CASE HISTORY: COMPARISON OF THERMAL INTEGRITY PROFILING RESULTS FROM CENTER BAR AND CAGE MEASUREMENTS FOR AUGER CAST PILES

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ABSTRACT

At a challenging project site in Los Angeles, CA, Auger Cast Piles (ACPs) were used to support a new city-owned automotive services building. The site was identified by the geotechnical engineer of record as having a significant depth of undocumented fill, while static and seismic settlement performance concerns warranted the need for deep foundations. ACPs were chosen as the desired option due to the geological profile, cost, and schedule advantages. The ACP reinforcement consisted of a partial length rebar cage with a center-bar for the remainder of the shaft. During the development of the final design and the load test program, the planned Thermal Integrity Profiling was increased from a single center-wire measurement to also include exterior wires for the portion of the ACP lengths that had rebar cages. Given the timing of this change and ordering constraints, the project became a unique opportunity to compare center bar and cage measurements when evaluating the effective diameter and quality of the ACPs. These results were further validated by Pile Integrity Testing and by select physical measurements. Each of the integrity test results showed meaningful agreement, empirically supporting the use of center-wire measurements for quality assurance for up to 30-inch diameter Auger Cast Piles.

Keywords: auger-cast, pile, thermal, integrity, testing

INTRODUCTION

This project encompassed the construction of a new 2-story multi-use auto repair facility. The proposed functions included offices, parts inventory, auto shop equipment, and manufacturing spaces. The preliminary recommendation for supporting the steel-frame building was deep foundations, given the depth of undocumented fill and expected loading conditions.

Menard USA (formerly Farrell Design-Build, Inc.) proposed installing ACPs based on relevant experience with similar projects and the anticipated geotechnical conditions. A total of 2 load test ACPs and 91 production ACPs were installed, with a diameter of 30 inches and shaft lengths ranging from 36 feet to 56 feet. Quality assurance was verified by load testing, thermal integrity profiling, and pile integrity testing, according to the project team's recommendations and project requirements.

A note: the ACPs for this project were designed in 2024 and constructed in February-April 2025, prior to the publication of the updated ASTM D7949-25 in May 2025. Accordingly, the TIP for this project was designed, installed, and tested under the 2014 version, ASTM D7949-14. There are minor differences throughout, the most meaningful of them relative to this case study being the recommended upper limit for single center-wire measurement increasing from 2 feet (600 mm) in diameter to 3.3 feet (1 m) in diameter between the versions. The data from this subject case history provides empirical support for the current version.

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SITE CONDITIONS

The project site was located in the rear of a large auto maintenance facility, squeezed between several existing buildings and an elevated parking area. The facility is situated between Interstate 5, Interstate 10, and the Los Angeles River channel. The site was flat and unpaved at the time construction began. See Fig. 1 below showing an aerial view of the project area during construction.

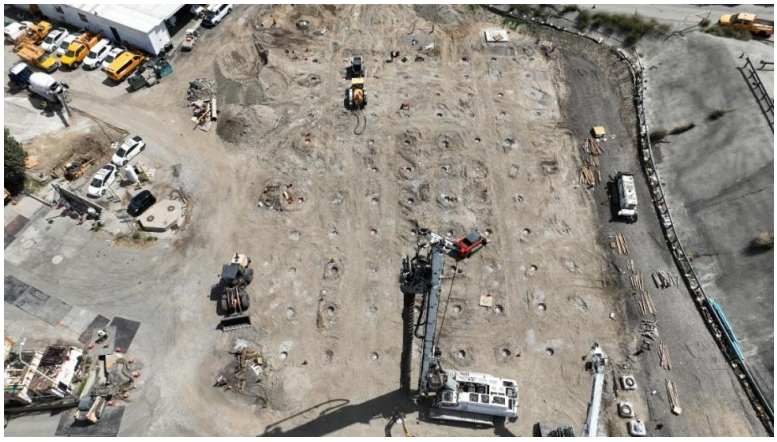


Fig. 1. Project aerial view

The geotechnical conditions of the site consisted of undocumented fill overlaying native alluvium deposits. The undocumented fill consisted of varying density/stiffness soils with debris and trash, which was estimated to be 15 to 34 feet in thickness. The native alluvium consisted of layers of medium dense to dense silty sands as well as very stiff to hard silty clay and sandy clay. Gravel was noted sometimes in the layers.

Groundwater was not encountered during the site investigation and was expected to be greater than 70 feet below the existing ground surface. No groundwater was observed during construction.

One unexpected condition at the site was the extent and nature of the debris found while drilling. Examples included apparent parts of cars, bricks, tiles, glass bottles, steel cable, metal grating, plastic conduit/pipe, and oversized concrete blocks. These went beyond the typical rubble fill and presented unique construction challenges. See Fig. 2 below for a sample of the debris encountered.



