

# TDI-BROOKS GEOTECHNICAL TOOL KIT

TDI-Brooks offers offshore, nearshore, and inland marine geotechnical survey services using a suite of innovative tools for soil sampling and measurement. We have developed a suite of geotechnical analytical services for characterizing offshore geotechnical samples. Our suite of innovative geotechnical tools is for soil sampling and measurement and including box corers (BC), piston corers (PC), gravity corers (GC), jumbo piston corers (JPC), cyclic t-bar instrument (TBAR), deep-reaching Shelby tube samplers (SPLR), and piezocone penetrometers including our CPT-Stinger and our Gravity CPT tool (gCPT).

Our vessels can also be used to accommodate some third-party geotechnical equipment packages. In addition to our offshore geotechnical sampling tool kits, TDI-Brooks can provide soil testing services through our in-house geotechnical laboratory.

Our Geotechnical Toolkit provides high-quality soil samples and in-situ data from the following tools:

- 0.5- and 1-meter Box Corer (BC)
- Double Van-Veen Grab Sampler
- Miniature Vane Systems
- 1-meter Cyclic T-Bar Instrument (TBAR)
- 6- and 9-meter Piston Corer (PC)
- 20-meter Jumbo Piston Corer (JPC)
- 40-meter Stinger Sampler (Shelby Tube)
- 40-meter CPT Stinger (CPT)
- 10-meter Gravity CPT (gCPT)
- Neptune 5,000 Coil Rod CPT System
- Ferritech FT 550 Vibrocorer
- Rossfelder P-5 Vibrocorer
- Multi-Sensor Core Logger (MSCL)
- Standard X-Ray CT System (XCT)



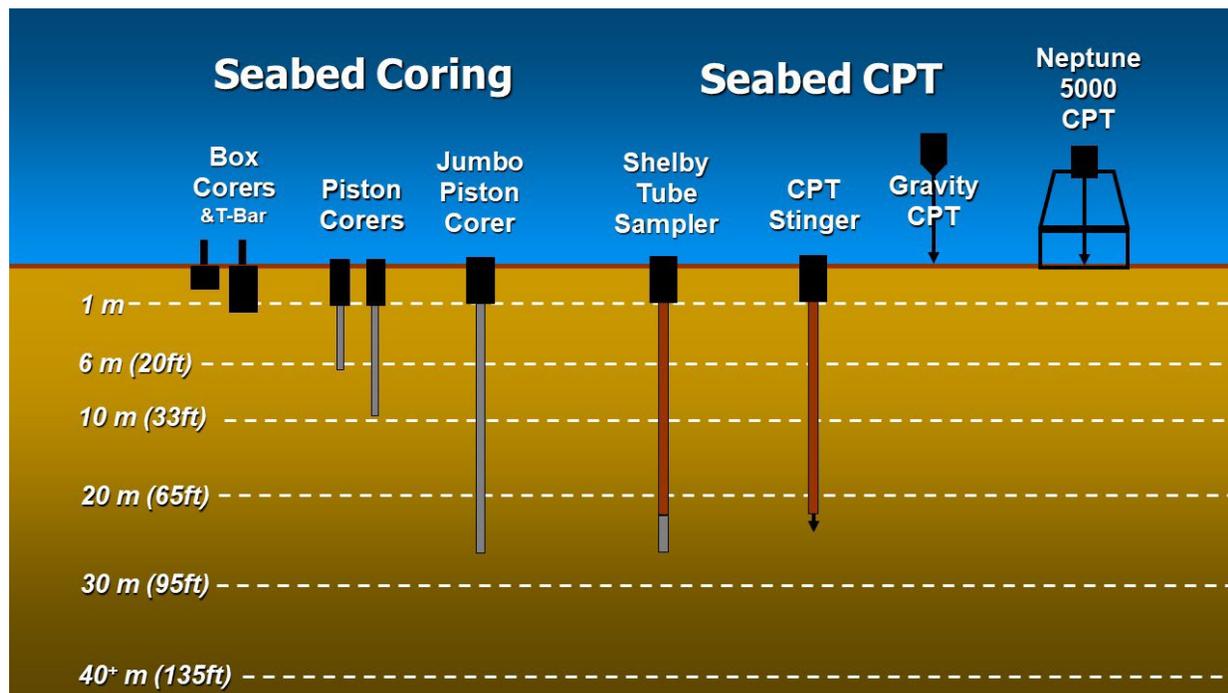
Box Core Recovery



Piston Core Recovery

# OVERVIEW

TDI-Brooks offers offshore, nearshore, and inland marine geotechnical survey services using a suite of innovative tools for soil sampling and measurement, including box corers (BC), piston corers (PC), gravity corers (GC), jumbo piston corers (JPC), deep-reaching Shelby tube samplers (SPLR), and piezocone penetrometers including our CPT-Stinger and our Gravity CPT tool (gCPT). **Figure 1** compares the soil depth below mudline that each of these tools can reach. All of these tools can fully operate in waters as deep as 4,000 m, and each can be fitted with a USBL transponder for precise lateral targeting. The tools are used to perform specified geotechnical and geologic testing on the soil to determine the pertinent physical properties and geologic interpretations.



**Figure 1) TDI-Brooks Marine Geotechnical Sampling Tool Kit**

The coring tools can recover continuous high quality undisturbed soil samples from the marine soil bed using a 50x50x50-cm (½-m-deep) or 50x50x100-cm (1-m-deep) box corer, a 3-inch ID piston or gravity corer, or a 4-inch ID Jumbo Piston Corer. Additionally, ASTM-quality piezocone penetrometer (PCPT) data can be collected using our innovative CPT-Stinger and gCPT tools. The CPT-Stinger gathers high quality PCPT data by being inserted to its full tool length into the soil and converting the acquired dynamic data to static values. It then advances its still- logging cone another tool-length into the soil at ASTM standard rates. The gCPT tool rapidly acquires high-quality PCPT data by inserting its cone ballistically into the soil and converting its acquired dynamic data to static values. All dynamically acquired PCPT data are normalized back to static data values using the known rate effect adjustment applied to the instantaneous insertion velocities measured every 2 ms by the tool. So-adjusted dynamic data profiles match static data profiles with negligible deviation, as we have published and proved with years of side-by-side tests.

TDI-Brooks also offers an innovative and cost-effective formation soil sampling tool called the Stinger Sampler (SPLR). The basic idea behind the deep-water Stinger SPLR system is to “transport” a Shelby tube down through the soil to acquire undisturbed, geotechnical-quality core samples at depths down to 40 m BML, thus nicely complementing the 0-20m continuous JPC soil samples and the 0-40 m continuous PCPT data. In practice, a Shelby tube sample can be acquired at any specified depth down to 40 m, with each successive deployment of the tool.

The economic benefits of quickly and accurately acquiring from a modest-cost vessel several high-quality geotechnical soil samples and PCPT profiles to 40 m BML are readily apparent. These tools allow more high-quality data to be acquired for a given budget, and affords more areal coverage through rapid deployment, compared to the amount of data obtainable from a much more expensive conventional soil boring. Thus, the TDI-Brooks geotechnical seabed sampling kit of tools helps reduce the overall risks associated with foundation design and installation planning.

## BOX CORING (BC) SYSTEM

The TDI-Brooks box coring systems consist of hardware assemblies designed to be rigged together into a working core rig and deployed to the seabed for extracting a standard cubic box core. Such a core is 50cm x 50cm x 100cm (1-m deep) or 50cm x 50cm x 50cm (0.5-m deep) in size.

Our box coring system is designed to be a safe, simple, effective mechanism for acquiring large-volume undisturbed shallow sediment samples from the seabed or lakebed. Such samples are essential for the accurate determination of geotechnical characteristics of submerged sediments, as well as for the assessment of the benthic ecology (infauna) as required in marine environmental impact assessments. **Figure 2** is a photo of both sizes of TDI-Brooks box corer.

The sample box of the core rig is fabricated from stainless steel and is clean and smooth to minimize frictional resistance between the box and the sediment. The corers have an adjustable weight capability so that the weight stack can be fine-tuned to suit the different seabed conditions that may be encountered.



**Figure 2) TDI-Brooks Half-Meter And One-Meter-Deep Box Coring Rigs**

The BC system is rigged to the main coring rope with a safety shackle, and then its trigger assembly is set for deployment. The main coring rope is load-tested and regularly inspected with Tuck eye splice termination woven into its loose end. The main winch, main coring rope, and the coring A-Frame is used for deploying and retrieving the box corer. In addition to the deployed hardware, support gear is mounted to the vessel working deck to manage the deployment and retrieval of the coring rig. These include the heel-block assembly and the main sheave from the coring A-Frame. Once the box corer is safely deployed, it is lowered to the seabed while performing the navigation protocols for lateral positioning, and then a core sample is acquired at the client-specified site.

Upon retrieval on deck the box corer is secured with the safety pin in the closed position and placed on its stand. The lid is opened and the contents inspected for quality and acceptability of the box core sample. The overlying water is siphoned off (gently as the water level approaches the surface of the mud so as to not disturb the surficial layers) to expose the sediment for sub-sampling, descriptions, and photography. The box corer is typically tilted slightly to one corner to facilitate pooling of the last amounts of water. A picture of the BC system with water being siphoned off is shown in **Figure 3**.



**Figure 3) Siphoning Water From The Top Of A Box Core Sample**

The sample is accepted if all the following conditions are met, and re-attempted if not:

- Box core jaws are fully closed and the box core is sealed. Water is not streaming out from the jaws of the closure device.
- Box core lid is closed.
- Overlying water in the box core is mostly clear. A box core sample with muddy water indicates a disturbance of the surficial layers.
- Surface of sediment is undisturbed (soil on the lid is disturbed by definition), not tilted, slumped or washed-out. A sample with a tilted surface (corer sticking at an angle less than perpendicular to the sediment surface) may be used with the appropriate precautions.
- Soil sample depth is greater than the minimum required.

For each cast or drop of the box corer, the following information is recorded on the sample log sheet and the sample labels:

- Date and time on bottom
- Water depth (wire indicator and fathometer)
- Site or Station Number,
- Penetration Depth (distance of sediment surface from lid of corer; soil sample depth is calculated from this)
- Pertinent comments regarding quality, etc. A brief description of the sediment surface noting texture, color, depth of loose surface layer, and any life seen for each box core.
- Digital photographs are taken of surface of representative box cores. Photographs are taken of any unusual surface features.

After the box corer is retrieved on board and is secured in its stand (**Figure 4**), Minivane (**Figure 5**) and/or T-bar (**Figure 6**) testing is conducted at vertical intervals as specified by the client. Minivane readings are recorded on the Laboratory Sample Sheet along with a description of the box core sample. The least disturbed part of the core sample is typically sub-sampled with push-core tubes (**Figure 7**). The bottom ends of these push-core tubes are pre-beveled to produce

a cutting edge no larger diameter than the ID of the tube. The sub-sampling tubes are placed approximately 2 inches apart. A digital photograph is taken.



**Figure 4) Processing the Box Core**

The bottom and top of the tubes are then capped immediately (the bottom capped before extraction from the body of soil in the rig). The tops and bottoms of the tubes are marked and the tubes are labeled. The tubes are stored and secured in a vertical position in a manner that minimizes vibrations and bumping. All tube and bulk samples are delivered to the onshore geotechnical testing laboratory in a timely, uninterrupted, temperature-controlled manner after completion of the coring activities.



**Figure 5) Miniature Vane On Box Core And Torvane**



**Figure 6) T-Bar Measurements On Box Core**



**Figure 7) Box Core Sub-Sampled With Push-Core Tubes**

# DOUBLE VAN-VEEN GRAB SAMPLER

The TDI-Brooks Double Van-Veen Grab Sampler allows for more efficient sampling operations in deeper waters, reducing the time needed on the vessel. Nonetheless, the system is suitable for projects in both shallow and deep waters. The double grab configuration allows sampling operations in any depth of water.

The Double Van Veen Grab is a universal tool ideal for taking dual samples for biological, hydrological and environmental studies, designed for comparable sampling where samples for chemical and also biological analysis are required from the same site.

The use of the Van Veen's grab is very simple which has made it the industry standard for surface sediment sampling.

The Van Veen grab is designed for collecting sediment samples in fresh and marine water, from soft or medium-hard bottoms like sand, gravel, consolidated marl or clay. It consists of two buckets connected by a hinge. During descent, the two buckets remain apart. When the unit hits the bottom, the locking mechanism releases, and when the main line is pulled to retrieve the grab, the buckets close allowing the collection of the sample.

The Van Vee grab sampler has upper windows which allow inspection of the sample or the ability to sub-sample before opening the grab.

