Field Measurement of Swept Cast-in-Place Piles

WILLIAM F. LOFTUS

The age-old dilemma of not knowing the condition or direction of a cast-in-place pile that undergoes sweep during driving may be on the verge of being solved. By using a simple method of an inverted flashlight on a measuring tape, the sweep may be plotted within reasonable limits. If one knows and can plot the slope of the top portion (i.e., the depth where full circumferential light ceases), the depth where no light can be seen from the top, and, finally, the overall depth of the pile, an acceptable prediction of final tip displacement can be made. This method, called the integrity OK (INTOK) method, eliminates the use of expensive and time-consuming equipment and the extra labor previously required to determine the slope and direction of the unseen portion of a driven cast-in-place pile.

In a recently completed foundation project, some 17 000, 10.75x0.188-in-wall 50-ton cast-in-place piles were driven to support a 100 million gal/day secondary sewage treatment plant in Cleveland, Ohio. The joint venture of Gibbons-Grable Company of Canton, Ohio, and Richard Goettle Construction Company of Cincinnati overcame the problems and successfully installed 210 miles of piling at an average speed of 0.25 mph by using Link-Belt 520 double-acting diesel hammers (26 300 ft-lbf). The piles were divided equally between plumb and batter (1 horizontal to 3 vertical) and averaged approximately 65 ft in length.

The soil profile consists of random and rather unstable loose sand and silt deposits that vary in depths of up to 40 ft. The underlying bearing stratum, which is a firm stiffer-with-depth clay layer, is in an almost level condition; the top of this layer has minimal elevation changes throughout the site.

Several straight plumb piles had initially been tested under the subject contract, and 10 others had also been tested under a previous contract (the latter was the one on which the design and specifications had been prepared). The drawings and specifications of previously built structures revealed that some 30 other load tests had been performed years before. Based on these tests and the boring and laboratory data, a 50-ton design had been recommended by using an adhesion value of 0.9 ton/ft^2 of embedded pile surface area and tip resistance computed on the basis of 11.5 tons/ft^2 of pile tip area. These values then dictated the length of penetration into the clay for each of the piles of the project.

Because the wall thickness of the pipe was not critical, the less-expensive 10.75x0.188-in-wall tube piles were ordered (half had already been delivered to the site or to storage); the waste was kept to a minimum. However, with the lighter wall, the probability of sweep and collapse became fearful anticipations. The sweep became immediately apparent when the bottoms of virtually none of the first 100 piles could be seen after driving.

Because all parties would gain from the less-expensive foundation, the initial requirements of having to see the bottom of the pile after driving and that zero loss of cross section be maintained had to be reanalyzed. Thus, William F. Loftus Associates, Inc., was commissioned by the contractor (with the support of the owner, the Cleveland District; the engineer, Malcom Pirnie, Inc.; and the geotechnical firm, Mueser, Rutledge, Johnston and DeSimone) to evaluate the situation, to devise an early production-oriented sweep-detection system, and to recommend conditions of acceptance for these swept cast-in-place piles.

A swept pile is one that departs from its original altitude line in a gradually increasing amount with the depth of the pile. This amount varies in each pile sweep and begins to be of concern if this rate of departure increases too rapidly. Inclinometers (developed by Slope Indicator, Inc., of Seattle, Washington, which consist of upper and lower pendulums swinging in the north-south direction and the other swinging east-west) were used to measure the sweep. The slope can be measured merely by digitally measuring the distance from the instrument line to the plumb pendulum. Eighty of the driven piles that were already noted as swept by the inspector were measured by using this device.

In an effort to determine the carrying capacities of these piles, one pile with a 7.3 percent sweep was load tested in the same manner that all other previous piles had been tested--namely, that the load was incrementally applied in 50, 75, 100, 125, 175, and 200 percentiles of the design load. These loads were generally held until settlement under the increment was less than 0.001 ft in a 2-h period and held for 48 h, and then until the settlement was less than 0.001 ft over a 4-h period. Because telltales for measuring tip movement were not installed, some cycling was done at certain increments throughout the test.

The movement of the pile both in full load and zero load conditions indicated that completely tolerable settlements had occurred. No consideration was given to the possible combinations of resistance to movement, as shown in Figures 1 and 2. (As an aside, further study should be given to the possibility that sweeps in cohesive soils actually increase the capacity of the pile.)

Having satisfied all parties that a maximum sweep of 7 percent (total off-alignment tip displacement) was acceptable, the next task was to develop a quick method for determining these values.