Fig. 2. Example debris encountered (steel cables, flattened metal tank, plastic conduit)

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Generally, the thermal conductivity of soil is one to two orders of magnitude lower than metal materials. Any thermal impacts related to the presence of this debris would likely manifest similar to a bulge or offset cage rather than an under-prediction of radius. For this particular site, the presence of large metal objects was very limited and not expected to materially influence the ACP radius calculation.

DESIGN CONSIDERATIONS

Historic photos from 1930 and 1941 show that the site had been cleared of vegetation and a farmhouse before being graded. Subsequent borings identified undocumented debris fill, which introduced significant challenges for new construction. The initial design assumed relatively low lateral demands for the prefabricated metal building and proposed 18-inch-diameter ACPs extending below the fill into native material to provide the required vertical capacity. Settlement estimates from the Geotechnical Engineer of Record (GEOR), ¾-inch total and ½-inch differential, were adopted as design criteria.

As design progressed, lateral load demands from the Structural Engineer of Record (SEOR) exceeded early assumptions due to seismic impacts, and uplift resistance became necessary. Coordination with the GEOR and City officials confirmed that the debris fill could not be considered to provide resistance in any way, making lateral pile capacity the governing design criterion. Geotechnical exploration defined three fill depths (15, 20, and 34 feet), requiring all ACPs to develop vertical and lateral capacity entirely below the fill.

To meet the increased lateral demands, 24-inch diameter ACPs were evaluated but 30-inch diameter ACPs proved more cost-effective, particularly given reinforcement limitations in smaller diameters. While the larger piles provided improved lateral capacity, spacing of less than eight diameters triggered p-multiplier reductions. ACPs were laid out in the widest feasible grid to reduce group effects, and the SEOR confirmed that lateral loads could be distributed across the pile group. This allowed ACPs in deeper fill zones, where lateral resistance was lower, to share load with ACPs in shallower more favorable zones.

Allowable ACP capacities varied by location and fill depth. All ACPs were designed for a vertical bearing capacity of 140 kips, with uplift capacities up to 46 kips where required. Lateral capacities ranged from 3.25 to 11.25 kips, reflecting differences in subsurface conditions. Figure 3 below illustrates the largest reinforcing cage used on the project.

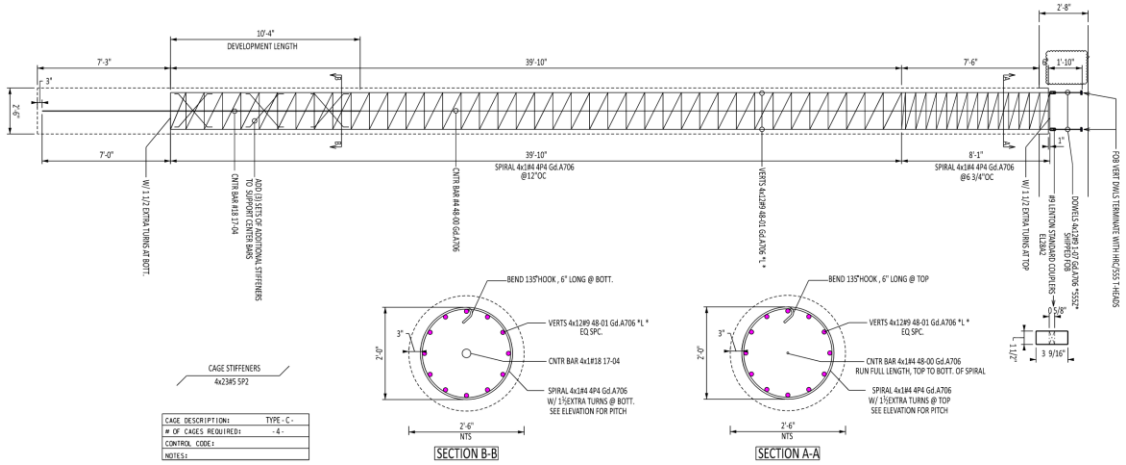


Fig. 3. ACP rebar cage type C

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CONSTRUCTION CONSIDERATIONS

The ACPs were drilled with a Casagrande B300 drill rig using 30-inch diameter hollow stem continuous flight auger tooling. The grout was injected by a Schwing SPTM 2000 concrete pump with a targeted grout factor of 1.15, and the reinforcing cages were set using a Mantis 9010 telescopic hydraulic crawler crane.

Rebar cages were delivered to the jobsite fully fabricated, after which the thermal sensor wires and centralizers were tied into the cages by Menard's field crew. In order to protect the wires, the cages were fabricated to include the center bar, and wires were routed on the inside of the cage rebar to prevent incidental scraping. Centralizer wheels were used to keep the cage from contacting the side walls.

High-slump grout was supplied by local ready-mix concrete plants. Each cubic yard of the production mix design consisted of cement (702 pounds), fly ash (280 pounds), sand (2,208 pounds), water (446 pounds), and admixtures to create a flowable mix. Placement temperature was in accordance with ASTM C94 Section 12.9.

The installation data from the drill rig and pump for each ACP were cataloged with a digital recorder. Hand-logs of key installation data were recorded concurrently as backup by Menard's field engineer.

