TDI-BROOKS GRAVITY CPT TOOL

The purpose of the Gravity CPT Stinger (gCPT) tool is to transport a piezocone penetrometer down to the seabed or lakebed to gather dynamic PCPT cone data from the mud line to 5 m or even 10+ m BML. In addition to its 800 kg driving head with lifting bale and coupling, the rig comprises a self-contained PCPT cone penetrometer that measures tip resistance, sleeve friction and pore pressure using standard ASTM cone protocols. The Gravity CPT system is deployed using the same winch, A-frame, and process as for piston coring. When just above mudline, the tool is triggered like a piston corer to ballistically insert itself into the soil.

OVERVIEW

Once the cone insertion into the soil is complete less than 3 sec after trigger, the system is immediately retracted from the seabed and retrieved to the deck. Cone data are downloaded from the probe for evaluation and analysis. The tool is readied for the next deployment, typically in less than 5 minutes, making numerous measurements per day feasible, depending only on water depth and winch speed. The maximum water depth for the gCPT is 4,000m Current tested minimum water depth for successful operation is 10 m.

As a result, high quality in-situ dynamic PCPT data can be rapidly acquired from the mudline to 10 m BML in a safe, rapid, and very cost-effective manner. We have deployed this tool in a lake from a 35 ft long boat, for example. Data from the probe are logged 200 times per second. This logging rate allows the cone parameters to be measured at sediment intervals no larger than 3 cm even at ballistic velocities approaching 5 m/sec. Parameters so logged include tip resistance (mPa), sleeve friction (kPa), pore pressure (mPa), cone acceleration (m/s^2) and cone tilt (°) from vertical. We adjust these dynamic cone data to static CPT data using our database of cone rate effect with soil type. Such comparisons between the static PCPT measurements from the cone push at 2 cm/sec with the rate-adjusted dynamic PCPT data acquired during the tool's insertion have been remarkably good at all test sites to-date (see above discussion of ***Dynamic PCPT Data***). Multiple "pogo" drops for rapid data acquisition along a route are possible with the 4- hour battery logging capacity before retrieving the tool to deck.

After the tool is retrieved to the deck, the PCPT cone is removed from the coupling end of the driving head and brought to a laptop for data retrieval and processing. The resulting data file is opened with a processing program designed for this system. After opening the raw data file, the program performs an integration and double integration of the accelerometer data. In this manner, a very accurate and reliable measure is derived of freefall distance in the water and freefall distance in the soil, as well as the instantaneous velocities of the cone during penetration into the soil.

The program then calculates the proper Tip Resistance baseline, Friction Sleeve baseline, Pore Pressure baseline, an insertion velocity profile with depth, and the cone depth upon coming to rest from ballistic insertion. This file also includes the baseline-corrected measurements of Tip Resistance, Sleeve Friction, and Pore Pressure for the duration of the cone insertion into the soil. In this file, each of the baseline-corrected cone load cell values is individually corrected for the velocity effect on the cone readings. Effective Tip Resistance values are corrected by the following formula:

Adjusted Tip Resistance = Velocity Correction Factor x Baseline-Corrected Tip Resistance

Cone Specifications

a. Tip Resistance (q_c) calibrated to 10,000 lbs (44.5 kN)
b. Sleeve Friction (f_s) calibrated to 1,400 lbs (6.2 kN)
c. Pore Water Pressure (u_2) calibrated to 5,000 psi (34.5 mPa)
d. Vertical Acceleration (m/sec^2) calibrated to ±4 g
e. X and Y Tilt (°) calibrated from vertical to horizontal

The cone has a 15-cm^2 projected end area and conforms to ASTM International Designation: D 5778-07, Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils. It also complies with ISSMGE International Reference Test Procedure for the Cone Penetration Test (CPT) and the Cone Penetration Test with pore pressure (CPTU).

