



## Coping with Stress

By Ryan C. Allin, P.E., Vice President, Pile Dynamics, Inc.

When monitoring pile stresses during dynamic testing it is important to note what stresses the PDA measures and what stresses are estimated. Further, the values being estimated require the user's understanding of how those values are calculated and the underlying assumptions/limitations of those calculations.

Strain measurements taken near the pile top (when multiplied by the material modulus) allow for direct measurement of the compression stress occurring at the pile top. While it is necessary and useful to monitor top compressive stresses, they are not always critical. In fact, in cases where the pile encounters bedrock the maximum compression stress may occur at the pile toe and may be significantly higher than at the pile top.

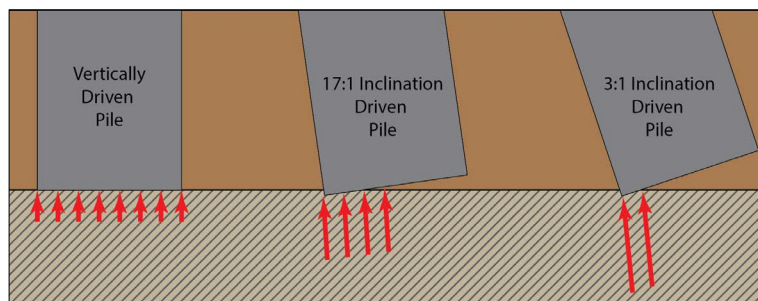
By measuring both strain and velocity near the pile top, the stress wave can be separated into downward traveling and upward traveling wave components. Based on these values, the maximum stresses at the pile toe can also be calculated. For these calculations to provide a reasonably accurate stress the PDA theory assumes that:

- The pile is uniform in cross-section and material.
- Critical compression stress maxima occur either at the pile top or bottom.
- Shaft resistance is relatively insignificant compared to end bearing (otherwise the toe compression stresses would be lower than those at the top.)
- The pile is one-dimensional, i.e., bending cannot be calculated below the sensor level.

Noting the last limitation is important, because stress wave analysis uses one-dimensional stress wave propagation theory which means that the estimated maximum compressive stress values average over the cross section.

This presents a problem in dealing with any type of pile and may be most extreme for large diameter open ended pipe piles (LDOEP). The likelihood of LDOEPs encountering bedrock uniformly over the full cross-section of the pile is low (**Figure 1**).

This issue was recently discussed in a paper presented at GeoCongress 2022. The paper outlines two sites where LDOEP piles were required to be driven through rock layers to achieve the desired



**Figure 1.** As the angle at which the pile encounters bedrock becomes more severe, the localized stresses become greater over a smaller area of the pile's cross-section increasing the likelihood of pile damage.

pile design requirements. At each site one LDOEP pile sustained damage during driving through a rock layer due to eccentric stresses at the pile toe. The pile toe would be expected to contact the rock on one side of the pile, while the opposite side remains in the softer upper soils. Two modes of failures can be envisioned. The non-uniform rock surface would require that the bottom force, estimated by the PDA from the pile top measurements, would only be supported by a fraction of the steel area and lead to local buckling. In a second scenario the bottom force would be causing bending over the whole cross section, some distance above the pile toe. To model this condition and estimate the eccentric stresses, numerous driveability analyses were performed. For these studies it was assumed that the soil resistance at the pile toe would have an eccentricity equal to approximately one half the inner radius of the LDOEP which would lead to an estimate of additional bending stresses due to overall bending. For an LDOEP encountering a rock at an inclined angle, a similar bending stress estimate may be possible as schematically demonstrated in **Figure 1**. The presumed eccentricity of one half of the pile's inner radius would be a reasonable and somewhat conservative compromise.

### Case 1

42 in (1070mm) O.D. pipe piles were driven into a shallow hard gypsum rock layer on a 1:17 inclination suggesting the piles would experience eccentric forces once bedrock was encountered. All four foundation piles encountered refusal conditions at approximately 16 ft (5m) penetration and pile damage was observed on the first of the four piles driven.



**Figure 2.** Extracted pile in Case 1, where upon encountering bedrock, eccentric stresses yielded one side of the pile.

CAPWAP® analysis indicated uniform average stresses near the

bottom of the piles were below the yield strength of steel at the pile toe. Modeling an eccentric stress with a moment equal to one-fifth of the pile's inner radius resulted in combined toe stresses where only the initial pile that experienced pile toe damage (**Figure 2**) would have been subjected to stresses above the yield strength. The other three piles had combined stresses near or below the yield strength of the steel.

### Case 2

42 in (1070mm) O.D. pipe piles were driven into a sand overlying limestone and calcarenite on a 1:17 inclination. Two of the four piles encountered refusal driving in the limestone at approximately 92 ft (28m) pile toe depth. Dynamic testing indicated one of the piles had a significant impedance reduction 13 ft (4m) above the pile toe, where the thicker walled "driving shoe" transitions to the nominal wall thickness of the pile. This damage was later confirmed through coring. Again, CAPWAP® results indicated uniform average stress values below the yield strength of the steel. In this instance assuming an eccentricity of one quarter of the pile inner radius, the combined eccentric stresses exceeded the yield strength for the pile that sustained damage and was

below the yield strength for the pile that encountered refusal without pile damage.