High strain dynamic load testing was performed on two test ACPs in substantial conformance with ASTM D4945. The tests were performed by GRL Engineers using their Apple V test frame system and Pile Driving Analyzer Model 8G (see below Fig. 4). Each load test demonstrated a factor of safety greater than the 2.25 required for the project.



Fig. 4. Dynamic load testing setup

It is worth noting that ACP installation methods inherently have lower construction risks than conventional drilled shafts, so long as good standards of practice are followed. This includes maintaining positive grout pressure and keeping the grout pump rate higher than the extraction rate, both of which are typically required in the project specifications and are recorded as part of the installation data. Additionally, the grouts used for ACPs are high-slump mixes lacking large aggregates and the reinforcement is placed after the grout has been pumped. All of these contribute to a negligible potential for concrete to stack inside the reinforcing cage and negligible potential for sidewall instability, particularly compared to conventional drilled shafts.

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BRIEF BACKGROUND ON TIP

The Thermal Integrity Profiling ("TIP" per ASTM D7949) method evaluates the integrity of cast-in-place deep foundations by measuring heat generated during concrete hydration along the full pile length and cross section. Embedded thermal sensors, typically installed at a rate of one wire per foot of pile diameter and spaced evenly around the reinforcing cage, capturing temperature data at one-foot vertical intervals. For piles installed with continuous flight augers or displacement tooling, a single wire may be attached to the center bar. TIP testing is conducted from concrete placement until peak temperature (generally within 24-72 hours) producing temperature versus depth profiles that reflect radial heat transfer along the shaft. See example TIP reports in Fig. 5 below.

Temperature readings correlate directly with cement content, concrete volume, and overall concrete quality. Because sensors detect localized temperature variations both inside and outside the reinforcing cage, TIP provides 100% cross sectional coverage. Abrupt temperature drops indicate potential defects or inclusions, while localized increases suggest bulges or oversized sections.

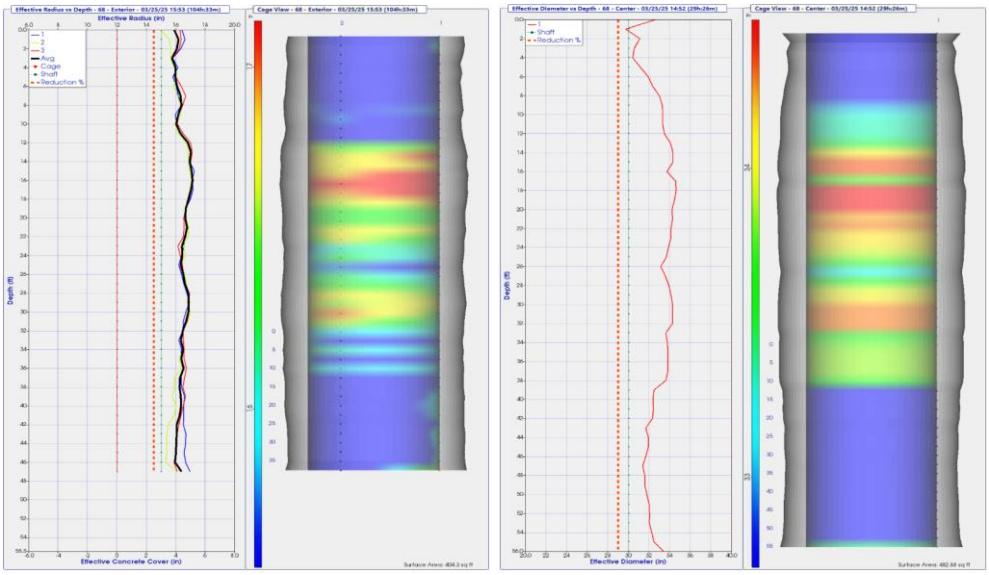


Fig. 5. Example TIP reports (left – exterior cage wires; right – center bar wire)

The thermal profile is converted to an effective radius profile by deriving a temperature to radius factor based on the average radius and average temperature. The average radius is computed based on the reported volume placed over the pile length. The average temperature comes from the thermal profile. Near the top and bottom of the shaft, the profile is adjusted through end-case calculations to account for the influence of additional surface area for cooling. These calculations are based on factors such as localized average temperature, inflection points, ambient temperature, and time factors.

Past studies incorporating thermal integrity profiling of drilled shafts of varying diameters have shown temperature rise of the surrounding soil is not observed past approximately 2 to 2.5 diameter spacing. These studies include both thermal modeling and field instrumentation. The closest ACPs installed on this project had approximately 6.5 diameter spacing.

For further information regarding the algorithmic procedures for analyzing the raw thermal data, please review the work by Mullins et al. 2020 and the work of Lewis et al. 2025 referenced at the end of this paper.

