Assessment of Bored Pile Verticality Using an Ultrasonic Caliper

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Abstract

Ultrasonic calipering of bored pile excavations allows for assessment of pile excavation shape. In a typical application, the device is lowered into the excavation in incremental depths. At each depth, a 360° sweep of the excavation wall is performed. A circle is fitted to the data points using a non-linear least-squares technique to approximate the cross-sectional profile of the pile for verticality, perimeter area, and volume calculations. To determine pile verticality, one profile ring is selected as the datum ring. The geometric centers of the datum ring and all other profile rings are compared. A center offset is computed for the divergence of each profile ring center point from the datum ring center point. "Encroachment" is also assessed as the portion of the excavation wall which would encroach into the perfectly vertical projection of the datum ring to the depth in question. Verticality is computed as either the maximum encroachment or center offset divided by change in depth, and may be expressed as an angle, a percentage, or as a deviation: depth ratio.

Typical practice for specifying required verticality is the simple ratio of deviation:depth, which does not take into account the diameter of the pile. Thus, a specified 1:100 tolerance allows for a deviation of 300 mm at a depth of 30 m, regardless if the pile diameter is 600 mm or 3,000 mm. For the former, this deviation represents 50% (a full radius) of allowable deviation, creating a vertical projection into which a rebar cage cannot be lowered without scraping the side wall, and/or a column support with a large built-in eccentric load. For the latter, it represents a 10% of diameter deviation, which is much less significant in terms of functionality, whether this is bearing capacity (axial pile) or creating a moisture barrier (secant wall). To overcome this, a normalized verticality calculation is presented. Rather than simply taking the ratio of deviation to depth, the compound ratio (deviation/diameter):(depth/length) is proposed.

BORED PILE CALIPERING OVERVIEW

Pre-concreting bored pile (drilled shaft) excavation calipering is an important QA/QC tool. There are several products on the market currently, based either on sonar or mechanical measurement methods (Hertlein et al. 2016). All of the data used in this study was obtained using the SoniCaliper ultrasonic caliper device. This device is lowered into the pile excavation in incremental depths. At each depth, a rotating transceiver performs a 360° sweep to measure distance to the sidewall. A circle is fitted to the data points using a non-linear least-squares technique (Gander et al. 1994) to approximate the cross-sectional profile of the pile for verticality, perimeter area, and volume calculations. Because the properties of drilling fluids vary widely, a calibration must be performed for each pile to determine fluid wavespeed. This is done by selecting a profile ring of known diameter (typically inside the casing) as the "calibration ring." The data analysis then back-calculates the fluid wavespeed based on the known dimensions of this ring. The fluid wavespeed is assumed to be constant over the entire column of fluid depth. Analysis of selected SoniCaliper data performed by Loadtest Inc., using documented poured concrete quantities as an independent measure of pile volume validates the approach. To determine pile verticality, a profile ring (usually, but not always the calibration ring) is selected as the "datum ring." The geometric centers of the datum ring and all other profile rings are compared. The "center offset" indicates the divergence of each profile ring center point from the datum ring center point. "Encroachment" is presented graphically as the shaded area representing the portion of the pile wall which would encroach into the perfectly vertical projection of the datum ring to the depth in question. The maximum encroachment value for each profile ring is also given numerically. Verticality is computed as the maximum encroachment or center offset (the "deviation") divided by change in depth. See Figure 1 for a schematic illustrating the definitions given above.