The lead-weighted jaws close positively, capturing the sample for secure recovery to the surface. The weights also enable reliable operation in strong currents, and extra weights can be added for hard seabed conditions.



- It has 2 arms that open and close the grab, and includes a chain with an attachment for the main line.
- Includes a locking mechanism that is released on contact with the bottom, allowing the grab to close.
- Has upper windows that allow you to inspect the sample or remove a sub-sample (\*Not available in SG-200).
- Includes 4 lead weights designed to help the grab enter the sediment (\*Not available in SG-200).

The sampling device is composed of two 0.04-m<sup>2</sup> samplers (.08-m<sup>2</sup> total) joined together in a single frame. The target penetration depth is 0.1 m, which is the nominal limit of the grab sampler.

One sample can be collected for benthic infauna (one side of the grab) and the 2<sup>nd</sup> side of the grab for geotechnical measurements at each site. A grab sample is deemed successful when the grab unit is > 75% full (with no major slumping). The grab sampler is recovered from the seabed and back onto the vessel at a velocity which minimized any potential loss or disturbance to the seabed sample.

Collection of benthic grab samples for bulk physical and macrofaunal analysis is collected using a Double Salish (Young-modified) Van Veen grab (**Figure 1**).



**Figure 1. Double Van Veen grab sampler (bottom view)**

The grabs are mounted on a common pivot and each bucket has the capacity to collect a sample of approximately 0.10 m<sup>2</sup>. Similar to the Salish Sea design the double Van-Veen comes with a weight frame and release mechanism which makes it ideal for hard substrates such as clays and gravels.

- Double 0.1m<sup>2</sup> buckets
- Bucket size: 20 cm penetration
- Sampling area: each of 2 at 0.10 m<sup>2</sup>
- Full ocean depth rating
- Inspection lids for easy sampling
- Supplied with deck stand
- Optional lead weights for extra penetration
- Configurable weights for strong currents and hard seabeds
- Material: 316 Stainless Steel

# MINIATURE VANE SYSTEM

The TDI-Brooks miniature vane instrument measures the torque and rotation at a vane shaft using the conventional ASTM method calibrated torque spring set and potentiometer, respectively. Its operation consists of inserting the vane into the soil sample and rotating it at a constant rate to determine the torque required to cause a cylindrical surface to be sheared by the vane. The torque is converted to a unit shearing resistance (shear strength) of the cylindrical surface area. The shear strength reported is the peak strength determined from the torque vs. rotation plot. In addition to the peak shear strength, the residual strength is determined from the same plot if the failure is not dominated by cracking of the sample. In the analysis of vane tests, it is assumed that a cylinder of sediment is uniformly sheared around the axis of the vane in an undrained condition with cohesion as the principal contributor to shear strength.

The standard motorized vane apparatus rotates at a constant rate of 10° per minute and includes the standard 0.5" x 0.5" (12.7 x 12.7-mm) vane. The special ASTM version S2301 has a speed of rotation at the faster rate of 60 to 90° per minute to conform to ASTM D4648 and is supplied with the alternative vane measuring 1" x 1" (25.4 x 25.4mm). Load on either version is applied through one of the 4 calibrated springs supplied. These springs are kept recently calibrated and a certificate of such is provided. A second calibrated spring set is provided for backup. The serial number of the spring set in service is recorded on each datasheet. **Figure 1** is a photo of one of our Minivane instruments, calibrated torque spring sets, and vanes ready for service.



**Figure 1) TDI-Brooks Minivane System, Ready For Service**

## AUTO T-BAR SYSTEM

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The TDI-Brooks Auto T-Bar instrument measures the progressive resistance of a soil column to a cylindrical rod (shaped as an upside-down **T**) as it advances down the soil column at a constant and standard rate of travel. The instrument is shown in **Figure 1**, with its T-bar protruding below.

Operation consists of mounting the instrument onto a box corer containing an undisturbed seabed soil sample, connecting the instrument to a shipboard source of compressed air, and starting the automatic advance of the T-Bar into the soil sample. The resistance of the soil is automatically logged during the downward advance until the bottom of the soil sample is reached by the T-bar. The instrument then reverses T-bar movement and logs the soil resistance generated during the upward, retracing return of the T-bar back up to any desired soil depth or to the surface. This sequence of a downward stroke followed by upward re-trace through the failed soil can be continually repeated as many times as desired. Sets of 10 to 30 such cyclic T-bar tests are typical in box cores.



**Figure 1) TDI-Brooks Auto T-Bar**

The instrument measures and logs the soil's resistive force on the T-bar 10 times per second. The T-bar typically auto-advances at 2.0 cm/sec, so a data set is logged every 2 mm of penetration (this standard rate of advance can be changed to address differing client specifications). A single down-stroke test to 100 cm soil depth thus takes 50 seconds with 500 resistive force measurements logged (**Table 1**). The resistive force is reported in pounds or newtons, and is converted by the processing program into units of pressure (ksf or kPa) by dividing by the cylindrical cross-sectional area of the T-Bar. The standard (medium) T-Bar cylinder diameter is 1.00 in. and its length is 5.00 inches. Smaller T-bars (0.75 in. and 0.50 in. dia.) are also available for quick change-out, each with cylinder length 5 times its diameter. The push rod is sleeved, rendering its frictional drag during advance in either direction to have no measurable component. The calibrated range of the tool is -100 lb. (445 N) upstroke to +100 lb. downstroke, which translates using an  $N_{t-bar}$  of 10.5 to maximum measurable undrained shear strengths of about 275 psf (13.2 kPa) using the large bar, 500 psf (23.9 kPa) for the medium bar, and 1,100 psf (52.7 kPa) for the small bar. An example of 30 cyclic auto T-bar measurements into a 1m deep box core sample are plotted in **Figure 2**.

In this figure, the pink trace represents the initial downward stroke of the T-bar into the soil. The two (right and left) nested sets of blue traces are the subsequent progressive upstroke and downstroke data, with the inner traces being the 30<sup>th</sup> and final stroke set. All measurements have been converted using an  $N_{t-bar}$  of 10.5 to represent undrained shear strength. This plot illustrates the progression of soil reworking toward fully remolded character during the course of the 30 sets of strokes. Such a data set can thus be used to project fully remolded values at selected soil depths.

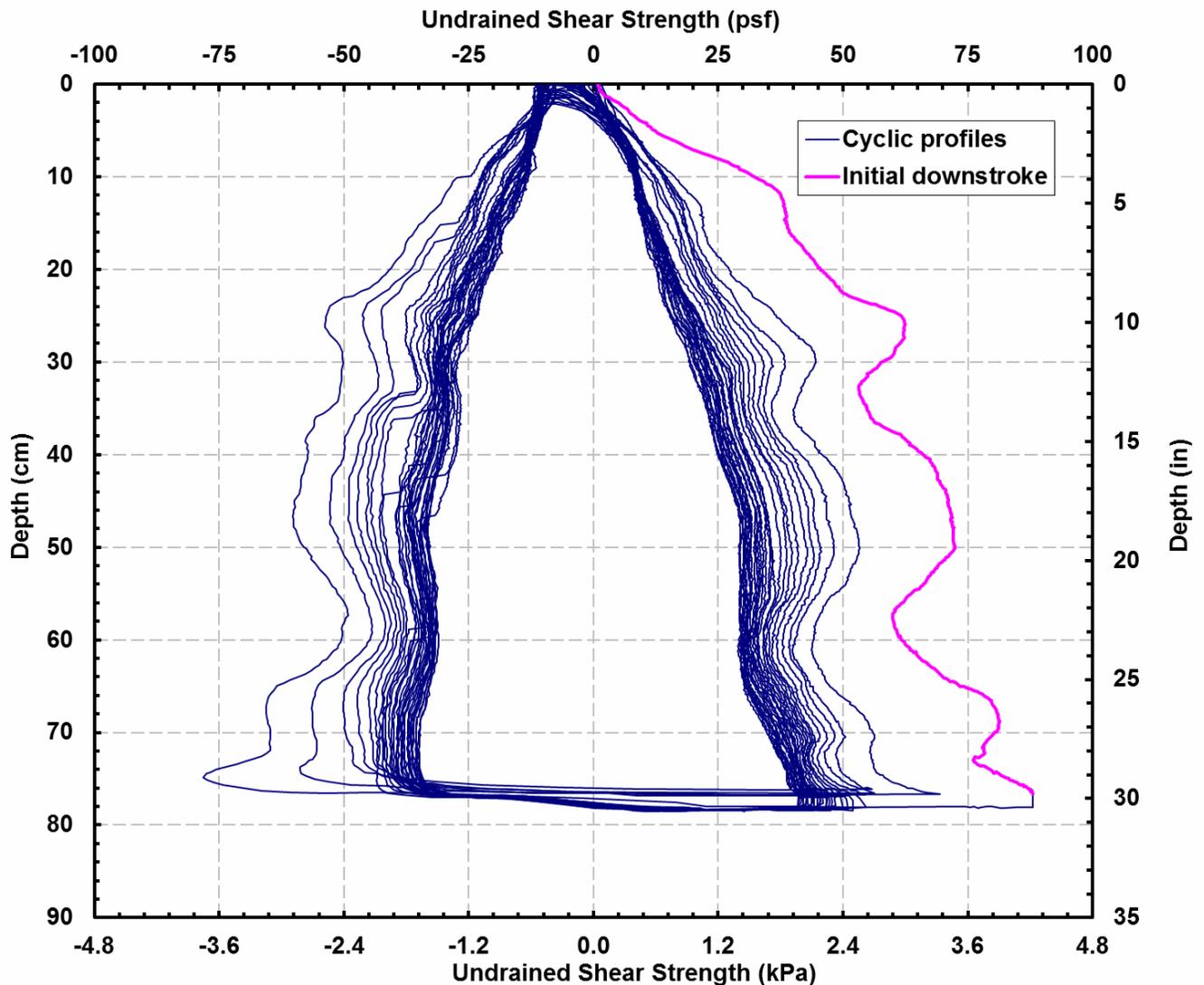


Figure 2) Example Plot Of Auto T-Bar Cyclic Data

1. **Parameters Measured:** The instrument measures the following at a rate of 10 times/sec for up to 3 hours:
  - a. T-bar Resistance (ksf)
  - b. Displacement or stroke advance (cm)
  - c. Load cell temperature ( $^{\circ}\text{C}$ )
  - d. Elapsed time (sec)
  - e. Vertical Velocity (cm/sec)
  - f. Manual events logged by button-push
2. **Conformance:** The instrument conforms to DeJong et al, Recommended Practice for Full-Flow Penetrometer Testing and Analysis, *Geotechnical Testing Journal*, Vol 33, No. 2, Paper ID GTJ102468, 2011, available from ASTM.
3. **Calibration Certification:** Load cell and stroke advance calibrations are performed prior to each job. Calibrations are certified as correct by an engineer with knowledge and experience materials testing for quality assurance. Applied forces are traceable to those retained by NIST.
4. **T-Bar dimensions:**
  - a. Large T-bar: 5.00 in. long x 1.00 in. diameter, with a resulting cylindrical cross-sectional area of 0.03472 ft<sup>2</sup>
  - b. Medium T-bar: 3.75 in. long x 0.75 in. diameter, with a resulting cylindrical cross-sectional area of 0.01953 ft<sup>2</sup>
  - c. Small T-bar: 2.50 in. long x 0.50 in. diameter, with a resulting cylindrical cross-sectional area of 0.00868 ft<sup>2</sup>
  - d. Push rod: 0.313 in. dia x 38 in. stroke
  - e. Push rod sleeve: 0.50 in. dia with 4.5 in. length of push rod exposed below sleeve bottom end
5. **T-bar Resistance Range:** Resistance is measured by a strain gauge attached to a temperature compensated load cell. Load cell calibrated range is 100 lb. Full scale response corresponds to a T-bar resistance in either advancing direction of
  - a. Large T-bar: 2,880 psf
  - b. Medium T-bar: 5,120 psf
  - c. Small T-bar: 11,520 psf
6. **Shear Strength Range:** Full scale response corresponds to an undrained shear strength using  $N_{t\text{-bar}} = 10.5$  of
  - a. Large T-bar: 275 psf
  - b. Medium T-bar: 488 psf
  - c. Small T-bar: 1,097 psf
7. **Materials:** The T-bars, push rod and sleeve are made of high strength stainless steel of a type and hardness suitable to resist wear due to abrasion by sand.
8. **Tool Dimensions & requirements:**
  - a. Stand width: 9.0 in.
  - b. Stand depth: adjustable from 9.313 in. to 9.875 in to securely mount in box corer
  - c. Height with T-bar retracted: 54.0 in.
  - d. Weight: 43 lb
  - e. Rod stroke: 38 in. by pneumatic to hydraulic power using compressed air to water
  - f. Battery life: 4 hours, rechargeable and indefinitely extendible with 115 VAC
  - g. Push power: Compressed air pressure: 1 CFM at 110 psi, duration indefinite, no use of electrical power.