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BRIEF BACKGROUND ON PIT

Pile Integrity Testing ("PIT" per ASTM D5882) is based on the stress wave propagation and reflection theory. A stress wave (generated by a hammer impact) in a uniform rod is reflected if the wave encounters an impedance change. The pile's impedance is taken as E*A/c, i.e., the product of pile cross sectional area and elastic modulus divided by wave speed. The pile impedance therefore reflects both the piles' cross-sectional size and its material quality. A structurally sound pile is indicated by (a) reflections from the pile toe and (b) only relative minor variations of the recorded amplitudes between impact and toe reflection. For drilled piles, a sound pile may also be indicated by negative velocity reflections, which are often caused by bulges where softer soils, auger-wobble, or excess grout pressure allow for an enlargement of the bored hole. See example PIT report in Fig. 6 below.

A defect is generally indicated by a relatively large positive (tensile) velocity reflection before the toe. For drilled piles, this can indicate a reduction in pile cross section, possibly caused by a void, soil inclusion, necking, honey combing, or a cracked section (horizontal crack). A positive velocity reflection can also indicate a reduction in elastic modulus, which could be due to soil or ground water mixing during installation. Generally, it is not possible to determine which case exists based on the PIT record alone, only that a reduction in impedance occurs.

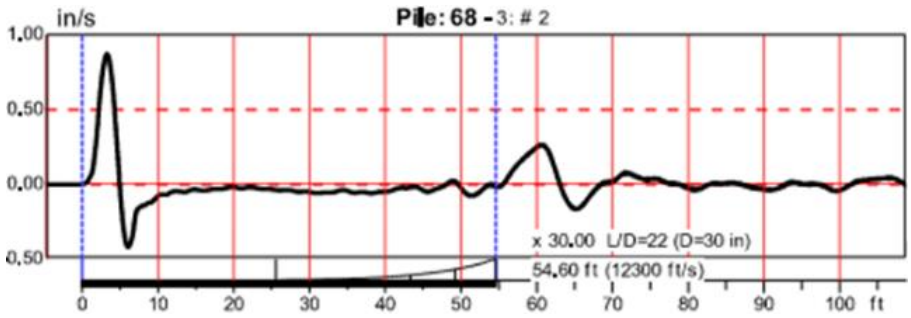


Fig. 6. Example PIT report

PREAMBLE ON RELEVANT ANALYSIS BACKGROUND

The following standard definitions apply unless specifically noted otherwise:

- Center-wire measurements refer to the calculated radius as reported by interpretation of the recorded temperatures taken at the ACP center bar and the placement volume.
- Exterior wire maximum and minimum measurements refer to the calculated radius as reported by interpretation of the recorded temperatures taken at the reinforcing cage and the placement volume.
- Exterior wire average measurement refers to the mean value of all calculated radius measurements for taken at the reinforcing cage and the placement volume.
- The percent difference refers to the center wire measurement minus the relevant exterior measurement divided by the center wire measurement, taken as an absolute (always > 0). Example: |C-Avg|/C for average percent difference.

A total of 23 production ACPs were evaluated at the site with TIP and PIT. Four ACPs were excluded from the data set used for this paper due to incomplete or corrupted TIP data, making them unsuitable for this analysis. Of the four excluded ACPs: two had external wire breaks, one had the center wire break, and one had corrupted data recording. Note that a higher rate of damaged TIP wires is expected on ACP piles (compared to the close to 99% survival rate expected on drilled shafts) due to the process of lowering the cage into the grout. The likelihood of damaging the TIP wires decreases if both cage and center bar are lowered at the same time, as was the case on this project.

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A radius measurement difference threshold of 5% was used for determining whether the comparison results were meaningful, as a reasonably conservative implementation of the "Satisfactory" radius reduction threshold proposed by Piscsalko et al. (2016). Put another way: if the radius measurement of the center bar wire exceeded radius measurement of the exterior cage wires by more than 5% of the design radius, then theoretically a potential anomaly could be missed under the typically implemented criteria.

INTERPRETING TIP DATA INTO EFFECTIVE RADIUS MEASUREMENTS

The radius interpretation for the full-length center bar wire and the partial-length exterior cage wires were calculated as two separate sets of data through the TIP reporter software. From these two sets of interpretation data the minimum, average, and maximum exterior cage wire radius measurements at each depth of each ACP were compared against the center bar wire radius measurement.

The placement volume was allocated linearly along the full shaft length, based on the grout factor reported by the installation data. The actual grout factor within the caged portion may differ slightly from the average grout factor recorded for the full element; however, the anticipated difference is minor and is not expected to materially affect the interpreted results.
Similarly, the reinforcing cage and attachment of thermal wires to the cage are inherent components of the standard TIP methodology. Therefore, the thermal influence of the cage is embedded in the established test configuration and method validation, rather than treated as a project-specific thermal input. The project analysis did not independently model steel heat capacity or conductivity, nor is such an input identified as part of standard TIP processing.

Lastly, the TIP data at the bottom of the partial reinforcing cages were taken as-is and were not adjusted with the typical end-case adjustments. This was because those sensors were located two or more ACP diameters from the bottom and were not expected to have been influenced by the end-case temperature fluctuations usually encountered at the top and bottom of the ACP.