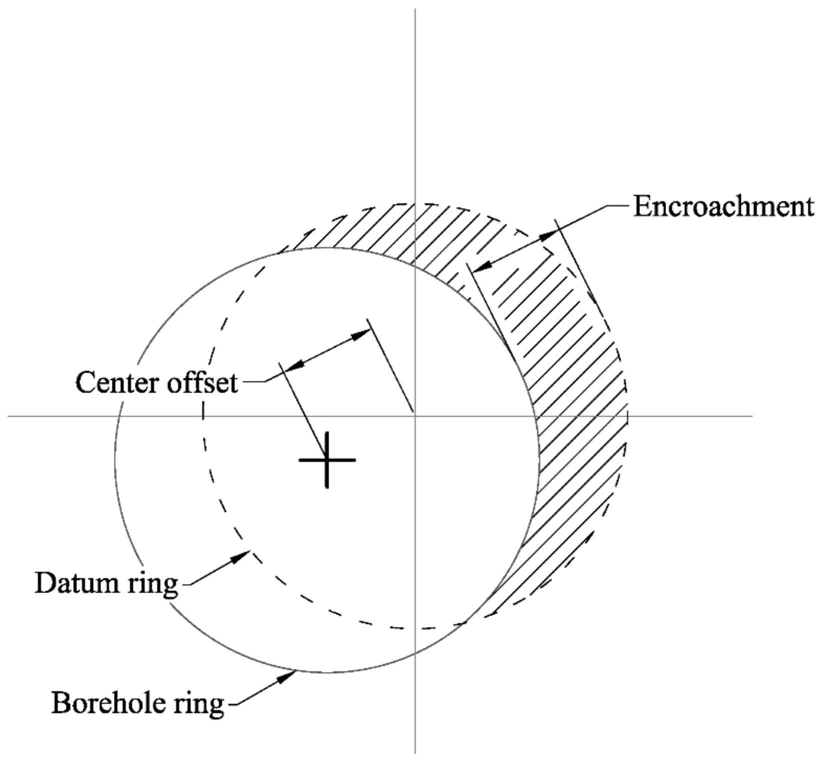

Figure 1. Verticality schematic.

SAMPLE DATA SET

A nominal 2,450-mm-diameter bored pile was excavated through layers of poorly graded silty sand and sandy silt to a depth of 26.8 meters under polymer slurry. The excavation was started by pre-drilling a 3,050-mm-diameter bore, installing a 2,800-mm-O.D., 6.1-meter-long corrugated metal pipe (CMP), and grouting it into place. A combination of auger and drilling bucket was then used for excavating the pile. Upon reaching toe elevation, the SoniCaliper was used to profile the pile excavation. The collected data were processed by fitting a circle at each depth, calculating a calibration wavespeed (near the base of the CMP) to scale the results, and finally computing the center offset for each ring with the base of the CMP selected as datum. A 3-D rendering of the resulting caliper profile is presented in Figure 2.

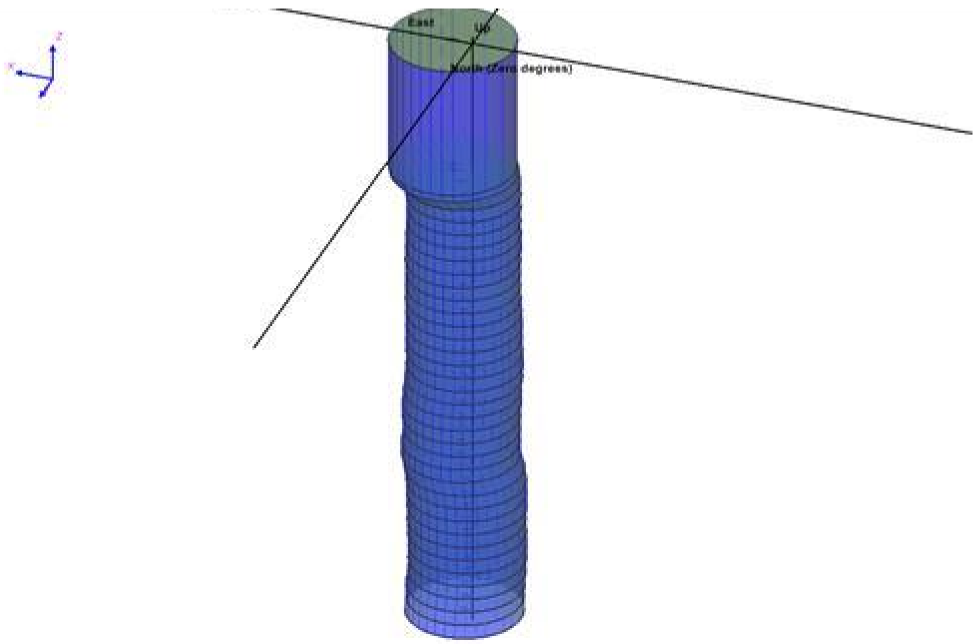

Figure 2. Mesh rendering of sample profile data.