ANALYSIS

It became apparent that (a) the slope of the upper portion of the pile, (b) the point where the sweep starts, and (c) an idea of the abruptness or gentleness of the sweep were important in the study. Thus, William F. Loftus Associates developed the Integrity OK (INTOK) method. After the initial slope of the pile was recorded, an inverted six-cell flashlight, which was firmly attached to a steel tape, was lowered down the pile. The following data were then recorded:

1. Point B--This is the depth beyond which full circumferential light is no longer visible from the top. For batter piles, it is critical to note if the sweep coincides with batter direction or, if not, the approximate clock-oriented deviation (e.g., assume 12 o'clock for batter direction and record the hour closest to the sweep direction). In all cases of batter piles, the flashlight will ride the low side of the pile.
2. Point C--This is the depth beyond which no light can be seen from the top of the pile.
3. Point D--This is the overall length of the pile.

Having all of the above data is fine, but what hap-

Figure 1. Swept pile.

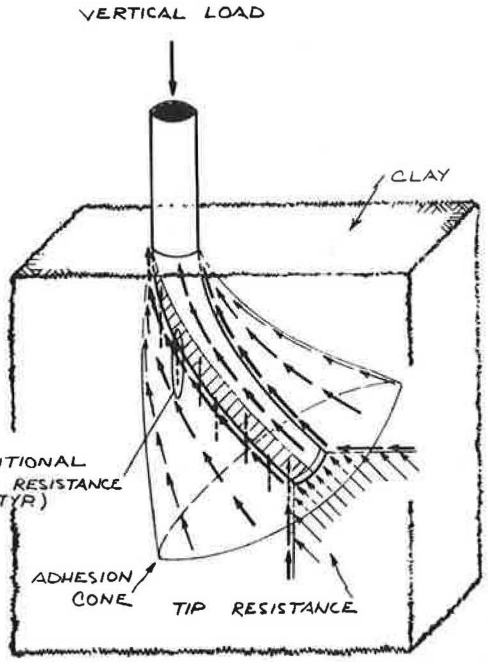
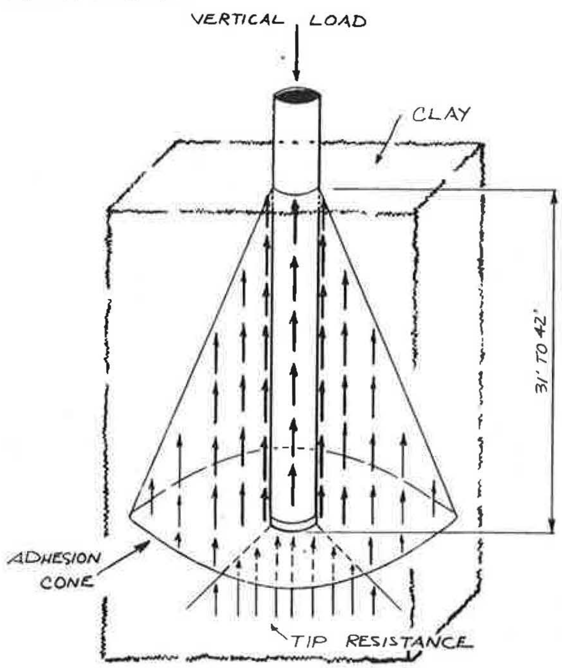


Figure 2. Straight pile.



pens to the sweep direction in the unseen, darkened portion of the pile?

The comparison with the slope indicator shows that the pile will continue in a circular path, either (a) keeping its cross-sectional area intact and remaining dry or going beyond its elastic limit; (b) "crimping" and rupturing itself into a "wet", rejected condition; or (c) the pile will straighten out and continue to a "tangential" alignment after its initial directional change.

Regardless of the interpretation (tangential or circular), the following conclusions can be made about the displacements prior to entering the darkened portion of the pile:

1. For plumb piles when point B is recorded, the displacement from axial alignment at the depth is always one diameter. When point C is recorded, the displacement from axial alignment increases to something less than two diameters. Geometrically, it can be proved that this value will be two or more diameters, only if the distance from the top of the pile to point B equals or is less than the distance from point B to point C, which, from a practical point of view, never happens. For field and conservative purposes, however, the use of two diameters displacement of point C seems prudent.
2. For batter piles when point B is recorded, the displacement from axial alignment at the depth is one diameter only when the sweep is in the direction of the batter (12 o'clock). For piles where the sweep is at right angles to the batter (9 o'clock and 3 o'clock), this displacement is one-half a diameter. For piles where the sweep is opposite the batter (6 o'clock), this displacement is very close to zero. This condition is extremely rare.
3. For batter piles when point C is recorded, the total displacement from axial alignment at the depth is two diameters for 12 o'clock piles. For 3 o'clock and 9 o'clock piles, the total displacement at point C is 1.5 diameters. For 6 o'clock piles, the total displacement approaches zero at point C.

