Introduction by John Dunnicliff, Editor

This is the seventy-sixth episode of GIN. One article this time, and also a discussion of a previous article, together with the authors' replies.

Costa Concordia—watch this space!

It was described by the media in England as "An absolutely sensational engineering spectacle" and "A monumental feat of engineering". The righting of the Italian cruise ship Costa Concordia—"The Parbuckling Project" (www.theparbucklingproject.com) - see the video "The Parbuckling phase in 90 seconds". Unless you've been on the moon during the last few months, you'll know about this. I have a promise of an article in GIN that will describe the measurements used to control the rotation.

Continuing education courses

In the previous GIN I said that there will be no more of these courses in Florida, but perhaps elsewhere. Plans are now well underway to start a new series in beautiful Tuscany, Italy, on June 4-6, 2014. By the time you read this, the website should be up and running: *www.geotechnicalmonitoring.com*. In addition to the content of the Florida courses, there will be substantial content on remote methods for monitoring deformation—my Italian colleagues are experts at this. There will also be six sessions on case histories and lessons learned. Additional information is on page 35.

Come and join us in the 13th century castle! The wine is good, too!

Graduate level course on instrumentation in New Orleans

The Civil and Environmental Engineering department at the University of New Orleans offers a graduate-level course on geotechnical instrumentation. The course includes:

- Soil and rock behavior
- Soil properties affecting geotechnical instrumentation
- Field monitoring principles
- Systematic approach to geotechnical instrumentation
- Review of geotechnical instrumentation hardware
- Theory and field measurement of deformation, groundwater pressure, stresses, load and strain
- Application of geotechnical instrumentation to real projects
- Advancement in remote monitoring and automatic data acquisition
- Case studies related to geotechnical instrumentation and field performance monitoring.

For more information, please contact: Malay Ghose Hajra, Assistant Professor at The University of New Orleans, tel. 504-280-7062, e-mail: mghoseha@uno.edu.

Out-of-state students can take the course online, and should contact Malay Ghose Haria for the arrangements.

Closure

Please send contributions to this column, or an abstract of an article for GIN, to me as an e-mail attachment in MSWord, to john@dunnicliff.eclipse.co.uk, or by mail: Little Leat, Whisselwell, Bovey Tracey, Devon TQ13 9LA, England. Tel. +44-1626-832919.

De hoje á um ano, com todos juntos e com boa saude! – "This day next year, with everyone together and in good health" (Portugal – yes, I know that I'm missing an accent in 'saude' – blame the symbols menu on my computer!)

A Reusable Instrumented Test Pile for Improved Pile Design

Jason DeJong, Aravinthan Thurairajah, and Mason Ghafghazi

Abstract

Accuracy in estimating driven pile capacity at a project site is limited due to an inability to capture the full complexity of the soil deposit, soil properties, pile drivability, dynamic soil/pile interaction, and pile setup. These potential errors/uncertainties are usually compensated for by using a safety factor. Development of an in situ testing device that replicates the anticipated construction conditions to the greatest extent possible and provides data to predict pile capacity at the design phase of a project would result in safety and economic benefits. This article presents an overview of a reusable instrumented test pile (RTP) being developed at the University of California Davis as an in situ testing device for improved pile design in granular soils. The RTP system consists of short instrumented sections that provide measurements of axial load, radial stress, pore pressure and acceleration, and are connected in series with standard Becker pipe