Note that the resulting profile clearly indicates that the drilling tool was not centered in the CMP. Primarily because of this, the computed maximum center offset (380 mm, representing a verticality of 1:70) was outside of the project specification of 1:100 verticality. However, as noted graphically in Figure 3, the magnitude of this deviation, relative to the diameter of the pile, is perhaps not crucial. Using real-time caliper results as a positioning guide, the contractor can install the rebar cage vertically, top to bottom, without touching the sidewalls at any point in the excavation.

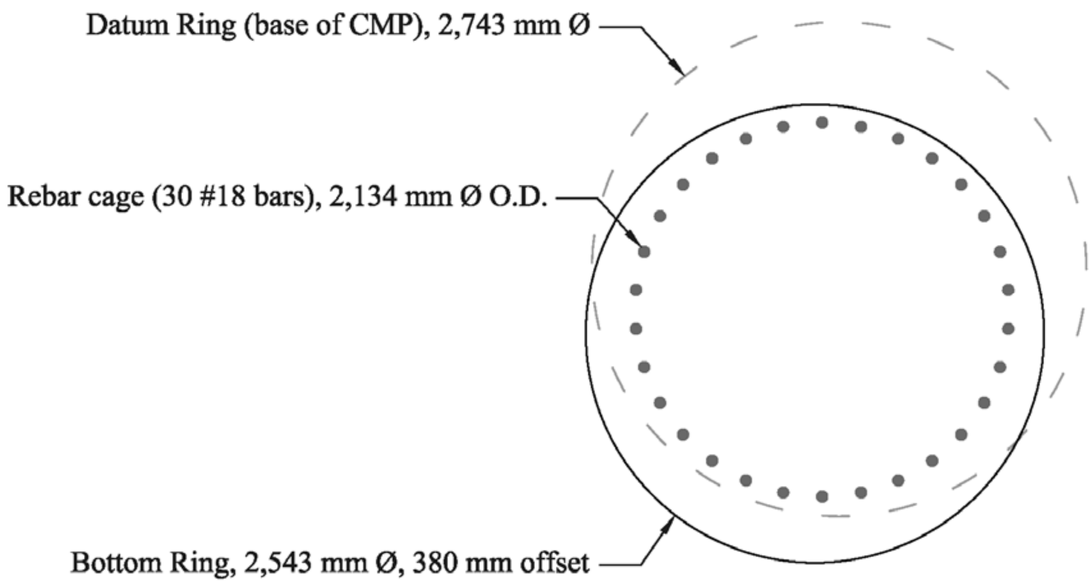

Figure 3. Rebar cage clear cover schematic.

This particular pile was in fact load tested using the Bi-Directional Static Load Test method, with very good results (Loadtest 2015). Given its large diameter, it may be considered that the verticality specification for a pile of these dimensions may not be an adequate measure of its quality or constructability.

PROPOSED NEW DEFINITION OF PILE VERTICALITY

Typical practice for specifying verticality is a simple ratio of deviation:depth, which does not take into account the diameter of the pile. Thus, a specified 1:100 tolerance for example allows for a deviation of 300 mm at a depth of 30 meters, regardless if the pile diameter is 600 mm or 3,000 mm. For the former, this deviation represents allowable deviation of 50% of the diameter, creating a vertical projection into which a rebar cage cannot be lowered without scraping the side wall, and/or a column support with a large built-in eccentric load. For the latter, it represents a 10% of diameter deviation, which is relatively insignificant in both terms of constructability and structural function. To overcome this, the following new definition of verticality, which incorporates pile diameter, is proposed. Rather than taking the simple ratio of deviation to depth, a compound ratio is proposed:

Verticality ratio = (deviation/Diameter):(depth/Length) Equation 1

To compare this ratio with the current industry standard, for the purpose of this study a reference pile is arbitrarily defined, with a diameter of 1,200 mm and a length of 30 meters. The dimensions represent an average bored pile. For this reference pile to meet a 1:100 verticality standard, the deviation may not exceed 300 mm at the base. The normalized verticality (300/1,200):(30/30) is equal to 0.25, rather than 0.01. Thus, a scaling factor **f** = 1/25 is added to the normalized verticality definition:

Normalized verticality ratio = f * (deviation/Diameter):(depth/Length) Equation 2

Using this definition, the example pile presented in the previous section would have a *normalized* verticality ratio of 1:160, rather than a raw ratio of 1:70, and thus be considered within the 1:100 specified verticality.

