Ground Water Monitoring&Remediation

CPT-Hole Closure

by Thomas E. Noce and Thomas L. Holzer

Abstract

The long-term stability of deep holes 1.75 inches. (4.4 cm) in diameter by 98.4 feet (30 m) created by cone penetration testing (CPT) was monitored at a site in California underlain by Holocene and Pleistocene age alluvial fan deposits. Portions of the holes remained open both below and above the 28.6-foot (8.7 m)-deep water table for approximately three years, when the experiment was terminated. Hole closure appears to be a very slow process that may take decades in the stiff soils studied here. Other experience suggests holes in softer soils may also remain open. Thus, despite their small diameter, CPT holes may remain open for years and provide paths for rapid migration of contaminants. The observations confirm the need to grout holes created by CPT soundings as well as other direct-push techniques in areas where protection of shallow ground water is important.

Introduction

Direct-push technology, which pushes both sensors and samplers into the ground, has become a viable alternative to conventional drilling methods for identifying soils and sampling ground water in unconsolidated sediments. This technology is particularly useful for environmental investigations of sites because it does not produce large quantities of extraneous subsurface material such as cuttings and pore fluids at the land surface as does conventional drilling. Cone penetration testing (CPT) is the most widely used example of direct-push technology. With CPT, a cone that contains two load cells to measure soil friction and penetration resistance is pushed (usually with a weighted truck) into the soil with 1.4-inch (3.7 cm)-diameter steel rods. The cone provides a continuous record of penetration resistance from which other soil properties can be inferred. The soil penetrated by the cone is pushed aside and creates a zone of compacted soil around the hole. Upon completion of the sounding, the cone and rods are pulled from the soil. During retrieval, very minor amounts of subsurface sediment typically are brought to the surface. Although there does not appear to be any published literature that describes the long-term stability of the open hole that results from a CPT sounding, environmental regulations usually require either in situ or reentry grouting to seal the hole.

This paper describes a field investigation that was conducted to assess the long-term stability of open CPT sounding holes. The holes, which were created by CPT soundings in alluvium, remained partially open both below and above the water table for approximately three years. In fact, rates of closure were very low, <1 foot/year (0.3 m/year), when the experiment concluded. The observations confirm the need to grout holes created by CPT soundings in order to protect ground water and prevent the spread of contamination.

Site Geology and Hydrogeology

The experiment was conducted in unconsolidated sediment located at the U.S. Geological Survey western region headquarters in Menlo Park, California. The surficial geological deposit at the site is part of a Holocene age alluvial fan complex. The fan at the site is inferred to be 22.0 feet (6.7 m) thick and consists primarily of clayey silt to silty clay (Figure 1a). It rests on a Pleistocene age alluvial fan unit of unknown total thickness. The underlying Pleistocene fan deposit at the site consists of dense sands interbedded with silty clays and clayey silts. Its precise age is unknown, but it is probably late Pleistocene.

Depth to the water table, which was monitored directly at the site, fluctuated seasonally from 25.9 to 31.2 feet (7.9 to 9.5 m) over the duration of the experiment. Local recharge is primarily by infiltration of annual winter rainfall, but is augmented by streambed infiltration from an intermittent stream that is 0.3 miles (0.5 km) south of the study site.

Description of Experiment

Five CPT soundings were conducted to depths ranging from 37.4 to 98.4 feet (11.4 to 30.0 m). Caliper surveys to measure diameters within each hole were not conducted, but the maximum diameter of the CPT penetration system is 1.75 inches (4.4 cm), the diameter of the friction reducer located 2.0 feet (0.6 m) above the tip of the cone. The friction reducer is a 1.25-inch (3.2 cm)-high ring that enlarges the hole after the cone has penetrated the soil, thereby reducing the friction between the formation and the steel rods used to push the cone. The diameter of the cone is 1.42 inches (3.6 cm). All soundings were clustered within a 50-square-foot (4.65 m^2) area to minimize stratigraphic and textural variations between the soundings. Because localized collapse in a hole could prevent