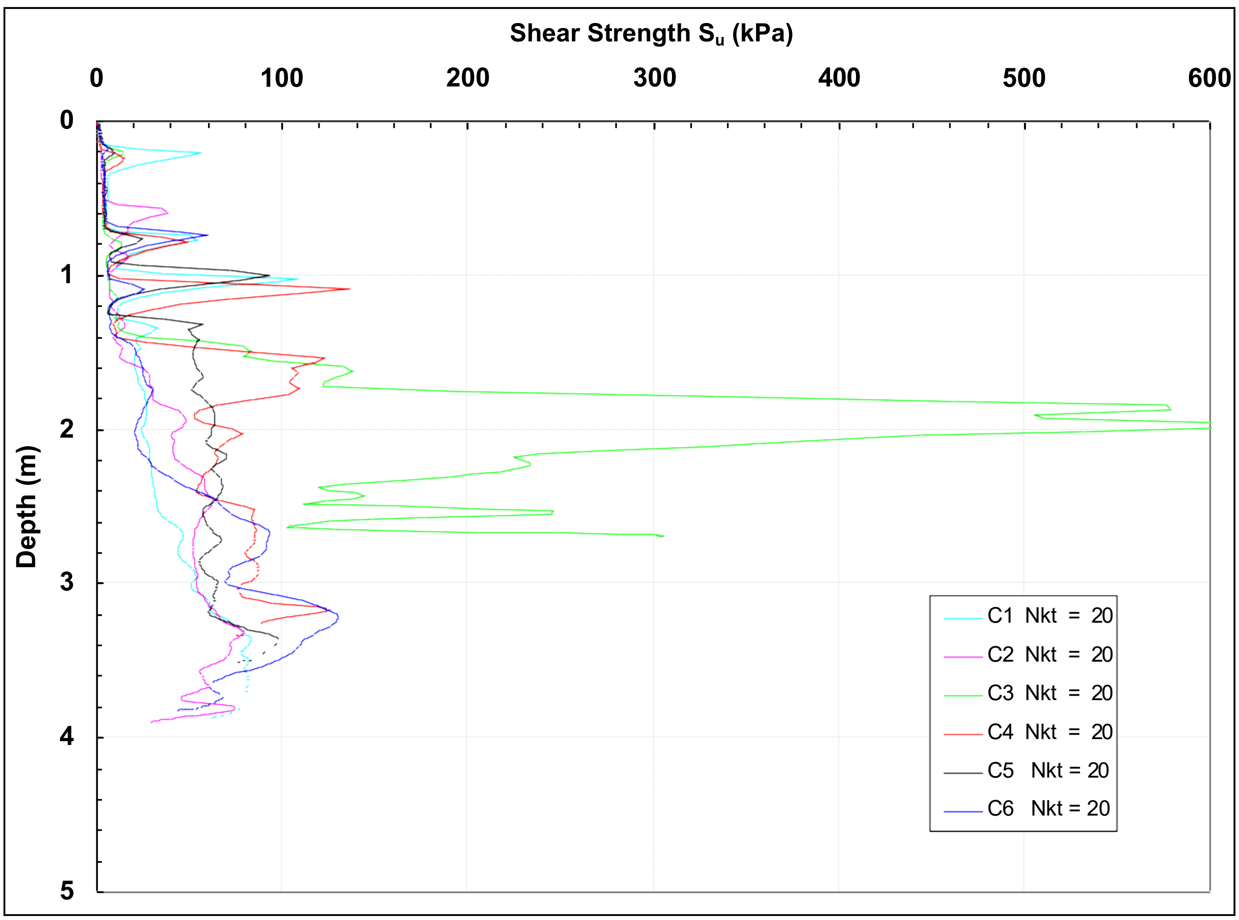
In practice, each of the several hundred baseline-corrected cone load cell values logged during tool insertion into the soil is adjusted for the rate effect on the PCPT cone readings using its individually measured instantaneous velocity. ASTM-equivalent tip resistance values are derived by the following formula, applied separately and uniquely to each data point:

ASTM-Matching Tip Resistance = Velocity Adjustment Factor x Baseline-Corrected Dynamic Tip Resistance

A typical velocity adjustment factor for tip resistance is 5% per decade of instantaneous cone velocity above ASTM rate. Sleeve friction has its own slightly higher velocity correction factor, and pore pressure typically needs no rate adjustment. Velocity adjustment factors have been confirmed again and again by our growing database of side-by-side cone data worldwide.