COMPARISON OF TIP RESULTS: CENTER BAR AND CAGE MEASUREMENTS

Overall, the center bar radius matched the exterior cage average radius measurements to a high degree when evaluating individual ACPs. The average absolute difference was less than or equal to 2% on a per-ACP basis. Furthermore, only 2.5% of the overall center wire data showed an over-prediction of the radius greater than 5% compared to individual exterior wire measurements.

The observed center-wire measurement generally aligned closely with average computed radius from the exterior wires. See below side-by-side comparison of center radius and exterior radius charts in Fig. 7. In this figure, the apparent transition from undocumented fill to native alluvium occurs at depths of approximately 10 to 20 feet, consistent with the geotechnical report.

On both an individual ACP basis and overall, the difference in prediction on radius (center minus average exterior) appears random at 56.5% underprediction and 43.5% overprediction. See Fig. 8 below for reference. Negative values indicate the center wire underpredicted compared to the exterior wire average; positive values indicate the center wire overpredicted compared to the exterior wire average. The differences are also plotted as a function of standard deviation, showing the expected nearly normal distribution.

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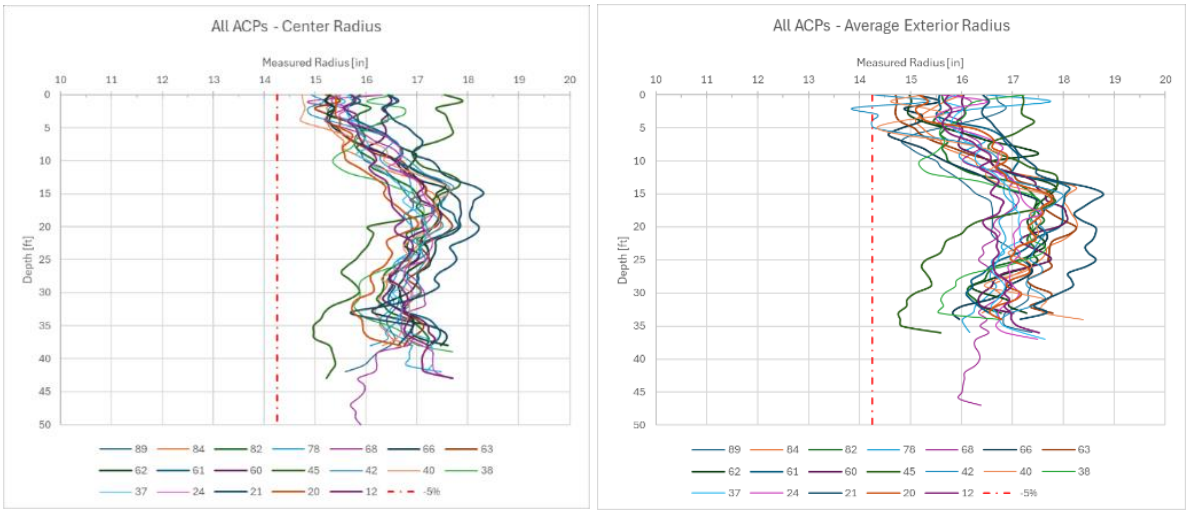


Fig. 7. Plotted radius measurements (left – center bar wires; right – exterior cage wires)

From Fig. 8, approximately 6.5% of data point comparisons showed the center wire underpredicted the radius versus the exterior wires by greater than 5% of the design radius, while 2.5% of comparisons showed overpredictions of the radius by greater than 5%. One data comparison point (0.15% of the total data) showed an overprediction that exceeded 10% of the design radius, while 3 data comparison points (0.44% of the total data) underpredicted by greater than 10% of the design radius. There is no apparent trend with depth for the over- vs. under-prediction.