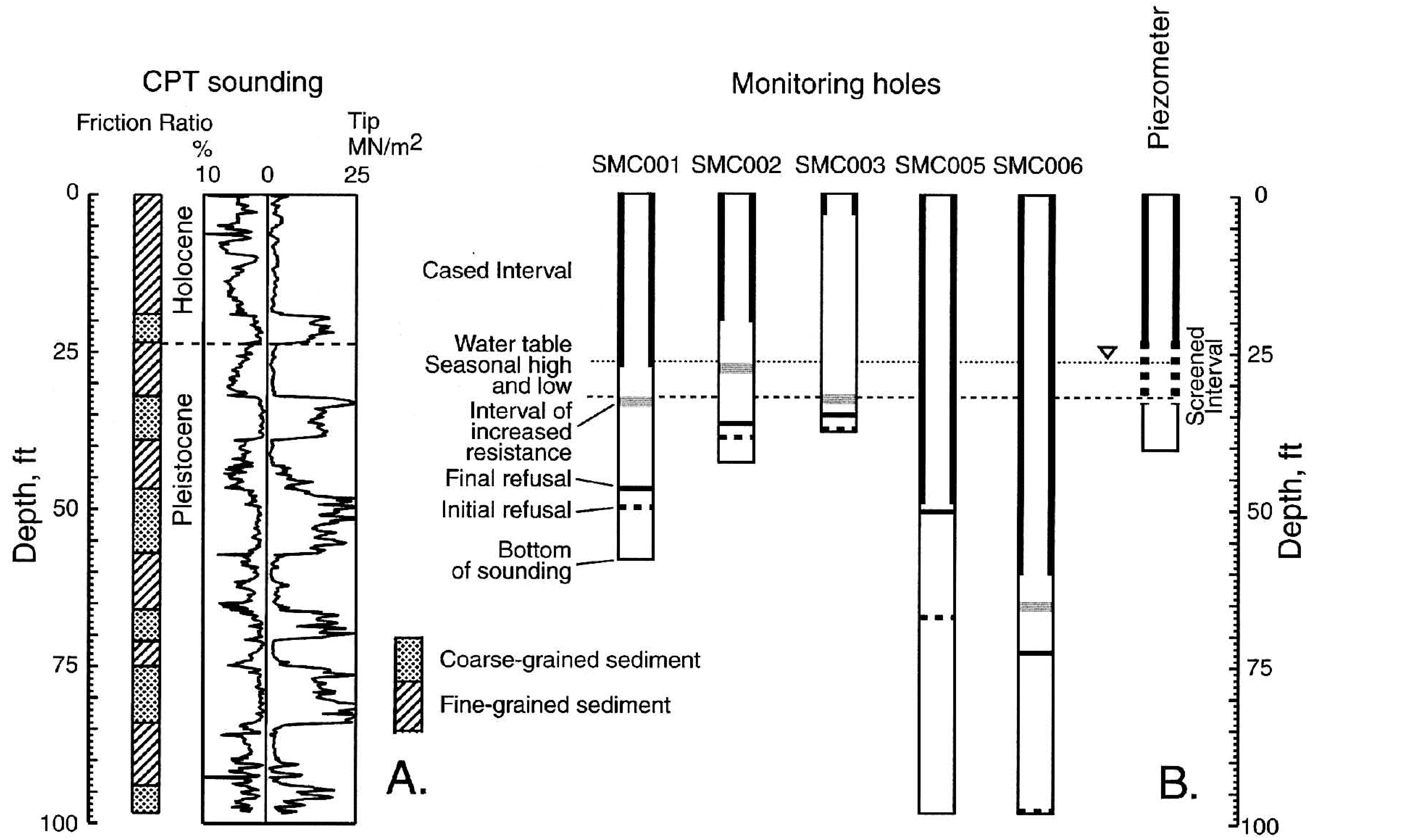

Figure 1. (a) CPT sounding profile with inferred lithology, and (b) monitoring holes and piezometer. Depths of initial and final refusal, respectively, were measured immediately and approximately three years after each sounding was completed.

detection of an open hole below the collapsed portion, holes were cased from the land surface to different depths. By varying the length of casing, different depths in both the Holocene and Pleistocene units could be monitored for closure. For example, if the investigation had consisted of only one uncased hole and only the upper portion of the hole collapsed, there would be no way to determine if the deeper portion of the hole had remained open. Total sounding depths and cased intervals are shown in Figure 1b. A sixth CPT sounding was also conducted to below the water table and a standpipe piezometer, which was screened from 23 to 33 feet (7 to 10.1 m), was inserted to monitor the water table. In addition to casing the upper portion of each hole, casings were sealed at the top with a removable cap to prevent runoff and surface debris from entering the holes.