**Table 1) Auto T-Bar Specifications**

# PISTON CORING (PC) SYSTEM

The TDI-Brooks 3-inch-diameter piston coring (PC) system consists of various hardware assemblies designed to be safely and robustly fastened together into a working core rig and deployed to the seabed for extracting a piston core. Such a core rig can be assembled to be 10 to 40 feet long and is 3 inches in barrel ID. An example of a core rig ready for deployment is shown in **Figure 1**.

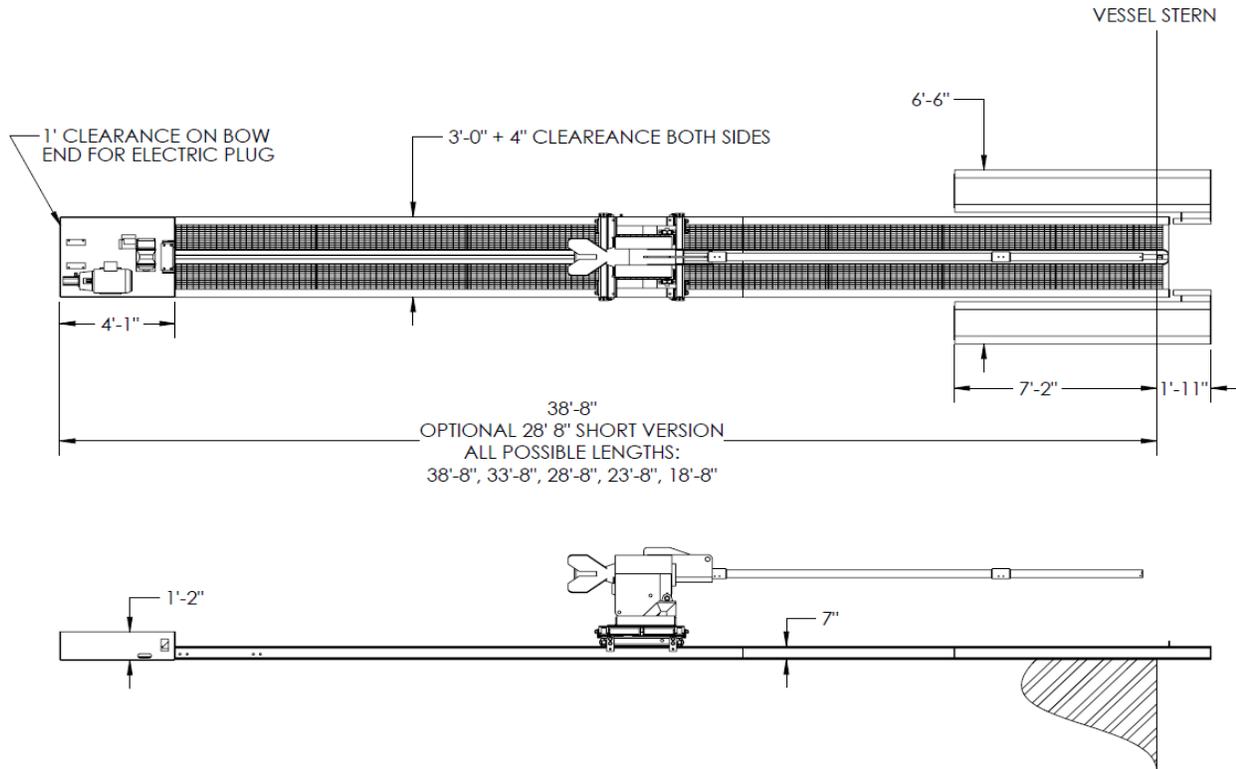
The deployed core rig comprises component assemblies of the core head, the core barrel, the piston, and the trigger system. The core head assembly is made up of a 2,000 lb. lead-weighted core head with nosepiece and a coupling with which to attach lengths of core barrel sections. It also has a lifting flange assembly that attaches to the trigger system. The trigger assembly is made up of the trigger pendant, trigger arm, pendant clamp, trigger weight, trigger wire, and trigger wire connecting system. The core barrel assembly is made up of selected lengths of core barrel sections, connecting collars, a core liner inside the barrel assembly, a core catcher, a core cutter, and set screws to hold the barrel assembly together. The barrel length can be adjusted in 5-foot increments by adding 5 or 10-ft barrel sections and connecting collars. The rig shown in **Figure 11** has a barrel that is 20-ft long, using one 10-ft barrel section and one 5-ft barrel section, and with the uppermost 5 ft of barrel built inside the core head. The extended piston corer (XPC) employs an additional barrel section and a longer trigger pendant.

The main winch, main-line coring rope, and the PC coring A-Frame are used for deploying and retrieving the 3-in. piston core rig on TDI-Brooks vessels. In addition to the deployed hardware, several assemblies are mounted to the vessel working deck to manage the deployment and retrieval of the coring rig. These assemblies include the main sheave from a starboard or port-side coring A-Frame, as well as core-head and trigger tugging winches with their hydraulic power pack.



**Figure 1) TDI-Brooks 3-Inch Piston Coring Rig**

We also have a deployment system for use on 3<sup>rd</sup>-party vessels not having a provision for a side-mount A-frame. This system includes a stern deployment track in addition to the kit described above. A schematic with dimensions is shown in **Figure 2**. A photo of the system in operation on a 3<sup>rd</sup>-party vessel is shown in **Figure 3**.

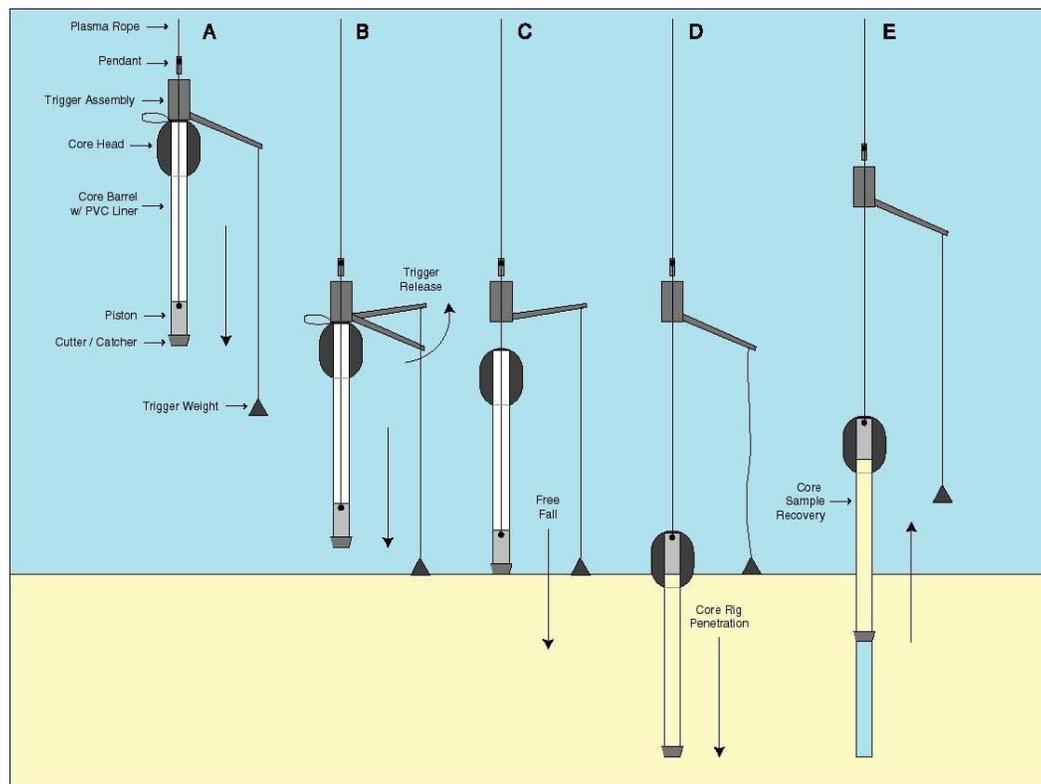


**Figure 2) TDI-Brooks 3-Inch Piston Coring Track For 3<sup>rd</sup>-Party Vessels**



**Figure 3) TDI-Brooks 3-Inch Piston Coring Track On A 3<sup>rd</sup>-Party Vessel.**

A piston corer uses a free fall of the coring rig to achieve the desired initial force on impact, and a sliding piston inside the core barrel to reduce inside wall friction with the sediment and to assist in the rapid evacuation of displaced water from the top of the corer. These elements act in concert to maximize core recovery. It uses a trigger assembly to release and allow the corer to free-fall with the core barrel tip starting just above the seabed. The impact speed of the piston corer into the bottom is independent of the winch payout speed. Proper pendant and trigger wire lengths, as well as stopping the winch payout upon trigger, are critical for the proper action of the piston within the barrel. The sequence of piston coring events is shown in **Figure 4**.



**Figure 4) Schematic Of A PC Or JPC Operation At The Seabed**

Referring to the schematic: As the corer nears the bottom (**A**), the winch payout speed is slowed and preparations are made to stop the payout at the instant of release. As the trigger weight impinges the seabed (**B**) the weight is released from the trigger arm, and the trigger arm begins to rise with respect to the rig. At this point, the core barrel tip is still above the seabed. When the trigger arm has risen through its full travel (**C**), the corer is mechanically released to free-fall down through the seabed. At this point, the barrel tip of the corer is just above the seabed, as programmed by the proper length of the trigger wire. The moment of release is noted by the Winchman as a sudden drop in main line tension. At the instant of release the payout of the winch is stopped, thus fixing the length of coring rope out. The corer separates from the trigger assembly and free-falls through the seabed, penetrating the upper several meters of sediment. When the falling core rig reaches the end of its pendant slack, the internal piston stops moving downward along with the core rig (**D**) and becomes fixed with respect to its height about the seabed. The still-falling core barrel then creates suction (much like a syringe and its plunger) between the piston and the soil entering the barrel, enhancing the distance the soil sample will move up the barrel.

The length of the trigger wire, the length of the pendant, and the halting of the rope payout are in concert such that the main rope becomes taut just as the core cutter at the bottom of the barrel comes within a few inches of the seabed. This results in a core with about a few inches of water head between the bottom of the piston and the soil surface inside the liner. When downward momentum of the core has stopped with complete penetration, a slow pullout on the winch is begun.

At the initial stage of pullout, the piston slowly moves to the top of the core barrel in response to the Winchman's tension on the core wire. The piston has a built-in check valve so that water can pass through it when it is moving at slow speed (E). It fetches up against the stop in the core head, and the corer is pulled from the seabed.

Retrieval after pullout can proceed as fast as the winch is capable. Winch speed is typically 60 to 80 meters of line per minute. The piston prevents washout of the sample from the top, and the core catcher prevents the sample from backing down out of the barrel tip. In extremely sandy areas, if core material is lost during the retrieval process, typically a "sock" is put in the core cutter to act as a one-way valve, and re-sampling at the site is performed in an attempt to obtain greater recovery.

A picture of the core rig barrel end with the cutter and catcher removed to show the internal piston protruding is shown at left in **Figure 5**. The core liner inside the barrel is visible. At right the installed cutter/catcher/piston assembly is shown. To rig the PC system, a load-tested PC pendant is inserted with one end hanging out the bottom of the core barrel and the other end hanging out the top of the core head. A piston pin is installed to connect the bottom end of the pendant to the piston (the pin is barely visible in the photo), and then the piston, catcher, and core cutting shoe are mounted to the bottom end of the core barrel with set screws.



**Figure 5) Barrel End Of The PC Rig With Piston Showing**

The trigger assembly is attached to the top 3 ft section of the pendant by clamping the trigger assembly bar on the pendant, and then properly configuring and securing the trigger assembly to the core head assembly. The system is rigged in such a way that the pendant wire rope will come out of the core head with the proper amount of extra loop available, as dictated by the core barrel length and soil strength at that location. This results in programming a free-fall loop in the pendant of precise distance.

All of the described lifting/rigging gear is regularly load tested and inspected. The main coring rope have a load- tested and inspected Tuck eye splice termination woven into its loose end. The pendant is connected to this termination using a pendant pin. This assembly is designed to roll through the sheave and heel block. For this reason, a rope thimble is not used in the termination loop, because the roll-thru-the-sheave acts with the thimble to incrementally cut and wear the rope over time.

