a limited number of restrike blows were requested. Since every blow was captured by the Analyzer, all data could later be retrieved when requested.

Recently, the Analyzer has adapted to transmit data through cell phones equipped to access the internet. Through internet communications, the system is now able to achieve a significantly higher speed of data transfer; typically every second or third blow can be sent in real time, and perhaps every blow in the near future.

BENEFITS FROM CHANGE IN PRACTICE

Compared with having the test engineer on site, what real advantages are achieved with this "new technology"? Will the test produce the same quality measurements as with traditional on-site testing? Assuming all parties are willing to step out of their "comfort zone", how is the new technology best implemented?

Consider that if the engineer did not need travel time to return from the site to the office, the engineer could instead immediately begin data analysis (e.g. CAPWAP) and write the report sooner. Getting the results sooner can be vital to the project since this information is often on the project's critical path. The installation criterion can be established sooner and production piles then installed with confidence.

In traditional on-site testing, the test is scheduled conveniently for both contractor and tester. Often the test engineer is not available for last minute requests or "emergencies" (e.g. pile obtains a different blow count or vastly different penetration than expected). If the remote equipment is already on the site, a quick call to the test engineer is all that is needed to test and resolve the current crisis. Testing costs are known which allows more accurate budgeting.

Tests which involve installation testing followed by restrikes after several days wait time (or multiple tests) to observe the ultimate capacity with time, or to observe hammer consistency, can be easily scheduled at the contractor's convenience. For example, the engineer may test on-site for the initial installation, but leave the equipment on site for several days to allow for set-up and then perform a restrike test in a remote mode. The end result is a better design with more complete testing, thus reducing risk, and possible significant foundation savings.

Although the above justifications are often more compelling reasons to implement this new technology, traditional on-site testing generates significant travel time charges and travel time costs. Further, much of the engineer's time on site is actually spent waiting for something to happen. The direct engineering time of collecting data is often a small percentage of time billed, particularly for restrike tests. At some sites, extra training for safety required to enter the jobsite can be eliminated with remote testing. By eliminating all travel time and all travel costs, and eliminating all on-site non-testing time, the actual cost of the test is significantly reduced.

From the engineer's view, travel to site can be greatly reduced, and in many cases eliminated. Remote technology allows the test engineer to efficiently test piles from multiple jobsites, even from multiple countries, during the same day. Since there is an increasing concern for quality of testing (Seidel, 2000), access to the more experienced testers can be improved.

These reasons all help to keep the project on schedule and under budget. So how is remote technology best initially implemented? On larger projects, the tester might come to the site at the beginning (and train the crew to attach the sensors to the pile, if needed), but leave the equipment on site for later restrike tests. After developing sufficient confidence, future tests may be performed remotely. An independent on-site observer, usually already present to collect a driving record or assure the installation criterion has been met, can be the test engineer's eyes and ears. The test engineer in the office sees the same data, and can easily assess data quality from his office. If there is a problem with data quality, the test engineer simply instructs the site personnel to address the attachment of the problem sensor, and repeat the test. The engineer can transmit his findings instantaneously during the testing to the site, and even direct when the pile driving may be terminated.

Swedish Experience

High strain dynamic tests on driven piles have been routinely carried out in Sweden for approximately 30 years (Gravare 2004). Most pile tests are carried out during redriving to evaluate the bearing capacity including time-dependent set-up effects. The long distances in Sweden cause several hours of traveling for typically less than one hour of testing, such as testing three piles in a bridge abutment.

Since the first remote test 10 years ago in Sweden, the transition to remote testing has been fast and nowadays most tests in Sweden are remote tests. Altogether 13 remote units are currently operated in Sweden (Fig. 3). To receive data from up to 10 sites per day, a team of four consulting engineers operates a network of six computers connected to the remote units via modem or internet connection. The network allows quick movement between different sites in busy situations. Multiple engineers can immediately review difficult to interpret data and reach a fast judgment. The new remote unit with internet transmission allows monitoring during driving.

Properly attaching the transducers to the pile is essential for good data quality. Even though many Swedish piling crews are familiar with attaching sensors, it is still important to study data quality of each transducer individually. The force transducers particularly require correct attachment. The most common problem, incorrect spacing between the attachment holes, stretches the strain transducer beyond its balancing

range. The experienced site crew will notice field equipment then displays "Not Available" and drill new holes before starting testing. The balancing status can be viewed by the remote engineer, and adjustments made if required, prior to testing. For concrete piles, if attachment bolts are too long they bottom out on the anchors rather than bearing on the transducer. This is not always discovered on site as the crew experiences they have tightened the bolts as much as possible. This problem is easily detected in the office by the transmitted vibrating signal. Accelerometers not properly oriented parallel to the pile axis result in poor force-velocity proportionality.