Casing was immediately installed in the upper part of each hole after completing the CPT sounding. Class 200 PVC irrigation pipe was used to case the holes. The largest diameter pipe that could be consistently pushed to the depth required to case off the desired portion of the soundings was 1.3-inch (3.2 cm) outside diameter (O.D.). It came in 20-foot (6.1 m) lengths with bell couplings premolded on the ends, which provided a smooth 1.1-inch (2.9 cm) inside diameter that facilitated passage of the rods used to determine if the uncased portion was open. The O.D. of the bell couplings was 1.4 inches (3.5 cm). Lengths of casing ranged from 3 feet (0.9 m) in the 37.4-foot (11.4 m)-deep sounding, the shallowest one, to 60 feet (18.3 m) in the 98.4-foot (30 m)-deep sounding, the deepest one (Figure 1b).

To monitor the length of the uncased interval of each hole that remained open, 1-inch (2.5 cm)-diameter aluminum rods in 100-inch (2.54 m) lengths were inserted sequentially by hand and lowered into the hole until refusal. If resistance to the rods was encountered in the hole, the weight of the individual doing the monitoring was applied to the rods. Refusal was the depth at which the individual could no longer push the rods. Initially, the five holes were monitored for closure on successive days. When the holes did not close, the frequency of measurement was slowly decreased from approximately two-day, one-week, one-month, two-month, three-month, and six-month intervals.

Observations

Initial time histories of the depth to refusal in each hole are shown in Figure 2a and the time histories for the duration of the experiment are shown in Figure 2b. Measurements taken immediately after the holes were cased indicated that none of the holes were open to the depth to which they had been sounded (see Initial Refusal in Figure 1b). In SMC001, SMC002, SMC003, SMC005, and SMC006, respectively, the bottom 8.3, 4.2, 2.2, 31.4, and 0.7 feet (2.5, 1.3, 0.7, 9.6, and 0.2 m) filled in within the first day. However, with the exception of SMC005, all holes remained partially open beneath the bottom of casing for the three-year duration of the experiment (see Final Refusal in Figure 1b). Closure in SMC005, one of the two deep holes, was rapid, being complete within 17 days after the sounding (Figure 2a). By contrast, 12.5 feet (3.8 m) or 33% of the 38.4-foot (11.7 m) uncased interval of the other deep hole, SMC006, was still open at day 1049 (Figure 2B).

During the first three days, two holes were temporarily blocked (see SMC003 and SMC006, Figure 2a). Subsequent insertions of the aluminum rods dislodged the blockage. Upon dislodgement, both holes remained open below the depth to the blockage over the duration of the experiment.