Sketches that show these measurements are included in Figures 3-5. All of the above points should be plotted for general understanding in accordance with Figure 6. Distances such as BC, CD, and BD can be plotted as in Figures 7 and 8 for displacement (sweep) predictions.

JOB SITE PROCEDURE

After the pile is driven and the dust has settled enough inside the pipe, the inspector who just recorded the driving looks down the pile. If he or she cannot see the bottom either with a mirror reflecting the sun or with a flashlight, the pile is marked for further inspection. Either later or at that moment the INTOK inspector is summoned, he or she measures the pile by recording the data (as outlined on the INTOK sheet) to be checked against the curves for an immediate determination of acceptability. If the pile is rejected, a replacement can be installed without sequence interruption.

INTOK CHECK

The INTOK check is completed in the following manner:

1. Check slope of pile below hammer-distorted area (±2 ft) to 5 ft below the top of the pile. In addition, repeat procedure at the 30-ft mark for plumb piles. If sweep is apparent at 30 ft, raise plumb bob to the 25-ft mark, 20-ft mark, etc., as required and record reading. All readings will be taken by using a lowered light or a sun-and-mirror combination. Record direction of bottom of sloped portion. The slope at 5 ft (30 ft) is point A.
2. Lower the inverted light (attached to a tape) down the pile. Record distance from the top of the pile to a point beyond which circumferential light is no longer visible. Record direction toward which light is no longer visible (plan batter direction is 12 o'clock). The start of lost light is point B.
3. Continue lowering light to a point where the light can no longer be seen from any point on the circumference of the top of the pile. Record this

Figure 3. Sweep of plumb pile.

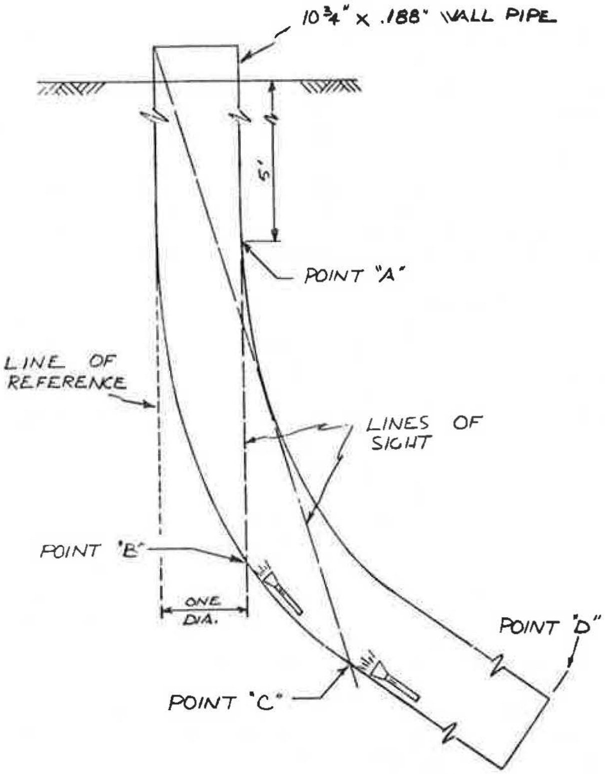
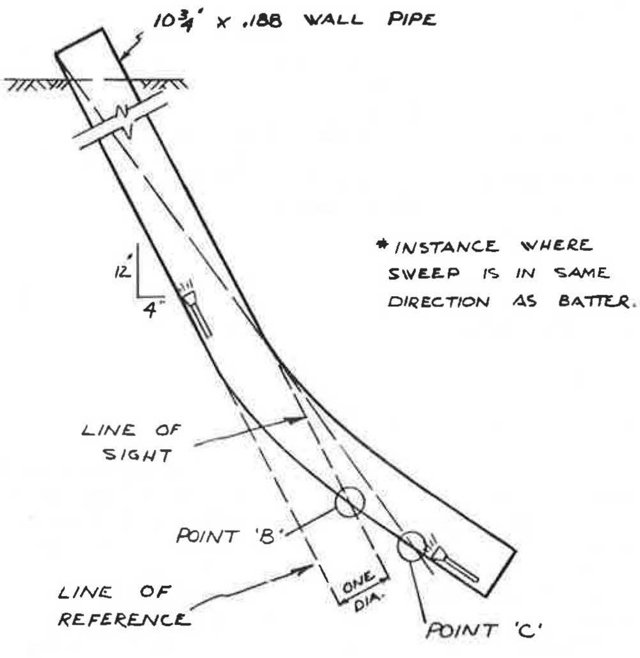


Figure 4. Sweep of 12 o'clock batter pile.