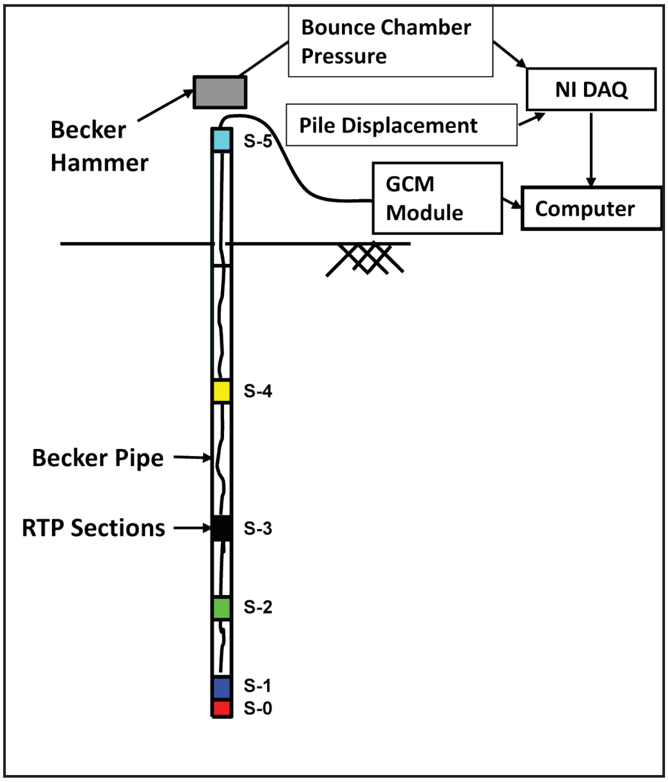

Figure 1. Schematic of RTP system.

Figure 2. RTP assembly.

sections. The RTP-Becker pipe string is driven using the standard Becker rig pile driving hammer. RTP measurements obtained during driving provide detailed information regarding pile drivability, measurements during static tests captures load transfer along the pile, and measurements during pile setup capture capacity gain over time.

Context and motivation

Improvement in prediction of driven pile capacity in granular soil is currently limited due to the factors of inability to capture the full complexity of soil deposits and its engineering behavior with available sampling and testing techniques, and inability to accurately model the soil/pile interaction during the pile driving process. In practice, these uncertainties are addressed using a large safety factor, typically ranging from 2 to 4. Furthermore, unexpected stratigraphic conditions can impact pile drivability resulting in costly change orders. The RTP is being developed to remove some of this uncertainty. The RTP will be deployed during initial site investigation, and all measurements obtained available during project bidding. Ideally this would enable engineers and contractors to increase the efficiency of pile design and the likelihood of arriving on site with the correct pile and installation equipment.

Removable test pile

The design of the RTP system was guided by the following primary factors:

- Mobility,
- Commercial integration,
- Durability and robustness,
- Measurement types,
- Measurement sensitivity and reliability,
- Measurement frequency and duration.

Of particular challenge, as evident in previous research, is development of a system that can withstand dynamic pile driving and that also has sufficient measurement resolution to detect small stress changes during pile setup.

The RTP system assembly is shown schematically in Figure 1 and photographs during testing are presented in Figures 2, 3 and 4. The central component is the modular instrumented pipe sections, which are 61 cm (2 ft) long with an outer diameter of 168 mm (6.625 in). Each instrumented section contains transducers for measurement of axial force, axial acceleration, pore pressure, and radial stress. The modular sections are assembled in series

Figure 3. RTP driving.

Figure 4. Load testing.

with standard 152 cm (5 ft) and 305 cm (10 ft) long Becker pipes, enabling positioning of the instrumented sections in the drill string at target final elevations required by project-specific soil stratigraphy. Installation is achieved using the conventional Becker drilling system that is equipped with an International Construction Equipment (ICE) Model 180 double-acting diesel hammer. Down-hole data acquisition units (computer modules manufactured by GeoDaq, Inc.) in each RTP section provides signal conditioning (sensor excitation, gain, and filtering), digitizes and buffers the signals, and transmits the data serially (i.e. through additional computer modules in line) to the control unit above ground (labeled GCM in Figure 1). The digital transmission results in only a single 4-wire cable running along the RTP connecting all instrumented modules to the above ground computer. The above-ground computer controls which modules and sensors are connected and should be recorded, as well as the sampling rate and duration. A separate above-ground data acquisition system (based on National Instruments hardware; labeled NI-DAQ in Figure 1) collects data from displacement gages (string potentiometers) to measure vertical displacement of the