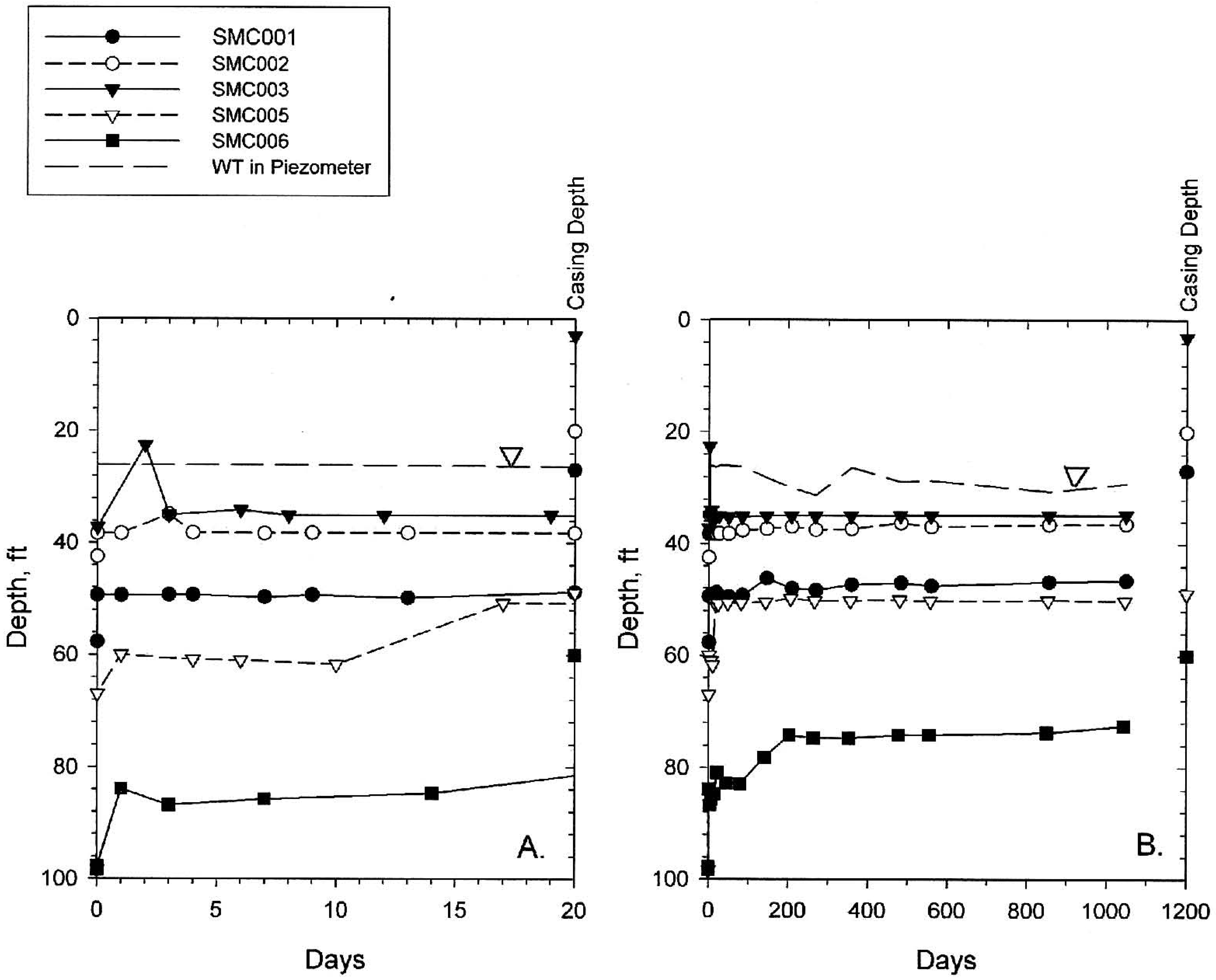

Figure 2. Time histories of depth to refusal in CPT monitoring holes and the water table (WT) at the USGS western region headquarters test site in Menlo Park, California, for (a) first 20 days and (b) duration of experiment. Isolated points plotted on the right abscissas indicate the depth to the bottom of each casing.

Slight resistance before refusal was encountered well above the bottom of most holes early in the experiment. By pushing through the interval of slightly increased resistance, a consistent refusal depth for each of the holes was achieved over the test period. Although these intervals with slight resistance persisted throughout the experiment, their depths were difficult to measure using the probe rods. By lowering a steel tape with a 0.8-pound (0.4 kg) brass weight on the end into each hole, the depth to the top of the uppermost zone of resistance could be measured (see shaded zones in Figure 1b). The thicknesses of the intervals of resistance could not be determined, and the thicknesses shown in Figure 1b are approximate.

Although most of the decrease in the depth to refusal occurred within the first few days after each sounding was conducted, modest decreases in the depth to refusal continued to be observed in all of the open holes for the duration of the experiment. The long-term rates of decrease in the depths of refusal were 0.65, 0.48, 0.11, and 0.70 foot/year (0.20, 0.15, 0.03, and 0.21 m/year), respectively, in SMC001, SMC002, SMC003, and SMC006.