### Conclusions

The possibility of eccentric stresses for LDOEP piles should be considered when encountering abrupt refusal driving conditions. Based on these two examples the assumption of an eccentricity equal to one-third or one-quarter of the piles inner radius would be reasonable for these piles driven at a relatively small inclination angle (1:17). Piles with greater inclinations as well as piles encountering sloped bedrock likely should consider higher eccentricities for calculation of the additional stress. The application of these eccentricities can be useful for pre-construction driveability as well as dynamic monitoring during installation.

To access the full reference paper please [click here](#).



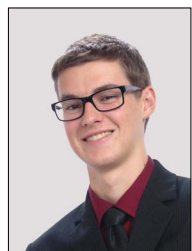
## Prometric Test Centers Offer PDA Proficiency Test Location Options – Globally

Pile Dynamics, Inc. (PDI), in cooperation with the Pile Driving Contractors Association (PDCA), has traditionally offered the "Dynamic Measurement and Analysis Proficiency Test" for engineers providing high strain dynamic foundation testing services during in-person workshops and seminars only. Recently, PDI/PDCA enlisted Prometric Test Centers to help provide global availability of the PDA Proficiency Test at secure testing centers across the world.

### Interested Test Takers

To preregister for testing availability near you, contact [proficiencytest@pile.com](mailto:proficiencytest@pile.com) with your **Name/Company/Address/Email**. Pre-approval and payment is required prior to scheduling your exam. All exams will be conducted in-person at a Prometric secure testing center. It is important to review all study materials provided, as well as prerecorded webinars prior to taking the exam.

For additional information on the Dynamic Measurement & Analysis Proficiency Test, visit [pdaproficiencytest.com](http://pdaproficiencytest.com). Additional details regarding Prometric Test Center registration process can be found [here](#).



### GRL Engineers Welcome Brad Klausing and Miguel Ramon

Two new engineers join the GRL team this quarter. Brad Klausing, EIT, will be located in the Ohio office and Miguel Ramon, EIT, in the Texas office.

Brad received his undergraduate degree from the University of Dayton in Civil Engineering and has worked as a field and a project engineer with construction organizations in Ohio, Indiana and West Virginia.

Miguel recently graduated from The University of Texas Rio Grande Valley with a BS, Civil Engineering. He is a member of the American Society of Civil Engineers/Blue Sky Team where he held a student leadership position.

Welcome Brad and Miguel!



## Upcoming Events

- Jun 23-25 Conference: 5th Symposium of Macedonia Association of Geotechnics, Macedonia, Ohrid  
[Register Today](#)
- Jun 24-26 **Seminar: QC/QA Deep Foundations Testing, Dubai, UAE**  
[Register Today](#)
- Jul 15 **Webinar: PDA Discussion Hours with Ryan Allin, P.E.**  
[Register Today](#)
- Jul 18-20 Conference: International Bridge Conference, Pittsburgh, PA  
[Learn More](#)
- Jul 18-21 Conference: ADSC Summer Meeting, Stowe, VT  
[Learn More](#)
- Jul 22 **Webinar: TIP Discussion Hours with Ryan Allin, P.E.**  
[Register Today](#)
- Aug 23-26 Conference: COBRASMEG, Campinas, Brazil  
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- Sep 12-13 Conference: GeoCarolinas, Charlotte, NC  
[Learn More](#)
- Sep 12-14 Conference: PDCA DICEP, New Orleans, LA  
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- Sep 15-17 Conference: DFI India  
[Learn More](#)
- Sep 28-30 Conference: Arizona Roads & Streets, Tucson, AZ  
[Learn More](#)
- Oct 2-6 Conference: ASCE SEI Electrical Transmissions and Substation Structures, Orlando, FL  
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- Oct 12 **Seminar: Deep Foundation Integrity Testing and Wave Equation Analysis Seminar, Cleveland, OH**  
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- Oct 13 & 14 **Workshop: High Strain Dynamic Foundation Testing Workshop, Cleveland, OH**  
[Register Today](#)
- Oct 16-22 Conference: 51st Annual Southeastern Transportation Geotechnical Engineering Conference (STGEC), Daytona Beach, FL  
[Learn More](#)
- Oct 21 **Webinar: TIP Discussion Hours with Ryan Allin, P.E.**  
[Register Today](#)
- Oct 28 **Webinar: PDA Discussion Hours with Ryan Allin, P.E.**  
[Register Today](#)

A complete list of PDI/GRL events can be found on [pile.com](http://pile.com) or [grlengineers.com](http://grlengineers.com)



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