PERFORMANCE

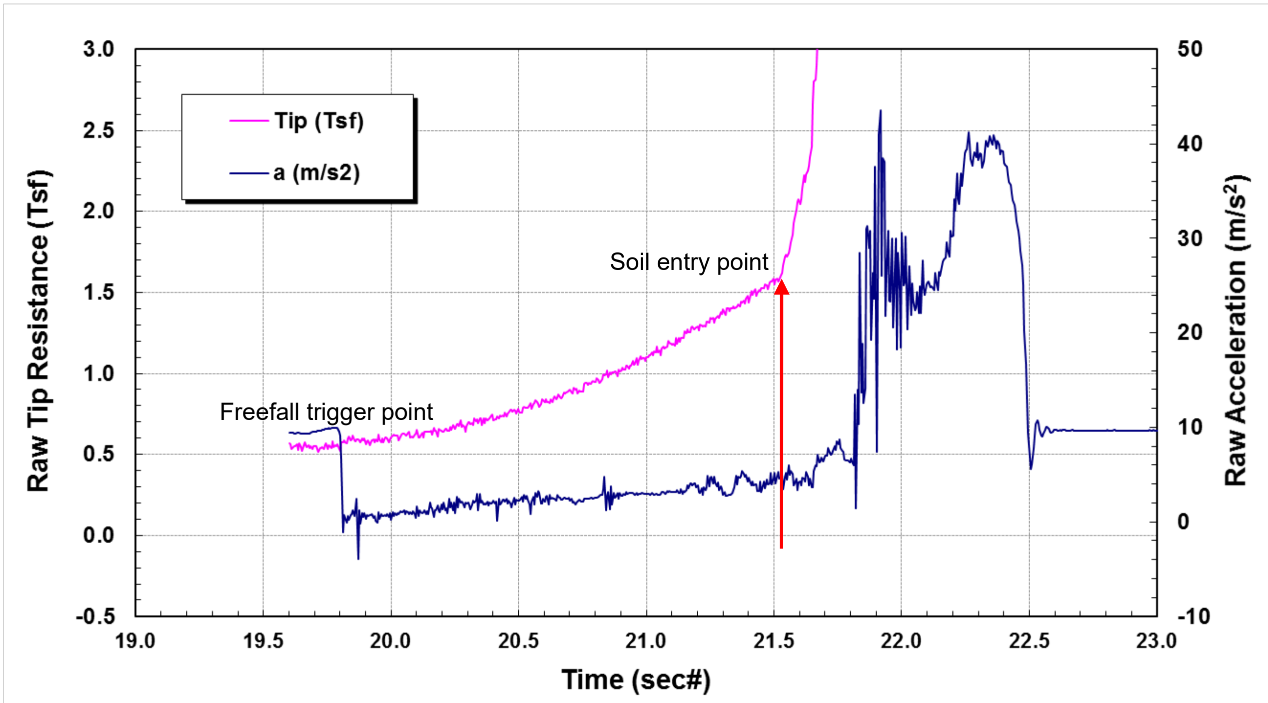
Below is an example of shear strengths derived from tip resistance measured in shallow water, nearshore Texas. The tool can penetrate stiff soils and sand lenses better than competing tools weighing more than twice as much, so the gCPT can be deployed from smaller boats than needed to deploy other tools.