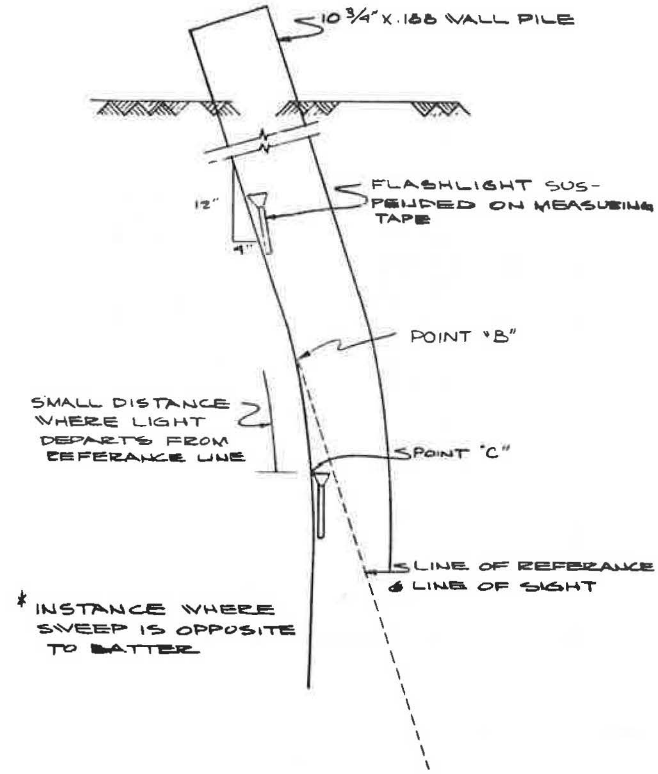


depth. Confirm continuity of direction. Completion of lost light is point C.

4. Continue lowering the light to the bottom of the pile and record sounded depth of pile. Sounded depth of pile will be shorter than driven length of pile by bottom plate thickness and by flashlight length. This is point D.

The above procedures can be performed in any order.

Figure 5. Sweep of 6 o'clock batter pile.



CONCLUSIONS

Although this is not a precise method of determining sweep in a driven pile (or caisson for that matter), it is nonetheless a good field approach toward telling the inspector if the sweep is large or small. For example, if a BC distance is very large and its corresponding CD distance is small, pile sweep is gradual and most probably not troublesome, regardless of total displacement. If the BC distance is very small and CD large, most probably this is a troublesome pile and almost an on-the-spot rejection. These are extremes, and if they are known immediately, production may not have to be interrupted.

When the in-between cases are encountered, the curves must be relied on. In addition, other tools are available, such as a wooden ball that has a diameter 0.5 in less than that of the pipe lowered throughout its length, thus assuring no collapse; a length of inflexible tubing precalculated in its length through which an unacceptable dogleg will prohibit passage; or the use of a pile scan device that actually measures the specific cross-sectional area at the constricted depth (this pile scan is from William F. Loftus Associates).

Another aid that requires interpretation and expertise by the inspector is the length of the reflected light beam of the flashlight itself. Consider a small BC and a large CD distance that normally may result in a rejection. What might alter the inspectors decision if he or she could see the reflection of the flashlight on the wall of the pipe throughout the entire CD distance? He or she may accept the pile after all, and properly so. Indiscriminate rejection is never the job of the good and knowledgeable inspector.

Some parameters that were used for pile acceptance at the Cleveland site are as follows:

1. If point C occurs within a distance of 15 ft

Figure 6. Sample plot of INTOK data with typical accuracy.