The main winch, main coring rope, and the port A-Frame are used for deploying and retrieving PCs. In addition to the deployed hardware, several assemblies are mounted to the vessel working deck to manage the deployment and retrieval of the coring rig. These include the track/bucket/heel-block assembly, the main sheave from the port A-Frame, and the core head and trigger tugger winches with their hydraulic power pack.

Safety precautions are paramount in our coring procedures and are regularly reinforced through safety meetings, JSAs, toolbox meetings, and other elements of our Safety Management System.

The following is a summary of our PC sample processing procedures:

Upon core retrieval, the core liner is removed, carefully carried and placed in the processing trough, and cut into 3-foot lengths. The core liner is marked with a water proof marker into 3-foot long lengths, starting with the top section. For PCs, the top section is a 3-ft section because the top-most sediment is very soft and a short section is difficult to handle and to measure for soil strength. (*NOTE: these cores will virtually always have one short or long “odd” section, due to recovery length not being an exact multiple of 3 ft. The short section of a JPC will be the top section, whereas the odd section of a PC will be the bottom section.*) Each section is numbered with a Section Number and an arrow pointing to the top.

The bottom end of the section is capped immediately after cutting. The top and bottom of the liner section are marked as outlined in a **Field Sediment Testing Protocol**. This information is recorded immediately in the Core log. Any smell of hydrogen sulfide (rotten egg smell) is noted on the log.

A digital photograph is taken and a visual description of each section is recorded. Lab testing as outlined in the **Field Sediment Testing Protocol** is performed and the top of the core section is capped. Top and bottom caps are securely taped to the liner. The core sections are stored and secured in a vertical position with the deeper portion of the section on the bottom. The core sections are stored in a manner to minimize individual movement with vessel heave, pitch, and roll. After completion of the coring activities, the core sections are delivered to the onshore geotechnical testing laboratory in a timely, uninterrupted manner.

## JUMBO PISTON CORING (JPC) SYSTEM

The TDI-Brooks jumbo piston coring (*JPC*) system consists of various hardware assemblies designed to be fastened together into a working core rig and deployed to the seabed for extracting a “jumbo” piston core. Such a core rig can be assembled to be 34 to 64 feet long and is 4 inches in barrel ID (**Figure 1**). The deployed core rig comprises assemblies for the core head, the core barrel, the piston, and the trigger system. The core head assembly is made up of a 5,000 lb. lead coring weight with an inserted flange-barrel and coupling with which to attach lengths of core barrel in 5 and 10 ft. sections. It also has a lifting assembly that attaches to the trigger system. The core barrel assembly is made up of selected sections of core barrel, connecting collars, a core liner assembly inside the barrel assembly, a core catcher, a core cutter, and set screws to hold the barrel assembly together. The barrel length can be adjusted in 5-foot increments by adding these barrel sections and connecting collars.



**Figure 1) TDI-Brooks Jumbo Piston Coring Rig**

The trigger assembly is made up of the trigger pendant, trigger arm, pendant clamp, trigger weight, trigger wire, and trigger wire connecting system. The assembled core rig weighs between 5,500 and 7,500 lb., depending on the length of core to be acquired. The weight of the core head is adjusted by adding weight as lead ingots to a starting weight of about 5,000 lb.

The TDI-Brooks extended jumbo piston coring (**XJPC**) system consists of various hardware assemblies designed to be fastened together into a working core rig and deployed to the seabed for extracting an even longer piston core. Such a core rig can be assembled to be 74 feet long and is 4 inches in barrel ID. This additional length is made possible by adding track extensions to the forward end of the track. These extensions can be quickly removed and secured for core processing.

The main winch, main-line rope, and the stern A-Frame are used for deploying and retrieving the JPC rig. In addition to the deployed hardware, several assemblies are mounted to the vessel working deck to manage the deployment and retrieval of the coring rig. These assemblies include the main sheave from the stern A-Frame and the deployment, retrieval and trigger tigger winches with their hydraulic power pack.

As the JPC trigger weight impinges the seabed and the trigger arm rises, the corer is released to free-fall into the seabed. At the moment of release, the payout of the winch is immediately stopped, thus fixing the length of coring rope out. The corer separates from the trigger and free-falls the mechanically-programmed distance into the seabed. The piston is set to stop moving vertically down when it is just above the seabed, but the core barrel continues to move down into the sediment.

Figure 2 is a screen-capture of the actual profile-view track of the JPC transponder from our APOS computer as it is lowered the last 80 meters above a target and then free-fell into the seabed. The free-fall track is seen from the profile to be about 23 m in vertical drop. The JPC rig for this core is 20 m long and the free-fall before the core cutter entered the seabed is about 2.5 m, so this profile gives confirmation that the rig penetrated fully into the sediment up to the top of the core head.



**Figure 2) Profile View Of The JPC Rig Before, During, And After Free-Fall**

Once the rig settled into the seabed in this example, we logged position for a minute, and then extracted the rig. This sequence can also be seen in the profile view of the figure. Once we confirmed that the rig is fully out of the seabed the Winchman increased winch speed and retrieved the rig. We have learned from experience that our JPC rig will sometimes “glance off” of stiff sediments on gradients more than about 22° from horizontal, so our policy is to make coring attempts into seabed gradients of 20° or less.

A step-wise photo sequence of a JPC rig in operation is presented as **Figure 3**. This sequence proceeds across the first row, then across the second row, and so on.



**Figure 3) Stepwise Process Of JPC Operations**

Each photo in the 15-frame photo sequence above represents the following:

*Deployment:*

- (1) Loading core liner,
- (2) Pulling the rig sternward down its track,
- (3) Rotating the rig vertically into the water off the stern, and
- (4) Installing the trigger,

*Retrieval:*

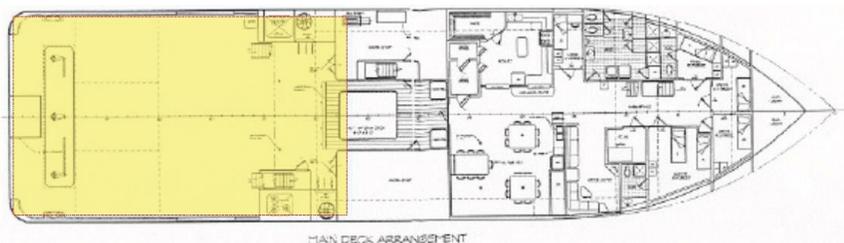
- (5) Securing the trigger pendant into its socket on the bucket to remove the trigger arm,
- (6) Retrieving the trigger weight,
- (7) Retrieving the core rig to the surface (it is now hanging on the bottom of the pendant),
- (8) Aligning the core rig with its bucket using the A-frame and main winch,
- (9) Securing the core rig into its bucket,
- (10) (11) & (12) Extracting the core rig and its bucket from vertical to horizontal,
- (13) Reaching the stop on the track,
- (14) Removing the core cutter shoe at the bottom of the rig, and
- (15) Extracting the core inside the core liner.

The JPC system is rigged by inserting a load-tested JPC pendant with the eye end hanging out the bottom of the core barrel and the double pronged jaw end hanging out the top of the core head. The piston pin is installed to connect the eye end of the pendant to the piston within the pre-assembled piston/cutter/catcher assembly, and then the piston/cutter/catcher assembly is mounted to the bottom end of the core barrel with set screws. The trigger assembly is attached to the pendant by unscrewing the knurled-nut cap of the pendant pin, placing the trigger assembly eye in the jaw, inserting the pendant pin through to capture the trigger assembly eye, and re-tightening the knurled-nut cap. The system is rigged in such a way that the pendant wire rope would come out of the core head with the proper amount of extra loop available, as dictated by the core barrel length and soil strength at that location. This resulted in programming a free-fall loop in the pendant of precise distance.

Having a precisely known and repeatable free-fall loop is important because the recoil of the main rope upon trigger must also be taken into account. This is done by adjusting the trigger wire length in relation to the pendant loop. Lengths of pendant and trigger wire are specified for each barrel length, but the trigger wire length is adjusted  $\pm 1$  to 3 ft as coring continued and a knowledge base is built from subsequent sites, in order to fine-tune the mechanical programming of the rig for optimum core recovery and quality. The length of pendant and trigger wire used for each coring attempt is logged.

The main winch, main coring rope, and the stern A-Frame is used for deploying and retrieving JPCs. In addition to the deployed hardware, several assemblies are mounted to the vessel working deck to manage the deployment and retrieval of the coring rig. These assemblies included the track and stern platform, the main sheave from the stern A-Frame, and the deployment, retrieval, and trigger tugger winches with their hydraulic power pack module. Safety precautions are paramount in our collection procedures and are regularly reinforced through safety meetings, JSAs, tool box meetings, and other elements of our Safety Management System.

A safety zone is established during deployment and retrieval as illustrated with yellow-highlighting in **Figure 4**. During deployment and retrieval when the main line is under load, no one is allowed to occupy a position in the yellow-shaded zone. At all other stages of the JPC process only the 5-man deck staff is allowed on the back deck aft of the anteroom just foreword of this yellow-highlighted zone.



**Figure 4) Safety-Restricted Area During Deployment/Retrieval Operations**

## CPT STINGER SYSTEM

The CPT-Stinger (**Figure 20**) is installed using a JPC core-head, deployed and triggered with the well-proven TDI-Brooks JPC process, and allowed to free-fall ballistically to insert itself into the sediment like a JPC. Once fully embedded in the seafloor with the resulting reaction force of 22,000+ lb. now available, the CPT-Stinger automatically extends its cone rod deeper into the formation at the ASTM and international standard “static” cone advance rate.

The standard Long CPT Stinger cone can be ballistically inserted to about 62 ft BML while gathering dynamic PCPT data, and then advances to about 115 ft (35 m) BML while gathering static PCPT data. The Extended Long CPT Stinger cone can be inserted to about 72 ft BML while gathering dynamic PCPT data, and then advances to about 135 ft (40 m) BML while gathering static PCPT data. A discussion of dynamic PCPT data is presented after the tool specifications.

The additional length of the extended tool is made possible by adding track extensions to the forward end of the track so that 10 additional feet of tool barrel may be added. These 10 additional feet of barrel allow 20 additional feet of cone penetration because the extended rod is essentially as long as its longer barrel, so a doubling is achieved with the telescoping process. In-situ PCPT data can thus be acquired to sediment depths double of that of the barrel length of the tool (or of a same-site JPC).

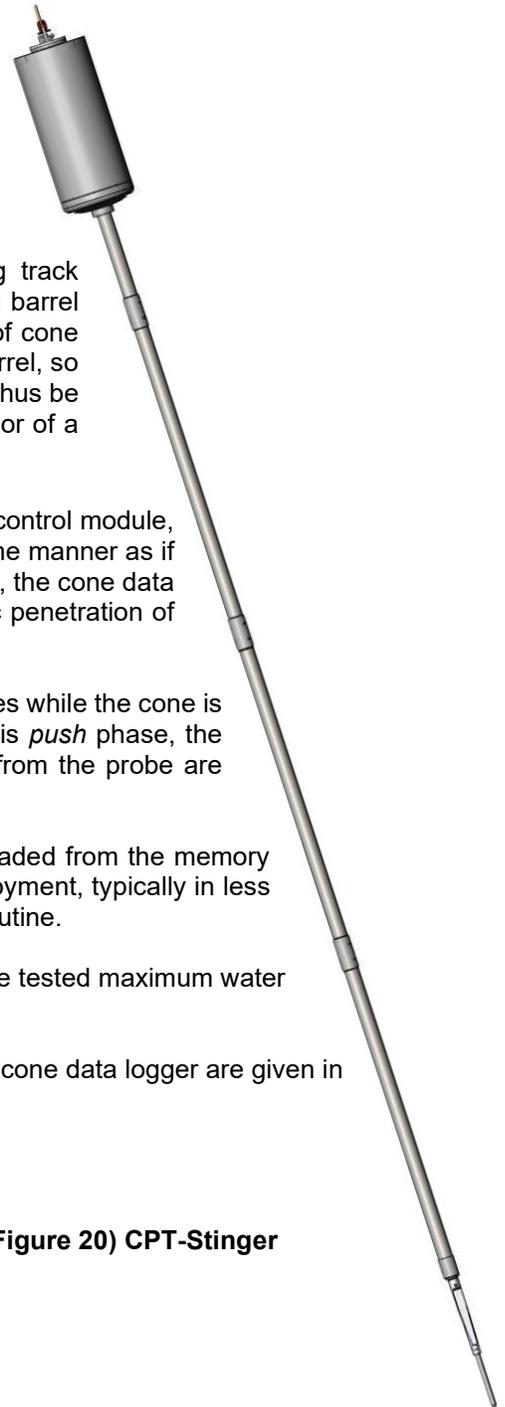
The CPT Stinger has its own barrel assembly, internal cone rod assembly, control module, and PCPT cone with data logger. The rig is deployed (**Figure 21**) in the same manner as if acquiring a JPC. After trigger with the cone less than 1 m above the seabed, the cone data continue to be acquired 200 times per second during the 3-second ballistic penetration of the cone into the formation.