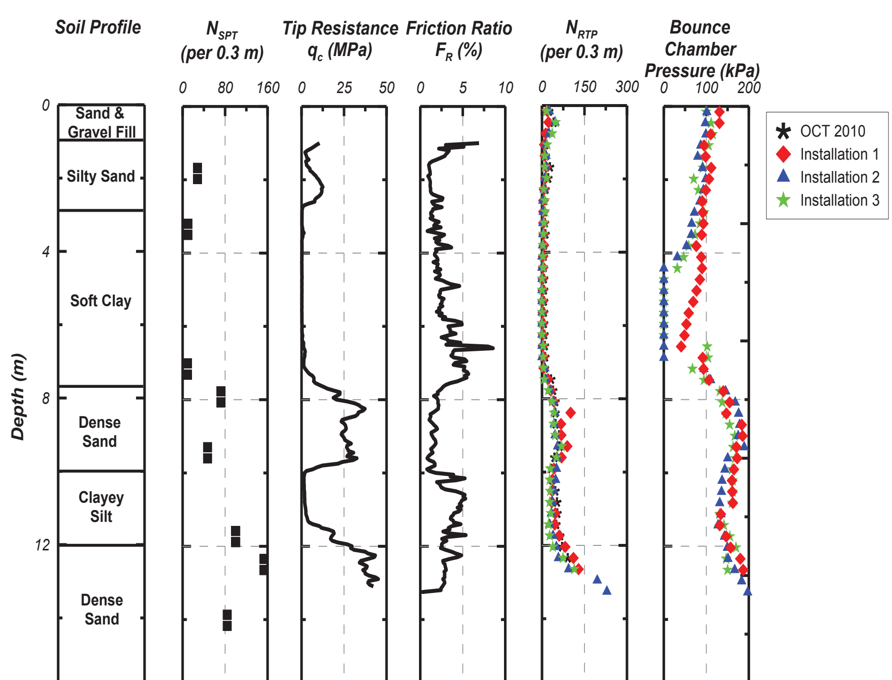

Figure 5. Site profile as well as resistance measurements from SPT, CPT and RTP systems.