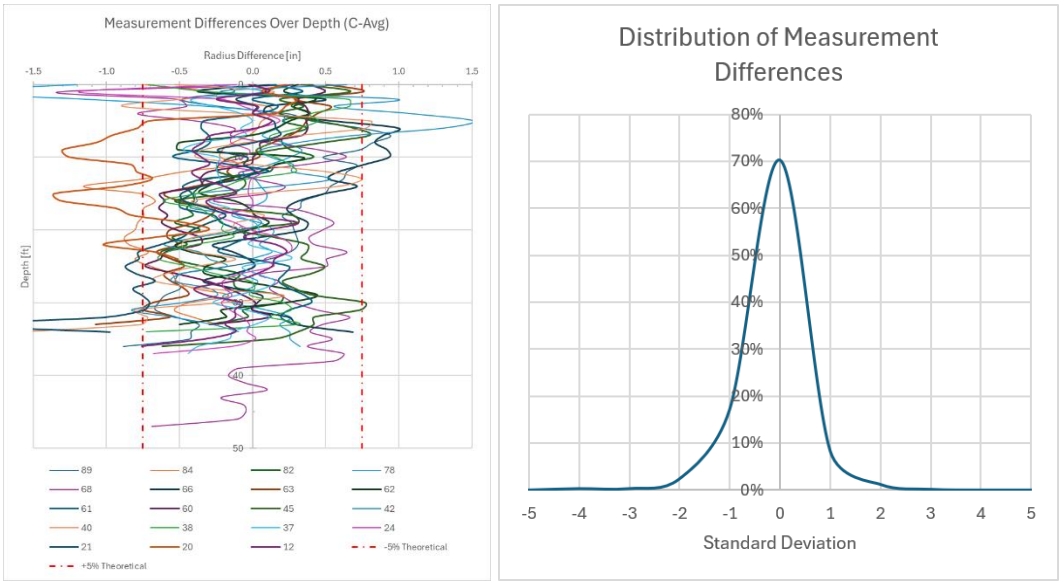


Fig. 8. Center minus average exterior vs. depth (left – actual; right – as normalized std. dev.)

The radius measurement differences indicate an elevated likelihood of disagreement near the tops of the ACPs. This increased difference is likely due to effects from the end-case calculation adjustments performed to adjust the radius measurements at the top of the wires (the "roll-off"), some localized environmental thermal variations near the shaft top (excess heat in the summer months or excess cold in the winter months), and/or due to greater near-surface soil disturbance during the ACP construction process. Some of these differences are more evident in smaller diameter piles (such as ACPs) due to the

smaller volume but generally have a lesser or unnoticeable impact in larger-diameter piles (such as drilled shafts).

Reviewing the global data set average measurements, the overall difference between radius measurements trends under ±5% at every depth. See Fig. 9 below plotting the average measurement differences and comparative "average" ACPs. It is important to mention that while the center bar covers the entire ACP length, the partial cage only covers a portion of it.

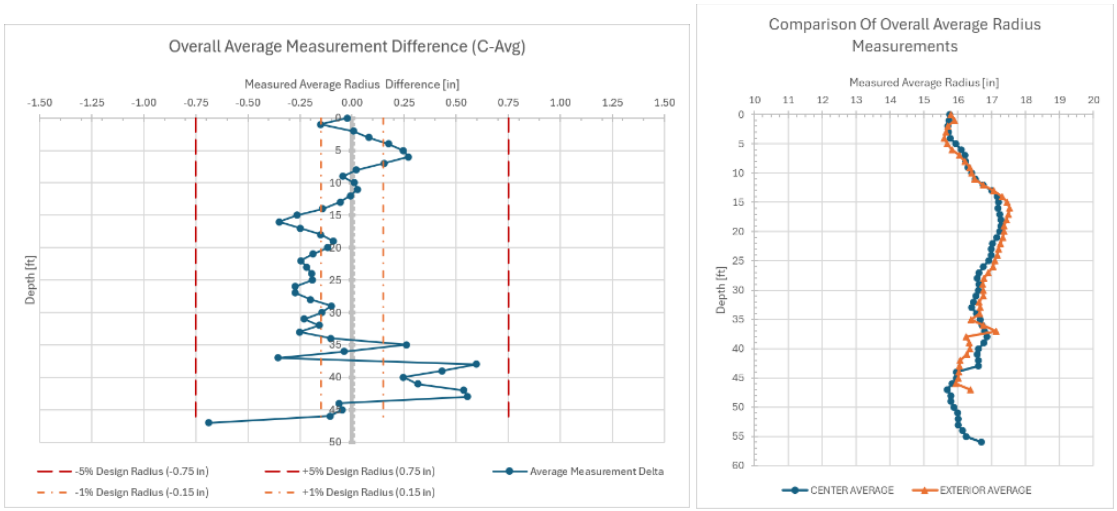


Fig. 9. Comparison of overall average radius measurements difference

Evaluating the average absolute measurement difference versus the maximum absolute measurement difference for individual ACPs, no apparent connection emerged based upon magnitude of difference. Rather, the maximum absolute measurement difference was contained to a consistent band of about 1 to 3 inches. This is reinforced by a linear analysis, which returned an uninspiring best-fit R^2 of 0.147. See Fig. 10 for further details.