Plumb pile—Pile 3-117

Sounded length = 67.07 (point D)
Lost light = 44.67 (point C)
Full light = 26.37 (point B)
% sweep from plot = ±7.0
% sweep from inclinometer = 7.3

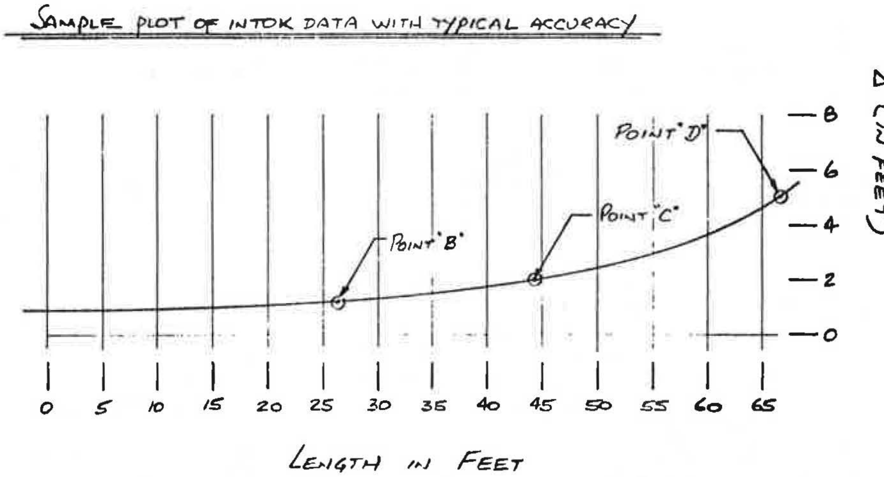


Figure 7. Typical sweep comparison between tangential and circular analyses.

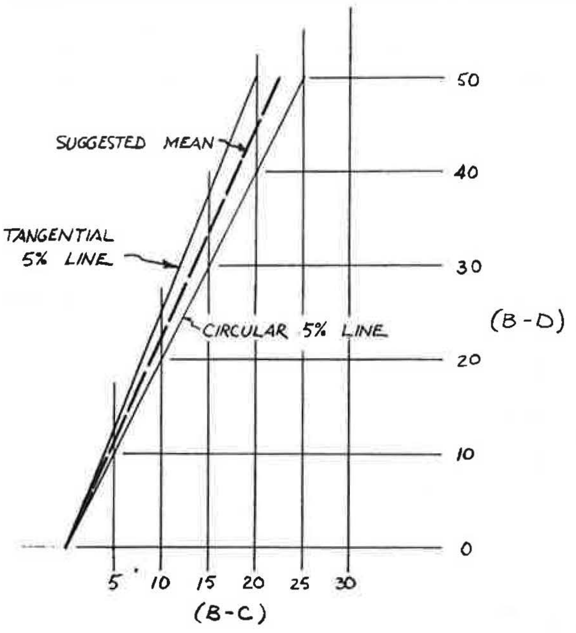
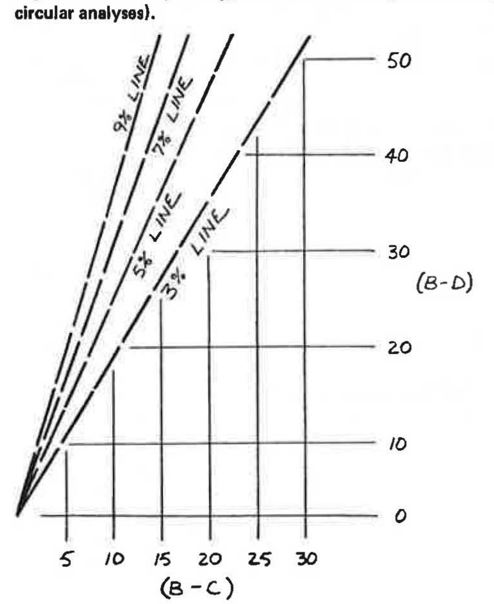


Figure 8. Summary of suggested means for all percent sweeps (tangential and circular analyses).



from the bottom of the pile and point B occurs within a distance of 45 ft from the top of the pile, the pile is acceptable with regard to sweep, provided that no shorter radius of curvature occurs in the unseen portion of the pile and that the top 5 ft of the pile is within a 2 percent tolerance of the out-of-plumbness criterion.

2. If the minimum distance between points B and C (as described in 1) occurs below 45 ft and the plumbness is within the 2 percent tolerance, this pile is acceptable.

3. All piles not covered by the above parameters will be plotted and analyzed further.

The all-important benefit of the INTOK method is that one person can inspect 30 to 40 piles in the same 8-h shift that two persons can inspect in 6-8 h with the use of the inclinometer. Once the data are taken, those values are simply plotted on the graphs (such as Figure 6) and the percentage of sweep is known. Production driving may then proceed with minimal delay.

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