After cone penetration to full embedment, the rapid data acquisition continues while the cone is advanced deeper into the formation at a constant standard rate. During this *push* phase, the probe advances at a controlled ASTM rate of  $2.0 \text{ cm/s} \pm 0.5 \text{ cm/s}$ . Data from the probe are logged every 0.1 mm as the push progresses at this rate.

Once complete, the system is retrieved to the vessel and data are downloaded from the memory cone for evaluation and analysis. The tool is then readied for the next deployment, typically in less than 20 minutes, making 3 to 5 deep-water deployments per 12-hour day routine.

The tested minimum water depth for the CPT-Stinger is currently 350 m. The tested maximum water depth for the tool is currently 4,000 m.

Specifications of the PCPT Cone are given in **Table 4**. Specifications of the cone data logger are given in **Table 5**.



**Figure 20) CPT-Stinger**

**Table 4. CPT-Stinger Cone Specifications**

1. The cone measures the following at a rate of 200 times/sec for up to 3 hours:
  - a. Tip Resistance  $q_c$  (ksf and mPa)
  - b. Sleeve Friction  $f_s$  (ksf and kPa)
  - c. Pore Water Pressure  $u_2$  (ksf and mPa)
  - d. Vertical Acceleration (m/sec<sup>2</sup>)
  - e. Tilt (° from vertical)
2. The cone has a 15-cm<sup>2</sup> projected end area and conforms to ASTM International Designation: D5778-07, *Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils*.
3. The cone sleeve has equal end areas and is inherently compensated. The sleeve load cell is hydrostatically compensated.
4. Cone Tip load cell calibrated capacity is 10,000 lb. The full-scale response corresponds to a Tip Resistance ( $q_c$ ) of 620 ksf and corresponding soil shear strength of about 25 ksf. The load cell will survive a force of 15,000 lb. without damage. Special 20,000 lb. cones are also available for water depths greater than 3,000 and for very stiff soils.
5. Cone Sleeve load cell calibrated capacity is 1,600 lb. The full-scale response corresponds to a Sleeve Friction ( $f_s$ ) of 6.6 ksf.
6. Pore Pressure transducer calibrated capacity is 5,000 psi. The full-scale response corresponds to a Pore Pressure ( $u_2$ ) of 720 ksf. Special 7,000 psi cones are also available for water depths to 4,000 m.

**Table 5. Cone Data Acquisition Specifications**

1. The analog-to-digital conversion uses 16-bits for a resolution of 1 in 65,000 counts.
2. The sample rate is 200 samples per second.
3. The memory capacity is 24-hours of data from the six sensors. The memory is non-volatile and will retain data in the event of a power loss.
4. The start command can be:
  - a. An operator programmed time,
  - b. A signal from the accelerometer indicating the corer has dropped.
  - c. A combination of a and b.
5. The battery life is a minimum of 4-hours.
6. An interface unit allows the download of the cone data to a laptop computer. The laptop is used to initialize the cone and document cone and site identification data.
7. A full charge of the battery is achieved in less than 30 min from previous deployment.

Total penetration is a function of barrel length as shown in **Table 6**. Our current best practice is to insert the rig so that the head protrudes 0 to 2 ft from the seabed. This typically produces a robust mudline indication on the head for confirmation of insertion depth. An on-board accelerometer is used to calculate the exact Stinger embedment depth.

**Table 6. Penetration ranges of CPT-Stinger vs. Barrel Length**

<b>Barrel Set Length</b>	<b>Free-fall Penetration</b>	<b>Push Rod Penetration</b>	<b>Total Penetration</b>
38 feet	43-45 feet	33 more feet	76-78 feet
58 feet	61-63 feet	52 more feet	113-115 feet
68 feet	71-73 feet	62 more feet	133-135 feet



**Figure 21) The CPT Stinger Ready For Deployment**

## DYNAMIC PCPT DATA

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The memory cone logging rate allows the acquisition of “dynamic” PCPT data for the 3 seconds of ballistic insertion of the cone into the soil formation. Data are logged during insertion at a rate that allows tip resistance to be measured at soil intervals no longer than 5 cm, even at maximum cone velocities approaching 9 m/s. After cone penetration to full embedment, the data acquisition continues while the cone is advanced deeper into the formation at a constant ASTM rate, generating “static” cone data for the second half of the total cone penetration.

After retrieving the deployed tool and its PCPT cone to the deck, the cone is removed, its active data set downloaded to a laptop computer, and the data are immediately processed into client-ready format. A data processing program is used to first graphically mark important data acquisition events (points in time). These events are the instant of: freefall trigger, seabed insertion, tool first at rest in soil, cone advance start, and cone advance end. From these marked events, the program calculates the cone’s freefall time in water and soil, as well as cone push duration. The program sets baselines for tip resistance, sleeve friction, and pore pressure, by averaging the values logged from each load cell just prior to seabed contact of the cone tip.

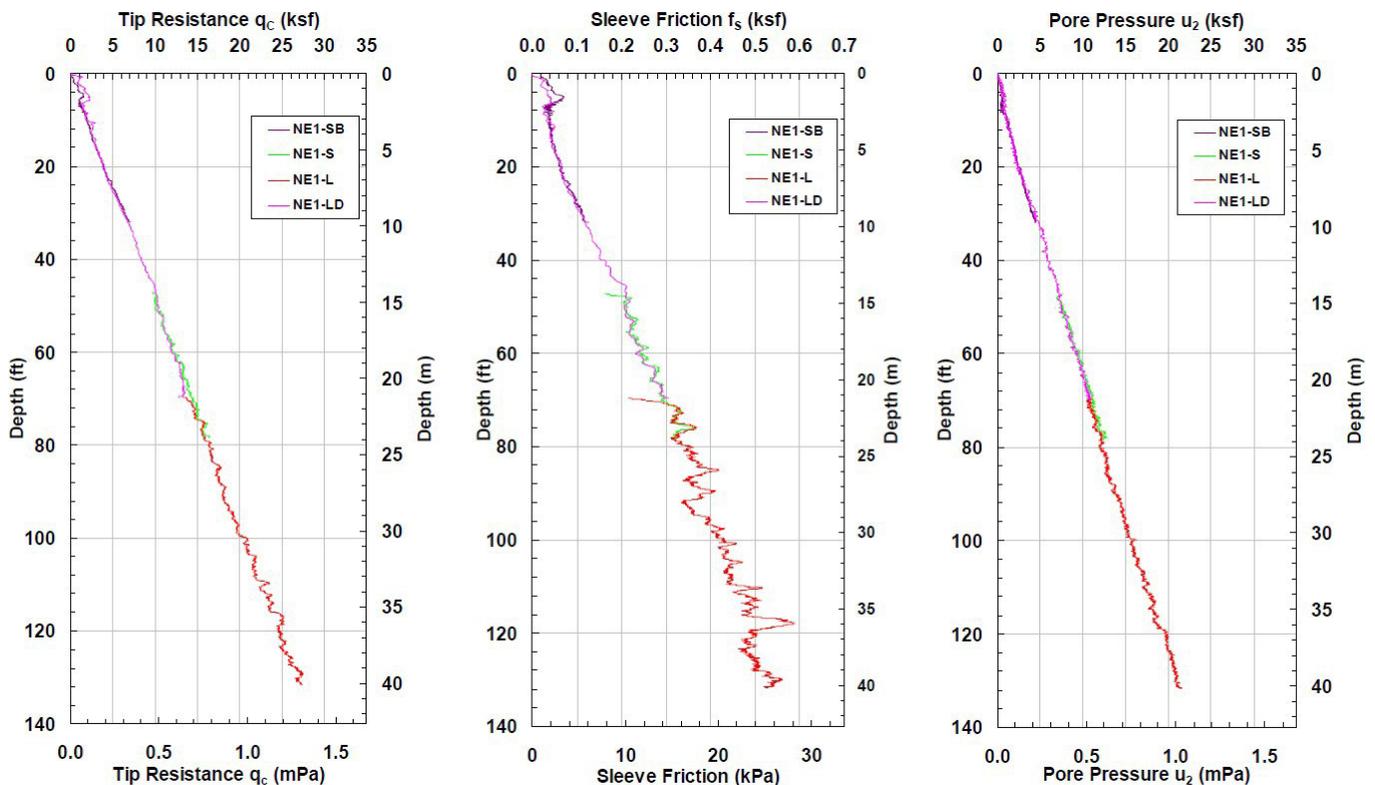
The program then integrates the accelerometer data into an instantaneous tool velocity profile. This velocity profile is later used by the program to calibrate dynamic cone data. The program then integrates the instantaneous velocity

values into a downward tool travel distance profile. In this manner, a very accurate measure is derived of insertion distance of the cone into the soil formation. From the event times and the travel distance profile, the program then calculates freefall distance through the water, cone depth at rest, cone depth at the start and end of push, and cone push rate.

The program then produces a CSV file of the measured static PCPT data from all sensors. This file includes the baseline-zeroed static measurements of tip resistance ( $q_c$ ), sleeve friction ( $f_s$ ) and pore pressure ( $u_2$ ) for the duration of the static cone advance into the soil. Values are reported for every 1.0 cm of cone travel, starting with the known depth of the cone when it started its static advance. The program also produces a CSV file that includes corresponding dynamic data for tip resistance, sleeve friction, and pore pressure during the ballistic insertion into the soil. In this file, each of the baseline-corrected load cell values is individually adjusted for the known velocity effect on the cone readings, and each is reported with its penetration depth recorded every 0.005 sec interval. Changing tool velocity causes a maximum spacing of about 5 cm of travel between measurements.

Plots of these files for all three soil sensors by the processing program are used to evaluate the acceptability of the acquisition prior to moving to the next site. Once each deployment's raw data file is successfully copied, processed, archived, and determined to be acceptable, the original file still residing in the memory module of the cone is erased, batteries are charged, and the cone system is prepared for a subsequent drop.

Such comparisons between side-by-side static PCPT data (2 cm/sec cone advance) with the rate-adjusted dynamic PCPT data acquired during the tool's insertion have been remarkably good more than 100 sites in our international database (**Figure 22**). This figure overlays adjusted dynamic data (NE1-LD) with three sets of same-site static data (NE1-SB, NE1-S, and NE1-L), each acquiring overlapping intervals. The remarkable match of the dynamic data with the three independent sets of static data is so routine now that most clients accept our adjusted dynamic data for engineering design purposes.



**Figure 1) Comparison Of Side-By-Side Dynamic And Static PCPT Data Profiles**

# GRAVITY CPT SYSTEM

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 (**Figure 1**). 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.

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 4,000 m. 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 ( $^\circ$ ) 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:

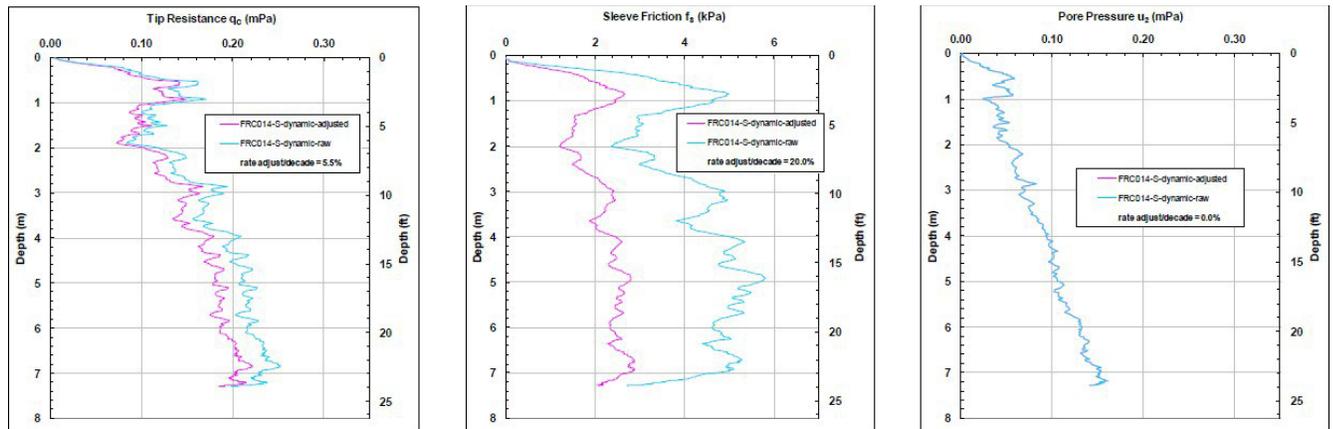
$$\text{Adjusted Tip Resistance} = \text{Velocity Correction Factor} \times \text{Baseline-Corrected Tip Resistance}$$

Dynamic values for Sleeve Friction and for Pore Pressure have their own velocity correction factors. The resulting adjusted data are calibrated by overlaying the dynamic data with existing static data or soil strength data at the same or nearby site. The files are small enough to be emailed from the vessel to the engineers in the office.