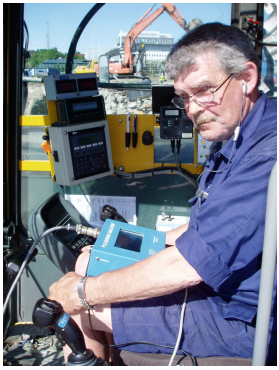

FIG.3. Remote tests in Sweden

To prevent the same pile being tested over and over again (with different pile numbers sent to the engineer), the engineer can inspect the strain transducer balancing which should change when moved from pile to pile and, of course, look at the data itself to see if it is identical to the trace of that just previously tested. During many past years of remote testing this has not been a big problem.

As mentioned above, the remote testing saves travel time that can be used for evaluating and reporting. In a very urgent situation, remote testing, CAPWAP analysis and report writing were carried out simultaneously (by three engineers on three piles) and the client received the results shortly after the test was finished.

UK Experience

Dynamic pile testing has been carried out in the UK since 1979. Initially testing was carried out mainly on driven precast concrete piles with some testing of driven steel tubular and H-piles. As experience grew, dynamic load testing was carried out to cast in place piles and steel sheet piles. In the early years, reliable dynamic load testing required highly trained engineers to travel to site to carry out the testing and physically transport the test data to the office for CAPWAP analysis. This analysis and subsequent report would often be carried out some days after the site testing.

In the late 1990's the advent of the first remote Analyzer presented an opportunity for a step change in the method of working, while still ensuring the highest quality of

test data, essential to valid data analysis by CAPWAP. This remote equipment was quickly adopted in the UK as soon as it was available. The ability of the remote Analyzer to transmit data from site, during testing, and for an office based expert to assess the data and carry out immediate CAPWAP analysis has many advantages. Today the client can now expect almost immediate test results and same day reporting.

Quality is a key issue in any test and dynamic load testing by the remote system allows the expert control of all aspects of the test. The expert sends commands to the remote equipment to control its operation as if he were on site. The expert sees the data from each sensor to assess the data quality (and if anything is amiss, then can instruct the field crew to address and correct the problem prior to completing the test). This expert control of all testing is a key aspect of quality control.

The UK is a geographically small area. Remote pile testing equipment based with centrally and regionally based testing technicians can service sites in the UK more efficiently than moving the equipment from site to site by courier. The use of a dedicated trained technician rather than client supplied operatives ensures consistency of test data and rapid testing with no site delays. It is possible to test 10 piles per hour.

Today in the UK the use of the remote equipment allows clients to have UKAS accredited dynamic load testing carried out by locally based testing technicians supported real-time by office based expert engineers. This delivers a fast reliable service demanded in modern UK construction.

Australian Experience - Contractor View

High strain dynamic testing has become a routine part of the quality assurance process for foundations in Australia since 1983. Today, except for small projects, 5 to 10% of all driven piles are dynamically tested. Remote dynamic testing has been in regular use in Australia since 2001.

The introduction of the remote system has provided substantial cost savings for many projects located more than 1000 km from the nearest office of the testing engineer, requiring many hours of travel to and from the site. The reduction in testing costs have been substantial (by up to 75%) where intermittent testing has been required, with one of the most significant savings being associated with the reduction in “down time” by the site crews waiting for the engineer to arrive on site after a special or additional test has been required. In some isolated project sites, the down time waiting for a traditional on-site test has been almost 24 hours. Where remote testing can be utilized, this down time can be eliminated. Not only are there time savings, but the ‘hidden’ costs of the safety of the engineer traveling long distances to isolated project sites cannot be under estimated. Additional cost savings can also be associated with the elimination of on-site safety instructions for the testing engineer, which in some circumstances for mining sites can be more than one day.

The early remote systems relied on the mobile phone network with relatively slow data transfer. Monitoring of the pile driving during installation was less than ideal as every 7th or 8th blow would only be received by the remote computer in real time. Therefore, many driving tests required the testing engineer on site and only the

subsequent restrike tests were completed in remote mode (in restrike mode, every blow is sent sequentially). However, the recent introduction of the high speed internet broadband communications allows all blows to be received in real time, creating no disadvantage for remote testing during initial driving.