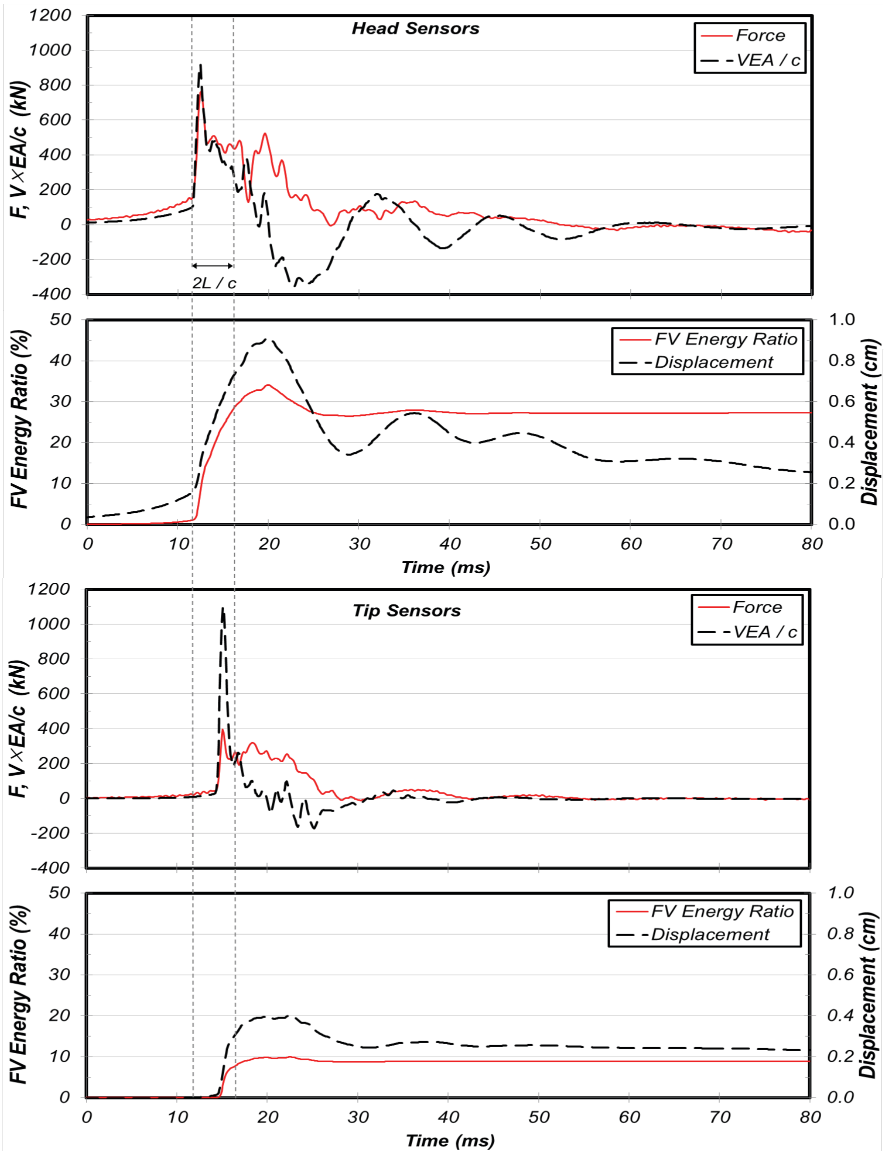

Figure 6. Representative measurements obtained during dynamic driving.

pile during driving and static loading testing. The modular nature of the RTP system and its integration with the Becker system enables testing down to 30 m to be completed in one day with limited time for pile setup.

Example results

A field test was carried out to evaluate the initial design and performance of the RTP sections. The field testing was performed at the Caltrans I-880 interchange site in Oakland, CA where the soil profile varies from soft clay to very dense sand. Figure 5 summarizes the soil variation with depth along with CPT tip resistance, CPT friction ratio, SPT N values, and RTP blow count values and bounce chamber pressure. As evident, the RTP hammer blows correlate well with SPT and CPT data.

RTP recording during dynamic driving provide insight into installation conditions, including forces, accelerations, energy, and displacements at all locations where the RTP modules are located. An example output from instrumented section position behind the tip and at the head of the drill string during hard driving through dense sand at a depth of 9.4 m is presented in Figure 6. The corresponding measured RTP blow counts were 89 for 0.3 m (1 ft) penetration. The force and velocity (multiplied by section impedance), as well as the displacement and energy time histories measured at head and tip sections is shown. The force-velocity proportionality is confirmed at the head section during the first *1L/c* interval with small deviations due to shaft resistance. The wave arrives at the tip section with an approximate *L/c* delay. As expected in hard driving conditions, a large negative velocity pulse returns at the head. There is a significant difference between the maximum displacement recorded and the residual displacement, showing the elastic compression of the pile during the impact. The maximum velocities measured at the head and tip are similar, while about 50% of the recorded force at the head arrives at the tip. Only a fraction of the energy measured at the head arrives at the tip. The residual displacements measured in the head and tip sections are close, providing more confidence in the accuracy of the measurements.

RTP tension load tests, with or without pile setup, provide insight into both overall capacity and the distribution of load along the pile length. Results from a tension load test performed after installation to 12.8 m and after 4 hours of pile setup are presented in Figure 7. The upper (light blue) curve corresponds to measurements above ground while the lower (dark blue) curve corresponds to axial force in the pile at 10 m depth. The displacement required to reach full pullout capacity occurred before 10 mm of displacement. The total tensile capacity of nearly 600 kN was observed to increase by 100 kN relative to an adjacent pile load test where no setup time occurred (not presented). About 50% of the tensile load was mobilized above 10 m depth, primarily due to the high shaft friction in the upper dense