Discussion

With the exception of SMC005, the holes created by the CPT soundings remained at least partially open for the three-year duration of the experiment. Two processes seemed to be contributing to closure: (1) debris falling to the bottom of the hole that caused closure from the bottom up, and (2) local squeezing shut or collapse of part of the hole. A relevant issue is the extent to which insertion of both the casing and aluminum probing rods disturbed the natural processes that promote hole closure and possibly even accelerated closure.

Insertion of the casing was probably more intrusive than insertion of the rods because of the snugness of the fit of the casing to the hole. Most of the decrease in depth to refusal occurred in the holes between the creation of the hole and the first few measurements after the casing was installed (Figure 1b). This suggests that insertion of the casing dislodged significant amounts of sediment. However, there is not a one-to-one correlation between the length of casing and the amount of sediment that was found in the hole immediately after the casing was inserted. In fact, sounding SMC006, which had the longest casing, initially had very little sediment in the bottom of the hole. It is possible that most or some of the initial closure occurred naturally as the CPT was being withdrawn from the sounding.

The cause of the slow, long-term decrease of the depth to refusal is also problematic. Although the measuring rods were inserted gently into each hole, it is possible that each reentry dislodged some sediment from the open portion of each hole. The net amount of the long-term closure does not correlate with the length of uncased portion through which the rods had to pass, which suggests that the rods were not uniformly dislodging sediment. The observation that the frequency of measurement did not correlate with closure rate also suggests that this process was insignificant (see Figure 2b). Taken at face value, the observed long-term rates of decrease in depth to refusal indicate it will take an additional 30, 34, 302, and 18 years, respectively, for the uncased portions of holes SMC001, SMC002, SMC003, and SMC005 to close.

The localized slight increase of resistance to the measuring rods as they were lowered into the hole and the stoppage of a weighted drop line suggest that the holes were squeezing shut for some interval at these depths. The type of natural sediment in these intervals can be inferred from the penetration resistance recorded by the CPT sounding (Figure 1a). The upper interval, which begins at depths ranging from 26.2 to 31.5 feet (8 to 9.6 m) in holes SMC001, SMC002, and SMC003, is silty clay. The lower interval at approximately 65.6 feet (20 m) in soundings SMC005 and SMC006 is silty sand. Both zones occur within Pleistocene deposits. It may be worth noting that the hole that showed the least amount of closure was the shallowest one, SMC003, which was open primarily in Holocene deposits above the water table.

The observations reported here, which were for a stiff soil, do not necessarily imply that all CPT soundings in all types of soil will remain open for long periods after a penetration test is concluded. During the course of this study, attempts were made to conduct a similar experiment in soft estuarine clayey silt overlain by fine-grained fill, but the shallow part of the hole would not stay open long enough to insert casing. This behavior is consistent with prior CPT soundings in these sediments in which gurgling, degassing, and ejection of water out of the hole after cone withdrawal suggested closure was immediate. Other experience during drilling when withdrawing split-spoon samplers from very low-density sands through hollow-stem augers suggests that small-diameter holes would quickly collapse in these soils. It is common for these sands to flow up into and plug the hollow stem of the auger. In contrast, in some CPT soundings, artesian flow emanating from sands below soft estuarine clay has occurred upward through the open hole after withdrawal of the CPT cone, which indicates that hydrogeologic conditions also may contribute to keeping holes open.

Finally, the quality of natural sealing in holes that appear to have closed should be cause for concern. If a hole in clayey sediment is filled with sandy material, it may create both an opportunity for preferential vertical flow through the low-permeability clayey sediment and a conduit for contaminants.

Conclusions

The main message of this investigation is that one cannot assume that all holes created by CPT and other direct-push techniques close rapidly by natural processes. Closure is clearly a very slow process in the stiff soils studied here, and is not even assured in soft soils as suggested by the CPT sounding in estuarine sediment with artesian flow. In fact, the burden of proof is on those who would argue that CPT holes close soon after soundings are completed. Despite their small diameter, CPT holes may remain open for years — and possibly decades — and provide paths for rapid migration of contaminants.

Acknowledgments

The authors thank David A. Stonestrom and John C. Tinsley III of the USGS for their helpful comments in review of this report. We also thank Michael J. Bennett of the USGS for his contribution to the fieldwork and thoughts on the design of the experiment.

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