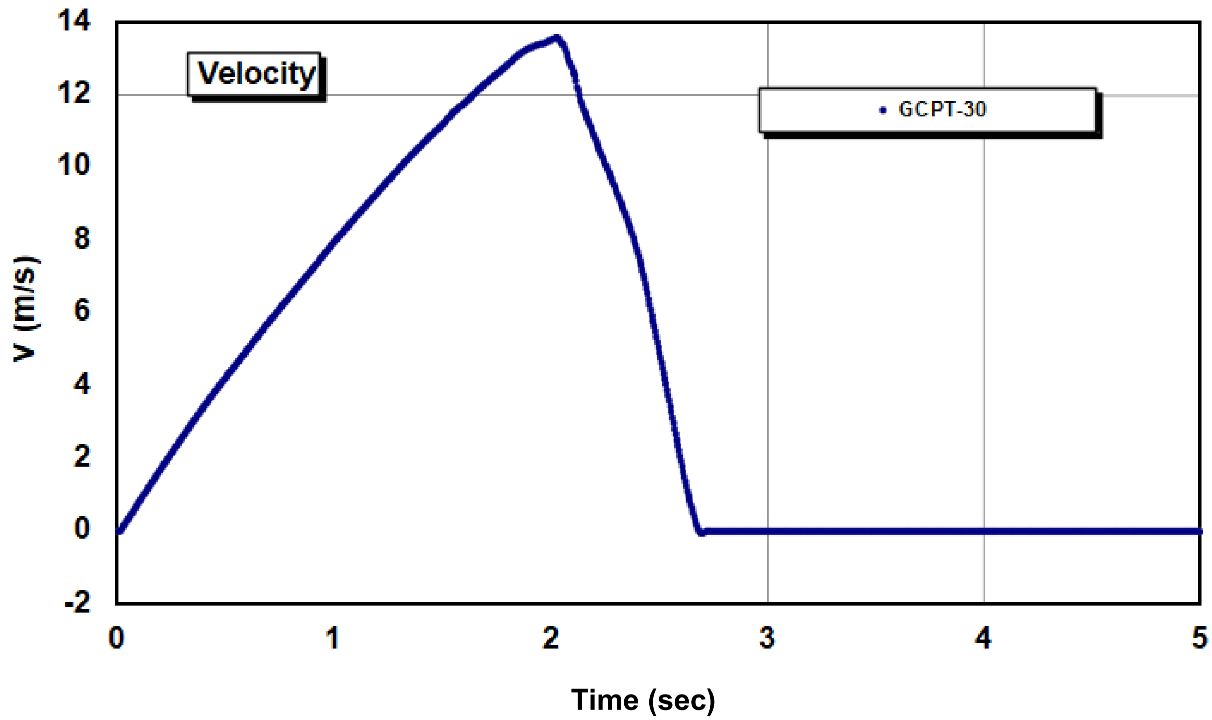
Measurements of Acceleration, Velocity, and Distance Travelled

After the gCPT tool has been retrieved to the deck, the PCPT cone assembly is removed from the end of the tool. The cone's data logger is connected to a laptop computer and the raw data file generated from the cone is copied to the project folder of the laptop.