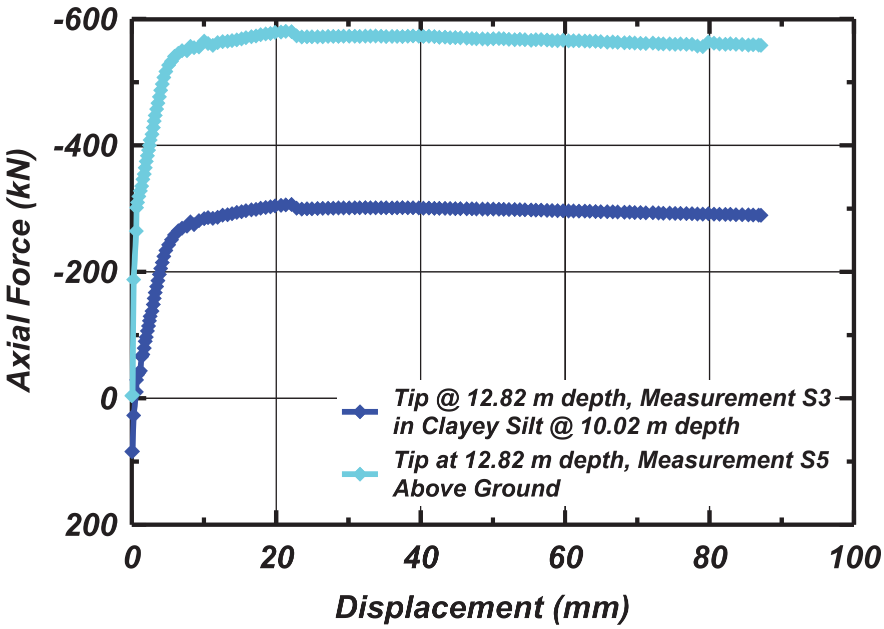

Figure 7. Representative load-displacement curve obtained from tensile load test.

sand layer between 7.6 and 9.9 m depth. The additional tensile capacity is primarily due to the lower dense sand layer.

Summary

A new reusable test pile (RTP) has been developed to improve the design of driven piles. The RTP measured blow counts generally agree with other in situ data. Dynamic measurements during driving provide insights into driving forces, energy propagation, and dynamic and permanent pile displacements. Static measurements during pile setup (not shown) and tension load tests provide insights into pile capacity and load distribution along the pile shaft. Further field testing at additional test sites where full scale pile load tests have been performed is underway.

Acknowledgements

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Discussion of: "Field monitoring challenges, Episode 2 Unforeseen movements (depth and magnitude)"

Marcelo Chuaqui and Wing Lam, Geotechnical News, Vol. 31 No. 2, June 2013

Storer J. Boone

The authors present a curious case related to the use of inclinometers and survey data for monitoring subsurface movements. The conclusions and data suggest that perhaps a few additional lessons could be learned if the authors are at liberty to answer a few questions provided below.

Lesson Learned 2

Lesson Learned 2 states that the field personnel did not understand that the inclinometers should be installed into a stable stratum at the bottom of the borehole. Fundamental to the stated communication problems may be training of the field people and the financial arrangements for the project and these issues prompt the following questions:

- Why were the selected field personnel installing the instruments if they did not understand their purpose and the associated critical need to install the bottom into a stable soil stratum?

- Were the budget and field plan fixed with no allowance for subsurface uncertainties?
- Was no sampling carried out during the drilling for inclinometer installation?
- Were the inclinometers only attached to piles that did not extend fully through the soft soils?
- Was the instrumentation part of a "low-bid-wins contract"? Were the least-costly personnel chosen for the work to meet a low-bid budget?

Authors' Reply

In response to Mr. Boone's questions we first have to emphasize that this was from the perspective of the instrumentation contractor. Typically, the field technicians are provided the depth to which the instrument will be installed such as a borehole inclinometer, or it is set in the case of an attached inclinometer to a pile. The field technicians were present for the installation of the instrument after drilling was completed and achieved that depth. Upon further review, the inclinometer was confirmed to be founded in stable ground at the correct depth; however, due to large horizontal deflections in the casing caused by the installation of adjacent drilled shafts, the inclinometer probe was not able to reach the bottom of the casing and the "zero" anchoring point was lost.

No sampling was done during the installation; however, independent sampling was done by the geotechnical engineer.

The work was of an emergency nature and there was a negotiated rate for the work and not a bidding process, so a low bid contract was not a factor. We concur that low bid is not the best route to a successful monitoring program.

The engineers designed the monitoring program with redundancy in mind, knowing that the combination of tight site access and difficult geotechnical conditions could result in damage to monitoring instruments. The team used the full complement of instrumentation to analyze the unusual inclinometer movements, therefore there was no reason to stop the job and add additional inclinometers.

Lesson Learned 3

Lesson Learned 3 states that innovative thinking was able to provide a solution whereby surveying was used to locate the horizontal position of the top of the inclinometer. While surveying of inclinometer tops can be useful to adapt to the situation the authors describe (and many others), accurately surveying horizontal positions is often far more difficult than commonly understood. Even with modern and highly precise surveying instruments, such measurements can vary by +/- 20 mm or more, reflecting the combination of instrument, skill level of some operators, set up, and sighting angles to reference points among other factors. With the right instruments, highly skilled operators and all other details carefully controlled the systematic variability in horizontal survey measurements can be reduced to +/- 3 mm or so. However, "the devil is in the details" and, unfortunately, details are often missed. The published sample inclinometer plot illustrates five virtually parallel lines of subsurface displacement data and they do not appear to indicate a discernible pattern, at least in comparison to the illustrated dates. For example, the first and last dates show the minimum and maximum displacements, respectively. The penultimate reading (#4), however, illustrates less displacement than the other two intervening reading dates (#2 and #3 in date order). Are the displacements real or might they be a figment of survey error? If the differences between individual and parallel inclinometer survey event plots are not figments of survey error, certainly there must be some other rational explanation for the changes.