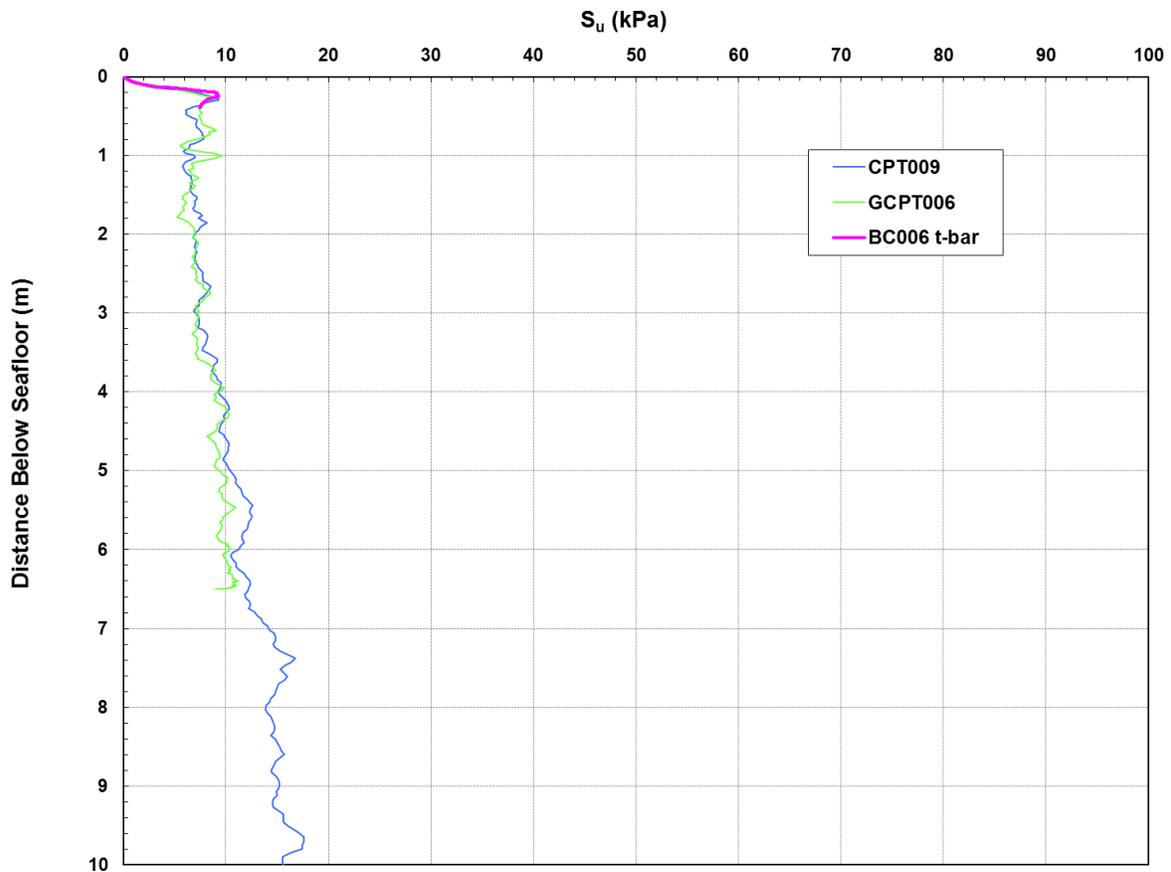
**Figure 1) gCPT Tool**

Graphical representation of the results from a recent gCPT deployment (**Figure 2**). Tip resistance and sleeve friction values have been adjusted for the rate effect on them, but pore pressure needs no such dynamic data adjustment



**Figure 2) Graphical Results From A gCPT Deployment**

A comparison of gCPT results with same-site box core T-bar and CPT-Stinger re shown in **Figure 3**. Overlay of derived undrained shear strength from each tool's data is remarkable.

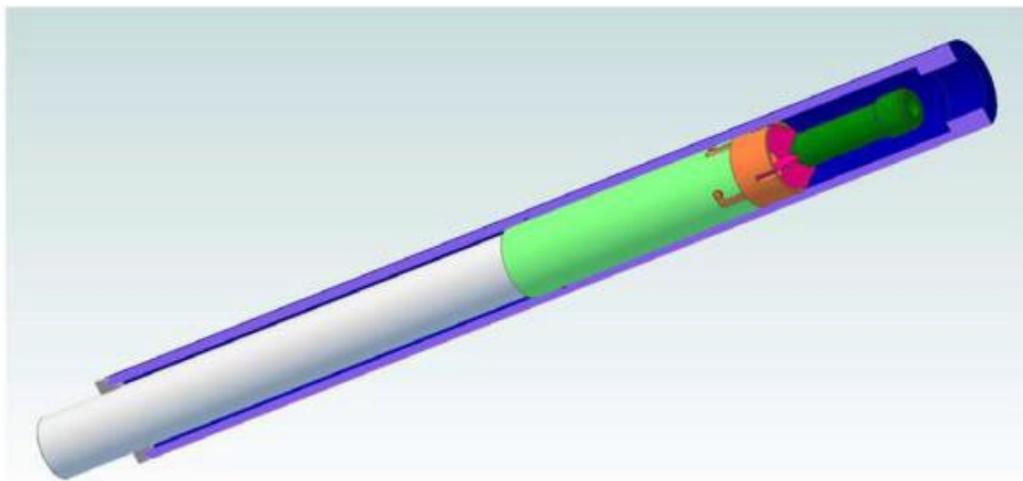


**Figure 3) Comparison Of gCPT Results With Same-Site T-Bar And CPT-Stinger**

# SHELBY TUBE SAMPLER

The high cost of conventionally drilled borings in deep-water limits the number of borings that can be drilled, the number of soil samples that can be collected, and the areal coverage for a given project. To remediate the situation, TDI-Brooks has developed and is now offering an innovative and cost-effective tool called the **Stinger Sampler**. The basic idea behind the deep-water **Stinger Sampler** system is to “transport” a Shelby tube down through the seabed to acquire geotechnical-quality core samples down to depths of 20 to 40 m BML, thus nicely complementing the 0-20m continuous JPC soil samples (**Figure 1**).

The economic benefits of quickly acquiring from a modest-cost vessel several high-quality geotechnical soil samples are readily apparent, in that the **Stinger Sampler** allows more high-quality data to be acquired for a given budget, and affords more areal coverage compared to the amount of data obtainable from a single, more expensive conventional soil boring. Thus, the **Stinger Sampler** helps reduce the overall risks associated with foundation design and installation planning.



**Figure 1) Schematic Illustration Of The TDI-Brooks Stinger Sampler**

The **Stinger Sampler** system consists of various hardware assemblies designed to be fastened together into a working tool that can be safely deployed to the seabed. The deployed tool is comprised of the weight-head assembly, the USBL transponder canister, the barrel assembly, the push rod assembly, the Shelby tube sampling system, the push control module, and the trigger system, as further described below.

- The weight-head assembly is made up of a core head with an inserted flange-barrel and coupling with which to attach 10-ft long barrel sections. The weight of the core head can be adjusted by adding or removing lead ingots.
- A USBL transponder is placed into a canister mounted inside the weight-head for monitoring the deployed tool's lateral position and depth.
- The barrel set can be assembled to a pre-determined length of up to 21 m.
- The trigger assembly is made up of the trigger arm, pendant clamp, trigger weight, trigger wire, and trigger wire connecting system.
- The push rod assembly can push the Shelby tube sampling system to 20 m more into the soil, down to 40 m BML. The depth reached by the push is controllable so that a sample can be acquired from two or more depths in the formation with subsequent drops

The **Stinger Sampler** operational process is essentially identical to that of the well-proven CPT- Stinger, with the **Stinger Sampler** tool deployed using the same existing TDI-Brooks CPT-Stinger safe deployment system.

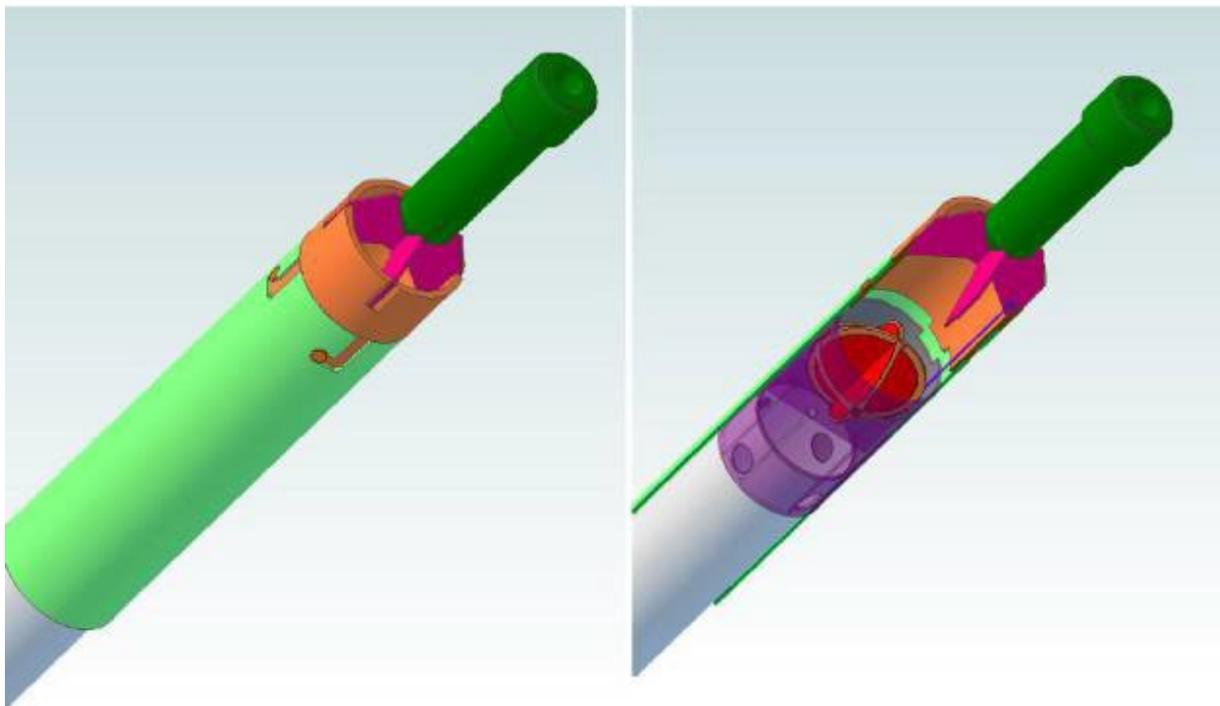
By simply replacing the PCPT cone of the already mobilized TDI-Brooks CPT-Stinger tool with a Shelby tube soil sampling system, the field crew can quickly and safely convert from PCPT acquisition to soil sampling mode. Same-site CPT data and 3-inch diameter, 2 to 3-ft long Shelby tube samples, each acquired down to as deep as 40 m, can be performed at a rate of several drops per day, as the conversion is safe, quick, and simple. Such samples can also be acquired at any client-specified depth, if a particular formation seen on a sub-bottom profile is desired.

The Shelby tube sampling system is installed at the end of the CPT-Stinger rod in place of the PCPT cone, deployed and triggered near the seabed with the well-proven TDI-Brooks free-fall tool insertion process, and allowed to ballistically insert itself 20 m down into the soil just like a CPT-Stinger.

During ballistic insertion, no soil fills the Shelby tube as it remains protected inside its housing. Once fully embedded 21 m deep into the soil, the reaction force of 22,000+ lb. is available to push the Shelby tube sampling system deeper into the formation (exactly like the PCPT cone of the CPT-Stinger) at a push rate of about 2 cm/sec. During this “static” push, soil flows through the Shelby tube and out its top-vents. When the tool push reaches its stop at the pre-set depth, the soil from that depth inside the Shelby tube is captured by valve closure and retained during retrieval in a materially undisturbed state.