METHOD ASSESSMENT

An analysis of 164 SoniCaliper tests (Loadtest database, 2010-2017) was compiled to directly compare the traditional and proposed verticality calculations. To be able to plot the results easily, the verticalities are calculated as percentage inclinations at the deepest depth which was calipered relative to the top of casing. The measured diameters, rather than nominal, are incorporated into the proposed inclination calculation. The analysis reveals that applying the traditional analysis to the dataset produces, on average, an increasing inclination with increased diameter, with 10 data points (6%) falling above 1.0% verticality deviation. The normalized method detailed in Equation 2 produces a more even distribution of inclinations, regardless of diameter, with only one data point above 1.0% deviation from vertical. An even distribution is the expected result if the assumption that verticality deviation is not a function of diameter. Figure 4 is a scatterplot of the results, which include the specific example discussed in the previous section. Trendlines for both methods are indicated by dashed lines.

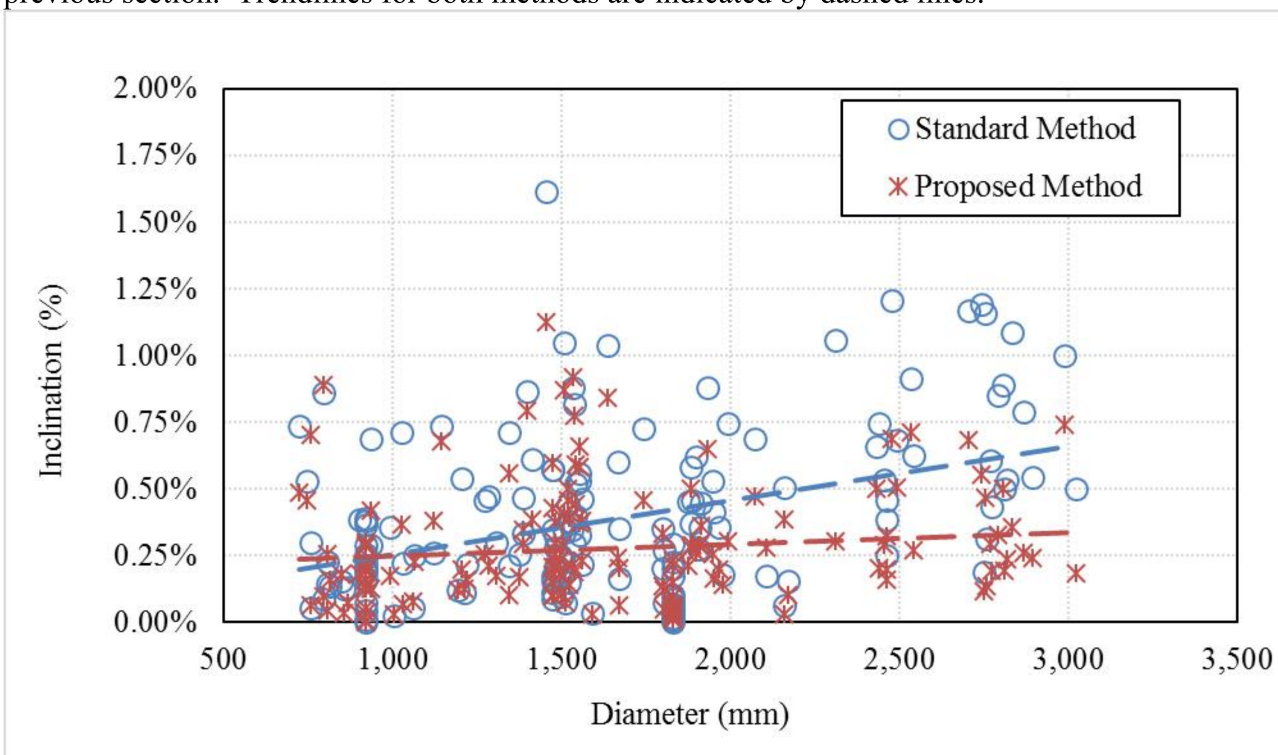

Figure 4. Inclination vs. Diameter.