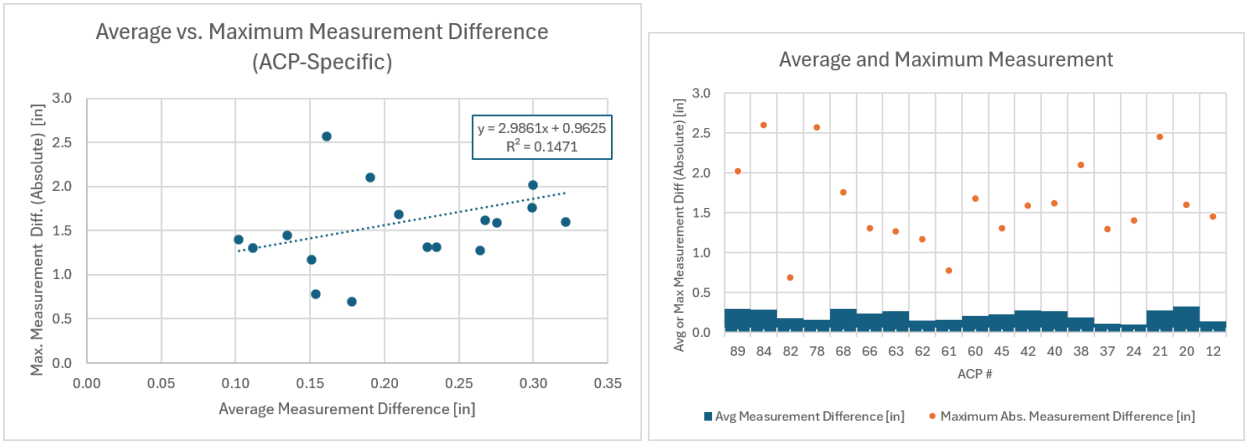


Fig. 10. Average vs. maximum measurement difference

Given the lack of connection from the Fig. 8 plot along with the measurement differences on a per-ACP basis demonstrated in Fig. 10 and 11, a tidy formula for adjusting the center wire measurements to precisely match the exterior measurements as a function of depth or as a function of ACP-specific standard deviation is not possible from this data set.

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This lack of a trend is repeated when comparing the measurement differences on a per-ACP basis against the standard deviation of center wire measurements, as shown in Fig. 11 below.

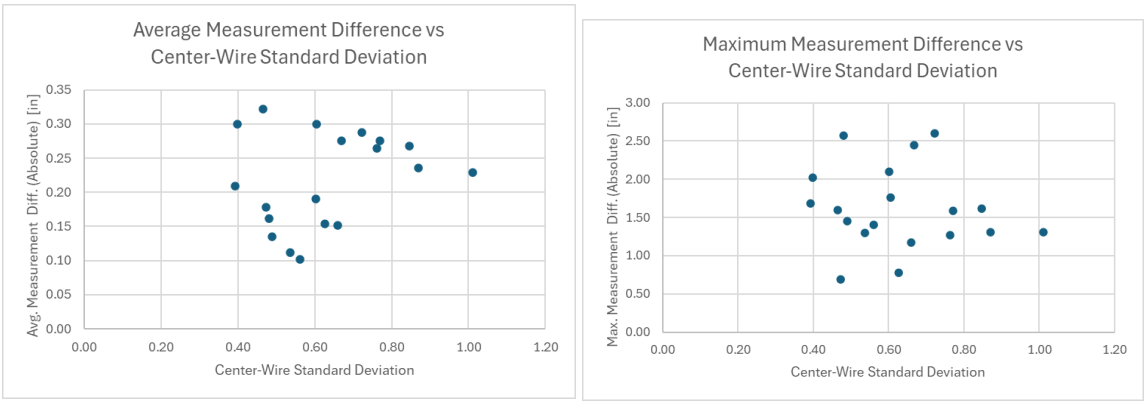


Fig. 11. Average and maximum measurement difference vs. standard deviation

COMPARISON OF TIP RESULTS WITH PHYSICAL MEASUREMENTS

There were three ACPs that required further investigation to validate irregularities in the TIP readings near the ground surface. These ACPs were exposed for the top 5 feet to allow inspection of the diameter, circumference, concrete cover, and concrete quality. No deficiencies were observed, so the excavations were backfilled and compacted around the ACPs. Likewise, no deficiencies were identified in the PIT measurements. As such, the ACPs were determined to be acceptable, and the irregularities were most likely a byproduct of the end-case calculation adjustments performed. See Fig. 12 below showing the three examined ACPs.

The physical effective radius measurements of the top 5 feet of these 3 ACPs showed the TIP data had underestimated the actual radius. The center bar effective radius measurements were lower by an average of 0.82 inches (range 0.11 to 1.31 inches), while the exterior cage effective radius measurements were lower by an average of 1.07 inches (range 0.34 to 1.62 inches). Without exhuming the entirety of several ACPs for physical measurement, it is not possible to be certain whether the underestimate trend was pervasive for the entire lengths or whether the end-case calculation adjustment performed at the top was overly conservative.