During deployment, as the tool nears the seabed during its water column descent, the winch payout speed is slowed and preparations are made for USBL position logging during the instant of release. As the weight is released from the trigger arm, the trigger arm begins to rise with respect to the tool. When the trigger arm has risen through its full travel, the tool is released to free-fall down into the seabed. At this trigger point, the Shelby tube sampling system in its housing will be one or two feet above the seabed.

At the moment of release, the payout of the winch is stopped, thus fixing the length of main-rope out. The pendant will help stop the tool’s weight-head so that it barely protrudes from the seabed. After this insertion, the Shelby tube sampling system will be extended from perhaps 21 m starting depth to as much as 20 m deeper into the formation. The rate of penetration is controlled at 2 cm/sec, so up to 15 minutes are allowed for this phase. When the rod push stops, the soil residing in the Shelby tube is a high-quality sample from that stop-depth. Once the push is completed, a slow pullout on the winch is begun to immediately close a valve at the top of the Shelby tube, and then to extract the extended push rod and the barrel set from the soil. While still vertical at the sea surface, the push rod automatically retracts back into the barrel, and the tool is then retrieved to the deck. **Figure 2** shows a schematic of the valve that closes at the onset of tool extraction after its stops pushing deep in the soil.



**Figure 2) Valve At The Top Of The Stinger Sampler Shelby Tube**

After the tool is on deck, the Shelby tube sampling system is removed from the end of the push rod and brought into the lab for processing. The tool's data logger is connected to a laptop computer, and then the raw data file generated from the tool's ballistic insertion is opened for processing the ballistic insertion data into acceleration, velocity, and depth profiles. In this manner, a very accurate and reliable measure is derived of freefall distance in the water and insertion distance in the soil, in an identical fashion as for the CPT-Stinger. **Figure 3** is a photograph of a tool just having acquired an undisturbed soil sample from 40 m depth.



**Figure 3) Photo Of The Stinger Sampler Shelby Tube With A Soil Sample From 40 M Depth**

# NEPTUNE CPT SYSTEM

The TDI-Brooks Neptune 5000 Heavy Duty CPT System is a coiled rod Cone Penetration Test System featuring a 35kN Push capability. A coiled tubing CPT system that is easy to mobilize and has a maximum penetration of 20 meters. This CPT unit is commonly used for site investigations for offshore renewables. **Figure 1** is a photograph of a during deployment.



**Figure 3) Photo Neptune CPT System during deployment**

The system has real time control and data acquisition and built-in automatic safety cut-outs making it perfect for the renewables market.

- 5cm<sup>2</sup> Detachable Cone, 10cm<sup>2</sup> Cone and T-Bar Cone
- 35kN Push Capability
- Up to 20m Penetration from Coiled Rod
- Easily Deployed Compact Sub-Sea Frame
- Real Time Control and Display
- Single Coax Connection for Power and Data
- Automatic Safety Cut-Outs
- Low Maintenance, Low Consumable Use
- Easy to Operate Windows™ based PC Control

# FERITECH FT 550 VIBROCORER

The TDI-Brooks Feritech FT550 Vibrocorer is a lightweight variable frequency high power vibrocorer. The FT550 can be used for cores of 1 to 12 meters deep.

The topside software informs the engineer of the information he needs to ensure efficient, successful and safe deployment and operation.

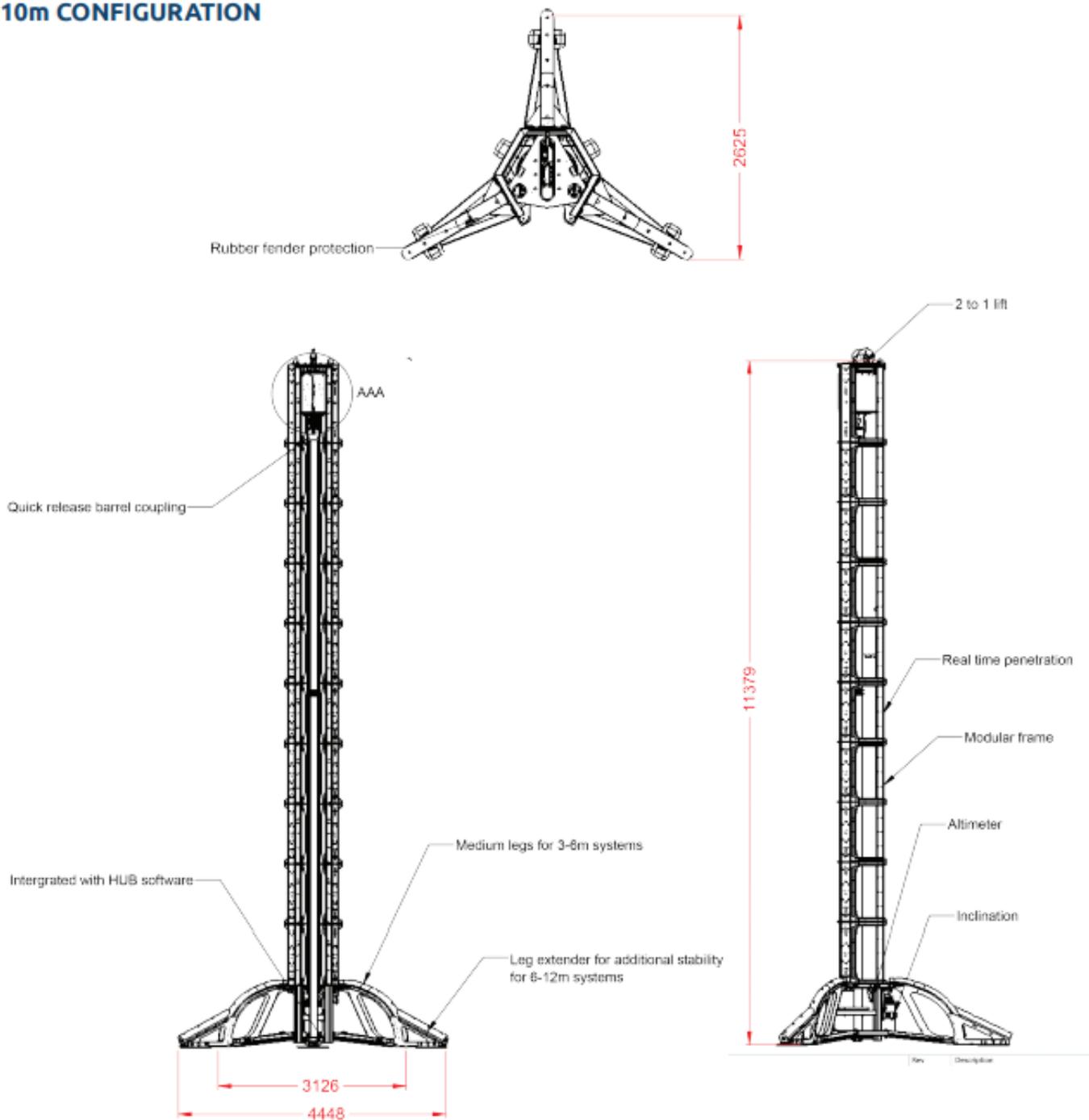
The system adjusts the vibrational frequency and effective thrust in real time. This ensures samples are collected with the minimum of disturbance of the ground but with the advantage of being able to turn up the penetration force when needed to ensure effective penetration and recovery of compacted samples with in the stratigraphy.

Force increases with an exponential curve against motor frequency, also amplitude is a theoretical constant. This is due to the operating frequency being much larger than the resonant frequency of the system. The amplitude above this range tends to the constant max value. You do experience a larger amplitude as the unit passes through various resonant frequencies of the system during start-up and run-down and frequency adjustment through resonant bands.



**Figure 1) Photo FT 550 Vibrocorer at deployment**

## 10m CONFIGURATION



**Figure 2) Configuration of the FT 550 Vibrocorer**

- Variable frequency of 5 – 50Hz
- High power with up to 75kN thrust
- 1 – 12m modular construction (in 1m increments)
- Rapid mobilization with plug and play setup

- Change barrels with the frame laid horizontally or vertically
- 2:1 mechanical advantage on lifting wire aiding barrel extraction
- Quick barrel release system
- 300m – 7000m depth rating available
- Stable operation in up to 10 knot currents
- Consumables compatible with Feritech Global gravity and piston corers
- Frame hot dip galvanized to BS EN ISO 1461:2009

The subsea equipment is built to withstand the harsh offshore environment and unforgiving handling. The topside software informs the engineer of the information he needs to ensure efficient, successful and safe deployment and operation. Due to its simple-to-assemble modular construction, the system can be mobilized very quickly for cores of 1-12m.

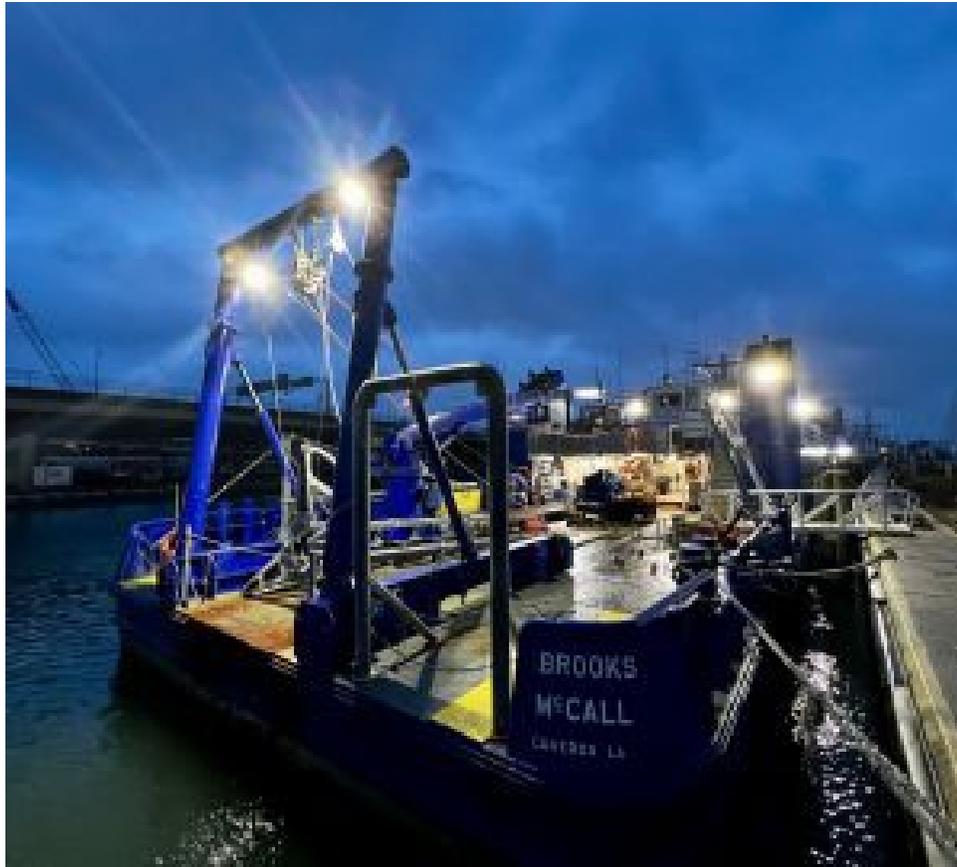
	Barrel Length				
	2m	3m	6m	9m	12m
Weight in water	1142kg	1437kg	1697kg	1968kg	2395kg
Weight in air	1470kg	1845kg	2145kg	2476kg	3017kg
Base frame diameter	1.8m	1.8m / 4.0m	4.0m	4.0m / 7.2m	7.2m
Title	3.2m	4.3m	7.2m	10.2m	13.2m

With variable frequency and thrust, Feritech vibrocorer is the only system on the market with an integrated high power variable frequency system. By using this unique variable frequency system, sample disturbance is minimized, ensuring a high-quality sample regardless of high-power settings.

Unlike any other vibrocorer system, the Feritech vibrocorer can be deployed and recovered to deck in the horizontal or vertical axis, meaning that the user can choose the best deployment and recovery method for the vessel they are operating from. The quick release barrel system ensures a fast barrel change optimizing operational equipment time.

A barrel can be changed in a matter of minutes, whether the system is being deployed in horizontal or vertical mode





With its modular construction, the entire FT550 system and spares can easily be packed into a standard 20-foot ISO shipping container.

The FT550 has a proven track record of quickly penetrating consolidated sediments. The variable frequency has been used time and time again to acquire high quality core samples from stiff clays, compacted sands, to sites with chalk and gravel.

The magCORE adds the ability to see oncoming ferro-magnetic obstructions within the ground. This has many uses from UXO (unexploded ordnance) detection to measuring the depth of sheet piling or other metallic foundations.