Note that choosing a different value for the scaling factor **f** will produce numerically different results. The 1/25 value was selected for this study primarily to illustrate a comparison of results to the traditional method. Verticality computed using Equation 1 is much less subjective, since it simply multiplies the traditional verticality ratio (deviation/depth) by the L/D ratio.

Figure 5 plots the proposed vs. standard inclination percentages. For comparison, a 1:1 correlation (dashed line) is plotted, illustrating that the proposed new method typically, but not always, results in less computed inclination than the traditional method.

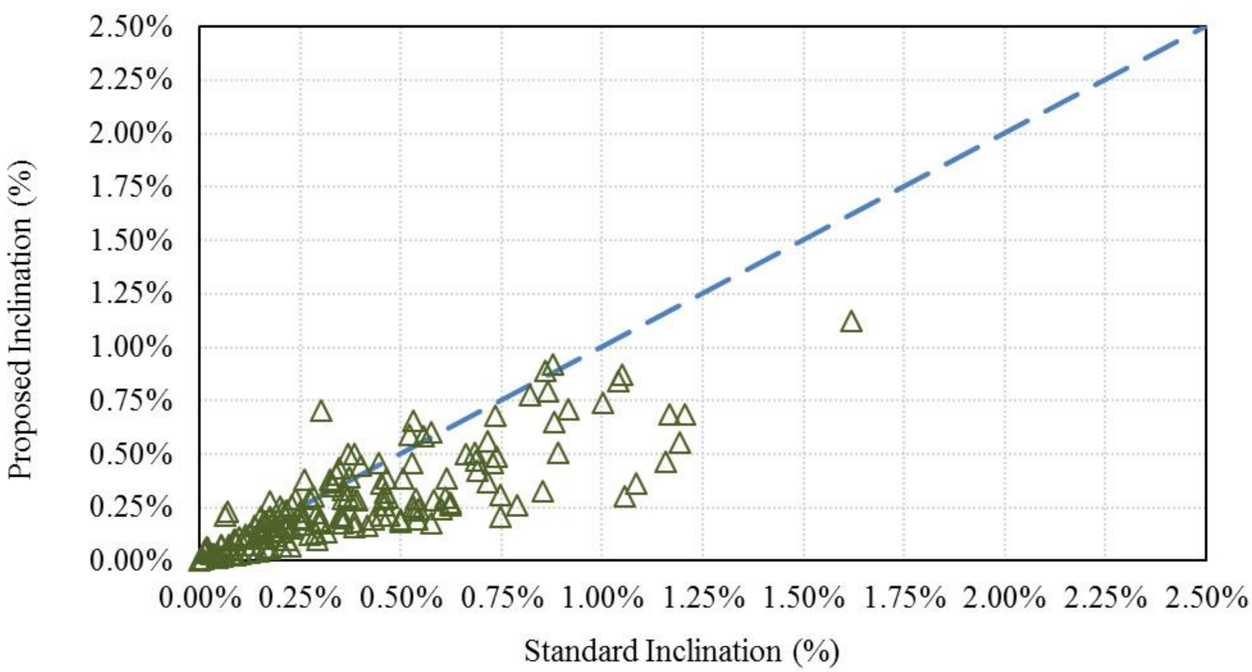

Figure 5. Proposed vs. Standard Inclinations.

CONCLUSIONS

For large piles, the current typical specification for verticality becomes harder to meet with increasing diameter, while not necessarily providing a useful assessment of the pile's constructability or structural performance. An improved definition of verticality is proposed which accounts for the pile diameter. In order to compare the new definition with existing specifications, a scaling factor is computed based on the existing specified verticality ratio, which then is used to normalize the verticality ratio. The new method appears to provide a more unbiased assessment of verticality regardless of pile diameter, based on a statistical evaluation of a database of profiles.

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