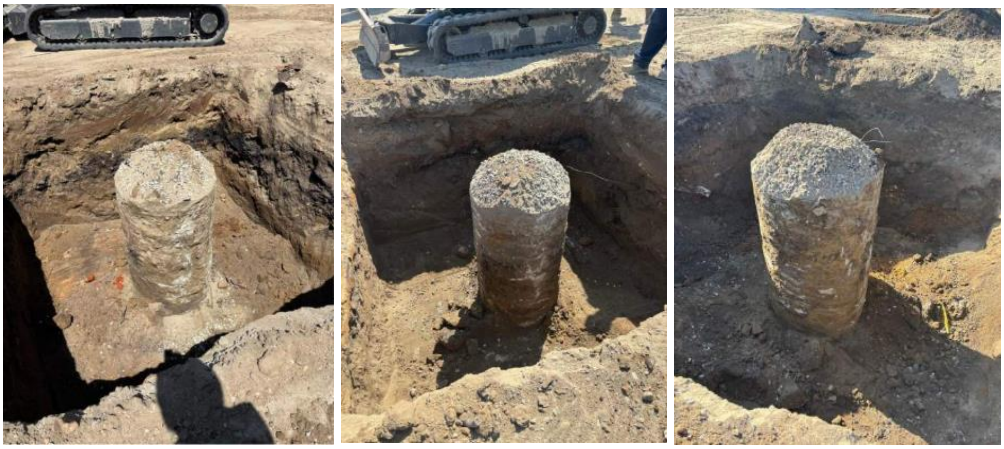


Fig. 12. Exposed ACP tops

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It is worth noting here that the one significant center bar wire overestimate (>10%) reading was field checked during this process. Physical radius and circumference measurements were taken at the depth of concern. From these measurements it was determined that the ACP had been installed to the design radius and that the exterior wires had underpredicted the actual ACP radius. For this specific ACP the center wire matched 99% of the measured radius while the exterior wires average matched 90% of the measured radius; both sets of measurement data underpredicted the actual radius. As mentioned previously, the difference was likely due to the end-case calculation adjustments performed to both sets of data.

COMPARISON OF TIP AND PIT MEASUREMENTS

GRL Engineering performed PIT on each pile that received TIP. Every ACP returned a clear toe response with no major defects indicated, earning a top AA rating. This aligns with the results of the TIP measurements, which also showed no major defects.

Although a more limited tool, performing the PIT was advantageous at this site based on the low diameter-to-length ratio, as there were several ACPs that suffered broken TIP wires or corrupted data. The impacted ACPs could still be evaluated, reviewed, and approved, based on the PIT results and installation logs.

COMPARISON OF RESULTS WITH RECENT LITERATURE

The 2017 Florida Department of Transportation study by Mullins and Johnson demonstrated agreement between both center bar and cage-based TIP measurements to identify as-built radius variations for 18-inch and 24-inch ACPs. Further numerical analysis showed center bar measurements theoretically being less successful in piles greater than 36 inches in diameter due to an expected loss in sensitivity to changes in outer dimension. The subject case study of this paper was in general agreement with Mullins and Johnson, evaluating 30-inch ACPs. Specifically, the findings in this paper support average results up to 30-inch diameter for center bar measurements at less than 5% overall sensitivity loss.

The 2015 case study by Becker et al. demonstrated general agreement between PIT and TIP results for 18-inch diameter ACPs with partial-length cage reinforcement and full-length center bars. The findings of this case study, evaluating larger 30-inch diameter ACPs also with partial-length cage reinforcement and full-length center bars, show similar agreement between PIT and TIP results. These findings not only support the conclusions made by Becker et al. but expand the application to larger diameter elements.

CONCLUSIONS

Based on the data from this project, center wire measurements returned a comparable (difference less than 5%) or conservative calculated radius 97.5% of the time compared on a per-ACP/per-depth basis against the data from the exterior wires. Only one of the comparison points (0.15% of total measurements) returned a center-minus-average overestimate that exceeded 10% of the design radius.

The use of PIT on this project showed the advantage of utilizing a second integrity test method: providing verification in instances where the primary method (TIP) data was incomplete or unavailable. In instances of broken wires or corrupted data recording, the PIT was still able to evaluate the entirety of the ACP and be used to verify the quality. Furthermore, the fact that the ACPs passed two independent integrity test methods gave a higher degree of confidence to the project team that the piles were constructed as intended.

Based on the TIP comparison and validation by PIT, the data and analysis from this project provides empirical support for utilizing ASTM D7949-25 in center-wire applications up to at least 2.5 feet (760

mm) in diameter for auger-cast elements. No contraindications arose during the analysis that would dissuade from application of the current recommended upper limit of 3.3 feet (1 m) in diameter for center-wire measurement.

SUMMARY

The ACPs for the project were a success. The TIP results showed statistically significant agreement between the center-wire and exterior-wire measurements, and both measurements were validated by PIT. The findings from this project demonstrated the possibility of using single-wire measurements for meaningful quality assurance for up to 30-inch diameter auger-cast elements on lower-risk projects.

The findings from this case study support adding PIT (low-strain dynamic testing) rather than increasing from only center-bar TIP (thermal integrity profiling) measurements to also including cage-based measurements. This keeps project costs lower while diversifying testing techniques, providing the ability to cross-verify results and allowing for redundancy in the event of test method breakdowns. This would also reduce the quantity of sacrificial materials and energy required, potentially lowering the carbon footprint of the project.

The results outlined in this paper would benefit from further research where ACPs were constructed with various deliberate defects to be evaluated by center wire TIP, exterior wire TIP, and PIT, to advance the study. These results would also benefit from evaluating additional ACPs of varying diameters on other projects to increase the sample size, and from evaluating ACPs constructed in higher-risk projects (such as flowing groundwater or longer ACPs through less favorable soil conditions).

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