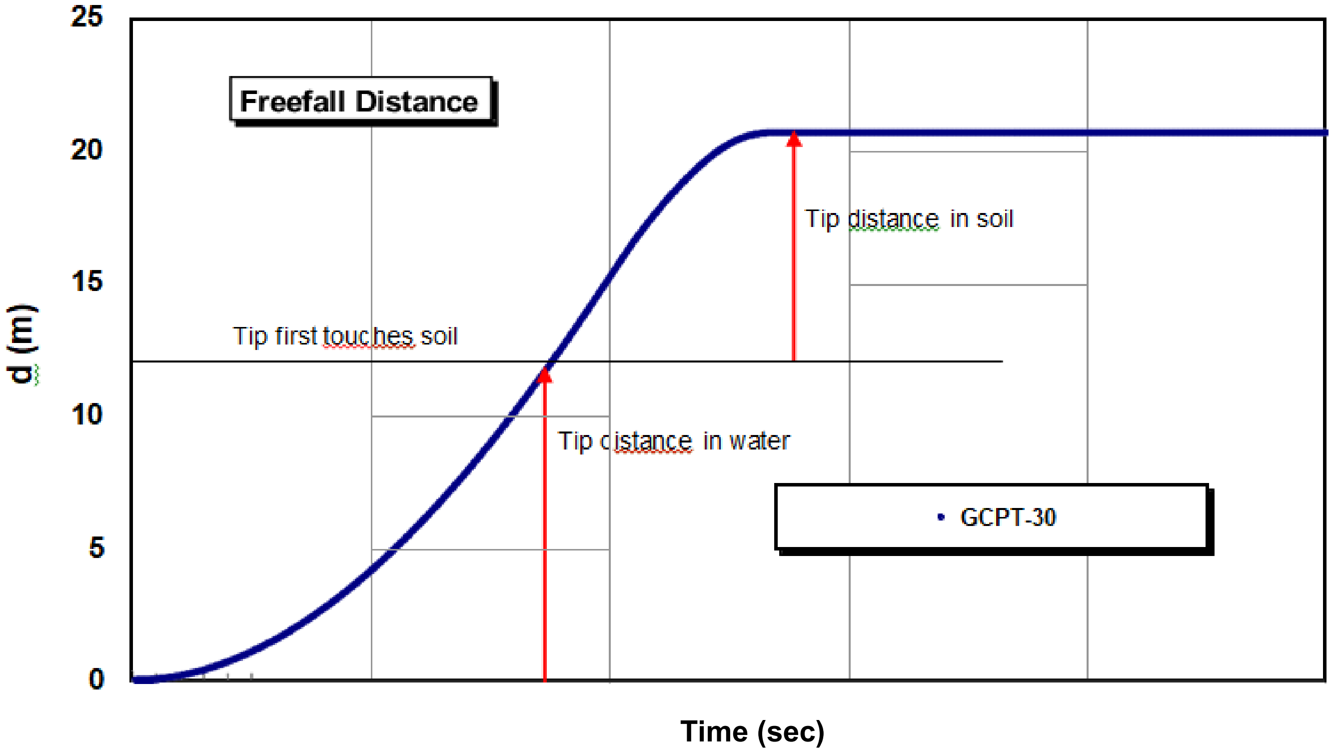
After opening the PCPT data file, the technician selects tool length from a drop-down menu, then uses the program to determine 3 points in time in the graphical data for acceleration and tip resistance. These are: freefall Trigger Point, soil Insertion Point, and post-freefall At-Rest Point. The program then determines the accelerometer baseline (m/s^2) from data logged during a set time interval after the At-Rest Point after the rig comes to rest in the soil. Below is an example of the accelerometer channel during a sounding.
In this example, the triggered freefall occurs at the 19.8 s point in time, the tip first touches the soil at 21.55 s (or about 1.75 s later), and the tool comes to rest at 22.6 s (or 2.8 s later). The elapsed time between the triggered freefall and the soil entry represents the cone advancing through the water, and the elapsed time after that represents the cone advancing into the soil. We are using round numbers in this discussion, but the actual measurements are made to a precision of 0.005 s. In addition, the point of first entry into even very soft soil is easily detected in the tip resistance response, so we know exactly where the tool is with respect to a soft interface, in contrast to other tools that sink into the soil before gathering PCPT data.



From these selected points, the program then integrates the acceleration values with respect to time from the freefall Trigger Point to the post-freefall At-Rest Point. This integration represents the velocity profile over time during this specific time interval. The derived instantaneous velocities are plotted below for the first 5 seconds after freefall trigger for this example from site gCPT-30.