Many piling Supervisors are very familiar with the processes required for collecting dynamic test data. Sensor attachment, cable connections and data communications set-up are routine. However, the successful completion of the remote test requires clear communication between the field staff and the testing engineer in the office. Firstly, the testing engineer needs to be familiar with the remote testing equipment to problem-solve any issues that may arise, particularly for field personnel unfamiliar with the process. Secondly, the testing engineer must have sufficient experience with piling to ask appropriate questions of the field staff to gather all relevant information about the pile being tested.

With the remote testing engineer usually located in an office environment, other more experienced engineers are usually on hand to provide assistance and advice where required, providing quick assessments of piling test data on the critical path.

Australian Experience – Consultant View

Independent consulting using dynamic pile testing operated by Australians first began in Australia in 1984. Projects were conducted with the operator on-site all over Australia and in many South East Asia and Oceania countries. Independent testing in Australia is mostly in ports and bridges and other heavy civil infrastructure with most projects now funded by the booming mining sector of the economy.

Remote testing is a method particularly adapted to Australia's vast distances and low population density. Independent consulting jobs tend to be in remote locations far from home base. Remote systems were readily accepted owing to low mobilization cost, speed of response owing to low/no travel time, convenience of having the remote equipment available full-time on site for unscheduled use, and low cost to postpone tests while problems with the piling system are being resolved. The most common solution on large remote projects is to station the remote equipment on site for the duration of piling, often now required under the project specification. Having the operator on site is now unusual and only necessary if there is no phone system available.

Each Analyzer system is equipped with some minimum spare sensors. Multiple remote units can be serviced by one test engineer. Simultaneous testing is not common, but can be accomplished with multiple receiving stations at the test engineer's office. Data can be received during off hours by unattended computers. The number of remote units operated by the sole operator, currently 7 units by this consultant, is only limited by the available time to analyze data and timely report the results.

Although many piling contractors and deep foundation engineers know dynamic test methods, a step by step, button by button, guide is provided for field personnel unfamiliar with remote testing because there are still frequent new engineers in the Contractor's staff. When talking to people on site, it must be assumed they have very low knowledge of the Analyzer system. Patience and consideration are essential.

Data is received on a notebook computer. Thus even a sole operator can receive data at almost any time and location. The test engineer can be measuring data on one site while at the same time receiving separate data on the notebook from another location on the other side of the country. Frequently data is received in airport facilities, while in transit stopped by the side of the road, and even in a moving taxi.

New fast internet-based remote systems, in parallel with new advanced 3G mobile phones for non-internet based systems, provide very fast and relatively stable transfer of data, but they require some knowledge of windows-based pc's by the user and require stepping through more menus by the user.

SUMMARY

The new Analyzer technology can improve dynamic testing practices and result in even better quality assurance and lower risk for deep foundations. Wireless data transmission from the pile to the Analyzer improves data quality, and improves safety on site. When remote Analyzer equipment is already on site, piles can be immediately tested should problems arise. Data can be sent remotely using modern cell phones and the internet from the pile crew to the test engineer, typically in his office, allowing for better scheduling of testing, a more efficient use of engineer time, and considerably reduced testing costs and reduced scheduling difficulties. Good communication with the site and careful review of data are required to assure reliable results. Eliminating the travel time, analysis of the data can then proceed immediately, resulting in faster reporting of results, keeping installation of production piles on schedule. Different operational experience is observed in remote testing, depending on the geography and position of the tester.

REFERENCES

Beim, G., and Likins, G., (2008), « Worldwide dynamic foundation testing codes and standards", *Proc. Of the 8th Int'l Conf. on the Application of Stresswave Theory to Piles*, MillPress, Lisbon, Portugal

Eiber, R.J., (1958), "A Preliminary Laboratory Investigation of the Prediction of Static Pile Resistances in Sand", *Master's Thesis, Dept. of Civil Engineering, Case Institute of Technology*, Cleveland Ohio.

Gravare, C-J.,Hermansson, I., Gravare, M. (2004), "Swedish Practice for Verification of Pile Bearing Capacity", *Proc. Of the 7th Int'l Conf. on the Application of Stresswave Theory to Piles,* Geotechnical Division of Institution of Engineers Malaysia, Kuala Lumpur, Malaysia

Seidel, J. (2000), "The need for quality assurance in the dynamic pile testing industry", *Proc. Of the 6th Int'l Conf. on the Application of Stresswave Theory to Piles,* Balkema, Sao Paulo, Brazil