Answers to these questions may provide additional valuable lessons learned. It would be very useful in a future episode for the authors to also illustrate how the other instrument data was used in combination with an understanding of the construction processes and soil mechanics to rationalize the measured displacements.

Authors' Reply

We agree that the type of instrument and skill of the operators is vital to achievement of accurate data. In our experience the survey measurements achieved are within ±1 mm with proper procedures in place. Of course there can always be bad readings and lessons learned from those experiences. In the inclinometer plot, the product was a sample created for the column. A re-zeroing of the survey data for the top of the inclinometer occurred that was not factored into the sample plot. In the actual reporting, minimal movement had occurred. Fortunately, these top-anchored inclinometer plots were supplemental data to the pile-attached inclinometers. Further research can be done in more controlled conditions rather than in emergency situations.

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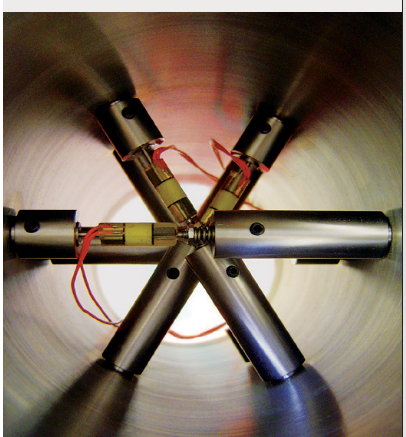

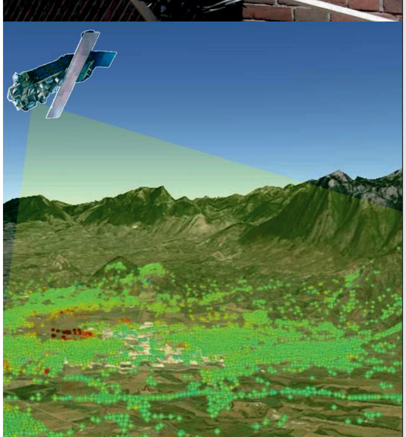

International Course on

Geotechnical and Structural Monitoring

June 4-6, 2014

“Castle of Poppi”, Tuscany (Italy)

Course Director: **John Dunnicliff**, Consulting Engineer

Organizer: **Paolo Mazzanti**, NHAZCA S.r.l.

NEW COURSE: This annual course in Italy replaces the long-standing series of continuing education courses in Florida. The format will be similar to the Florida courses, but with the addition of **substantial content on remote methods for monitoring deformation**.

COURSE EMPHASIS: **is on why and how to monitor field performance.** The course will include planning monitoring programs, hardware and software, recent developments such as web-based, wireless and monitoring, remote methods for monitoring deformation, offshore monitoring, case histories, and lessons learned. Online sources will be included, together with an open forum for questions and discussion.

WHO: Engineers, geologists and technicians who are involved with performance monitoring of geotechnical features of civil engineering, mining and oil and gas projects. Project managers and other decision-makers who are concerned with **management of RISK during construction**.

OBJECTIVE: to learn the who, why and how of successful geotechnical and structural monitoring while networking and sharing best practices with others in the geotechnical and structural monitoring community.

INSTRUCTION: **provided by leaders of the geotechnical and structural monitoring community**, representing users, manufacturers, designers and people of academia from Italy, England, Australia, France, Germany, Norway, Switzerland, USA, Hong Kong and The Netherlands.

WHERE: the 3-day course will be held in Poppi (Tuscany, Italy), in the main room of a 13th century castle (www.castellodipoppi.com). Poppi is in the countryside of Tuscany, near the city of Florence. **Dedicated transportation to Poppi from Florence main train station and city airport will be available**.

www.geotechnicalmonitoring.com