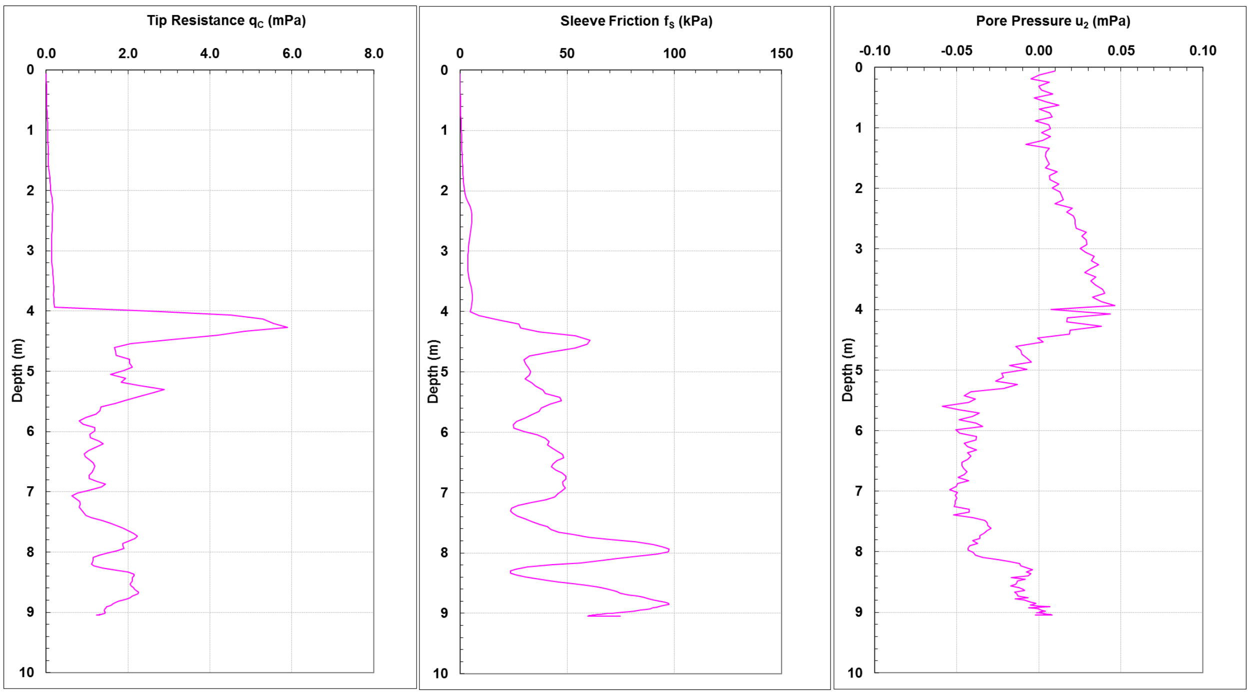


The program then determines the initial velocity (m/s) at freefall trigger from data logged during a specific time interval after the rig comes to rest in the soil, then integrates the velocity values with respect to time from the freefall Trigger Point to the At-Rest Point. This integration represents the profile of distance travelled by the tool over time from the onset of freefall to the time the tool comes to rest in the soil. In this manner, a very accurate measure of travel distance of the cone in the water and travel distance in the soil is derived. The derived distance the cone traveled with respect to time is plotted below for the first 5 seconds after freefall trigger for this example on a site gCPT-30. The dashed line marks the point that the cone tip first touched the soil. Therefore, the exact distance of travel in water and travel in soil is measured, and the instantaneous velocities are known at a time interval of 200 measurements per second.



The program also calculates and logs the proper tip resistance baseline, friction sleeve baseline, pore pressure baseline. Now having a table of instantaneous velocity measurements coincident with the tip resistance, sleeve friction, and pore pressure measurements acquired 200 times per second, the program also individually adjusts the values of for tip resistance and sleeve friction to account for rate effects on these measurements.

The program then produces a CSV file that includes PCPT data for tip resistance, sleeve friction, and pore pressure, as well as instantaneous acceleration and velocities every 0.005 s during tool advance into the soil. Tip resistance and sleeve friction values now have been individually adjusted for the rate effect on the cone readings so that they match values generated at standard advance rates. The rate-adjusted results for this example sounding are plotted below. These plots are typically indistinguishable from side-by-side measurements made at ASTM advance rates, thus proving the process’s validity.



Measurement of Water Depth

One additional feature of this gCPT tool is that, if the height of the tool above or below the water line is known (or purposefully set), then the water depth of the sounding location can be very simply and accurately calculated. For example, for a project in Lake Erie, the deployment team set the rigging height of the top point of the tool at 4.17 ft (1.27 m) above the water line at the point of freefall trigger for each tool sounding. Because (1) we derive from the accelerometer the total distance travelled by the cone tip from the point of freefall trigger to its at-rest point in the soil, (2) we know the distances of cone-tip travel in the water and in the soil by detecting the soil entry point in the tip response, (3) we know the exact tool length from the top point of the tool down to the cone tip by physical measurement, and (4) we know the height of the top of the tool above water by physical measurement (the tip starts underwater but the tool top starts above water), then by simple arithmetic we can calculate the water depth at the sounding location. The error associated with the integrations of the calibrated accelerometer data are less than 0.15 ft (5 cm).