The sensors measure in 3 dimensions and so can detect a target both in front of and to the side of the barrel.

The topside controller shows the engineer the information he needs to ensure an efficient, successful and safe deployment and operation. The rugged top screen unit displaying and logging real time data from the system for the user, including:

- Penetration distance and rate
- Depth sensor
- Inclination
- Settlement into seabed
- Altitude from seabed
- Frequency and power

## FERITECH FT 550 VIBROCORER

The TDI-Brooks Rossfelder P-5C Modular Vibrocorer is the newest version of the original P-5 vibrocorer. It is designed for coring unconsolidated waterlogged sediments at sea, in lakes, rivers and harbors. Its light weight enhances its vibratory performances and facilitates its delivery and operation in sites hard-to-reach. It is adaptable to various coring requirements through its modular components and it is well suited for hazardous environments as it is fully encapsulated without external moving parts.

The letter "C" in P-5C indicates that the pressure housing is a solid casting. A cast housing eliminates all seams that requires welding.

The vibrohead consists of a pressure case housing two contra-rotating motors of 3 hp each with eccentric cams. These eccentrics enter into spontaneous synchronization and a percussive force of 32-48 kN is delivered at 3,600 cycles/minute.

The pressure housing is designed for operation to depths of 1,200 m (4,000 ft). Under proper voltage conditions the internal vibrator motors have a 1,000-hour operating time before requiring service and lubrication. Accordingly, at 2-3 minutes per core, this implies servicing every 20,000 cores. However, prior to shipping and using, the unit is extensively checked with major focus on the water-tight integrity of the pressure seals.

The unit is equipped with ten foot long, three-inch diameter core barrels and the appropriate clamps and clamp-adapters. The steel core barrels, with a wall thickness of 0.125" (3.1 mm), has expendable liners of clear polybutyrate. The vibrocorer is also supplied with 3" heavy wall pipe clamps to fit our standard piston coring barrels.

The unit can handle core tubes from 3" (76mm) to 5" (127mm) diameter with appropriate clamps and clamp-adapters. However, it comes normally equipped with a 4" (101.6mm) clamp for 4" diameter core tubes (100mm if requested).

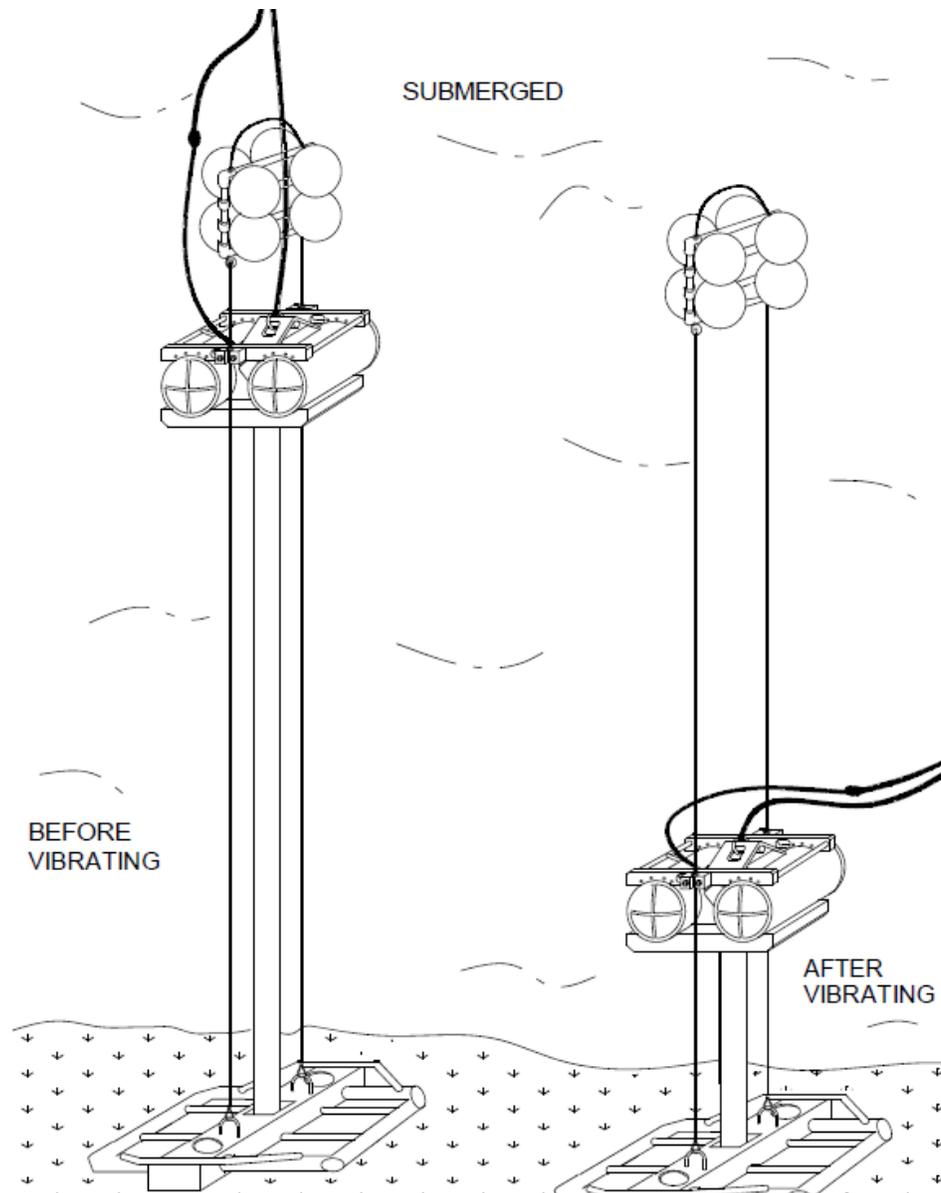
The depth of penetration of the core tube depends upon the force of the vibrahead, the characteristics of the core tube (material, length, wall thickness) and the characteristics of the sediment.

Force increases with an exponential curve against motor frequency, also amplitude is a theoretical constant. This is due to the operating frequency being much larger than the resonant frequency of the system. The amplitude above this range tends to the constant max value. You do experience a larger amplitude as the unit passes through various resonant frequencies of the system during start-up and run-down and frequency adjustment through resonant bands.

The Vibrocore barrel is customized with a moveable ring that served to mark the depth of penetration. A clear polybutyrate liner is inserted and a flexible fingered catcher is used retain the sample in the tube. Early experimentation showed that the operation of check valve at the head of the unit is critical for long core retention. This ball and its seat were washed out and silicon greased before each core. In addition, a series of rubber hose sections were fitted and acted like a spring, forcing the ball to seat properly. During coring the displaced water easily flowed up and out past the ball, but did not flow back in during core removal.

The core, intact in its clear liner is removed and placed horizontally in the rack for trimming, capping and labeling. The liner is then stood on end, so that the sand could repack, and core length is measured. This measure is used in resource calculations, as a lower bound of the sand thickness at that site. If the core is determined to be homogeneous, the liner is emptied into a large tub and mixed thoroughly using a shovel. Approximately 1 kg of sample is packed into a large Ziploc bag for archive, two 125 ml splits are sub-sampled, and 125 ml is sieved.

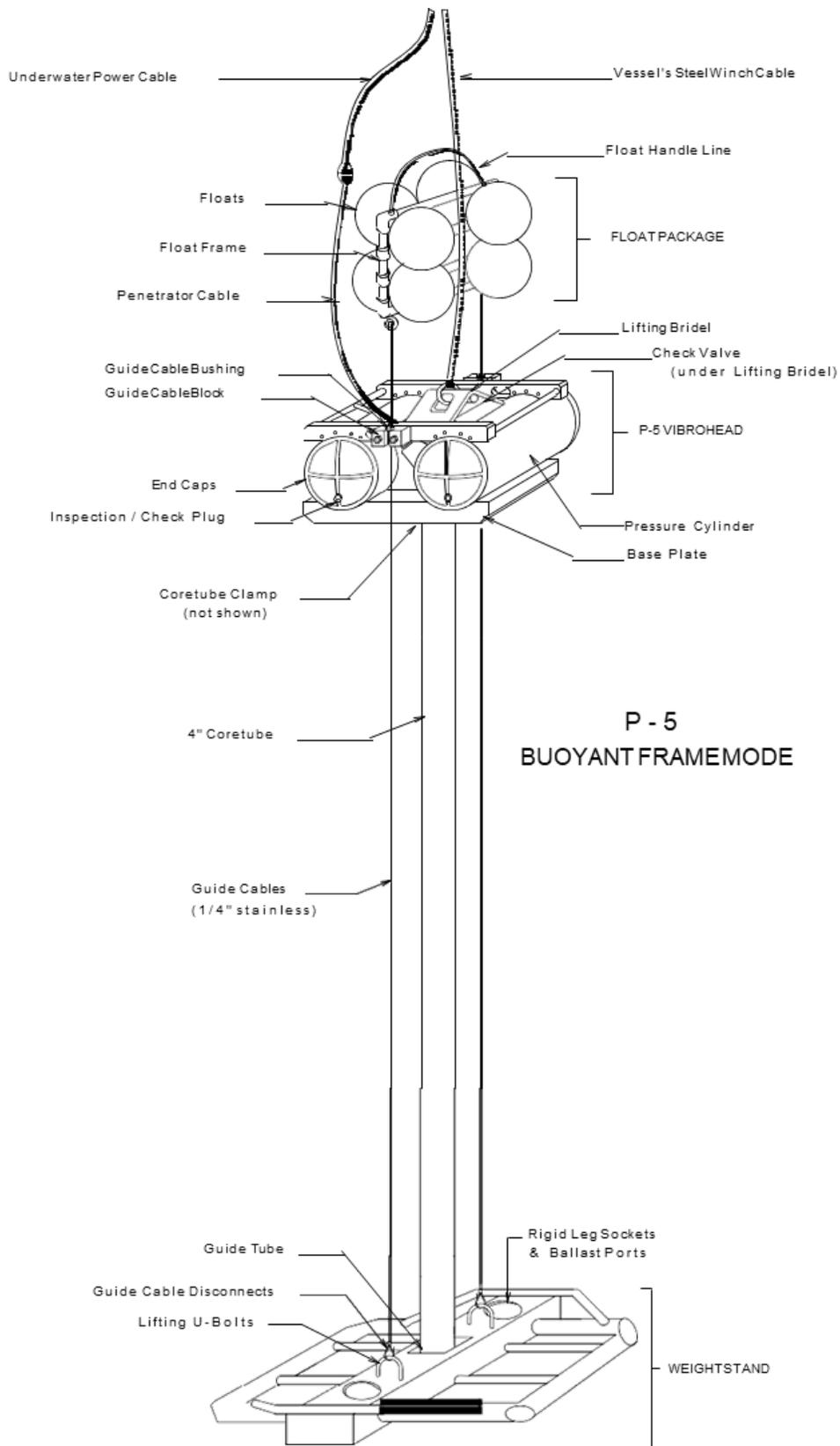
The main components of the Rossfelder P-5 Vibrocoring System are the vibrahead, "buoyant frame" with float-package and weight-stand, core tube and plastic liner, underwater electrical cable coming from the vessel, and the control box located between the underwater cable and power source (**Figure 1**).



**Figure 1 - General schematic of vibrocoring operation**

The patented "buoyant frame" allows handling of the overall system with ease and with limited draw works and deck space. It consists of two thin cables held taut underwater between a weight stand and a float package and guiding vertically the vibrocorer. The weight stand has provisions to accommodate an extension arm and two rigid vertical legs topped with a cross-beam transforming the frame into a conventional rigid support unit for special situations, such as shallow swift waters. The P-5C can be implemented with or without the "buoyant frame". Usually, no frame is needed in calm waters to, say, 20m (65ft) depths with an anchored platform.

The buoyant frame consists of two thin cables held taut underwater between a weight-stand and a float package and serves to vertically guide the vibrocorer (**Figure 2**).



**Figure 2 - Assembly and main components of Rossfelder P-5 Vibrocore system utilizing the Buoyant frame**

The main components of the P-5C Vibrocorer System are:

- the vibrohead.
- the "buoyant frame" with its float-package and its weight stand.
- a core tube, equipped with or without a plastic liner.
- the underwater electrical cable coming from the surface support platform to the vibrohead.
- the control box located between the underwater cable and
- the power source.

The P-5C vibrohead consists of a pressure housing incorporating two contra-rotating motors of 3HP each provided with eccentrics. These eccentrics enter into spontaneous synchronization and the force being delivered is null when they are in horizontal opposition and maximum when they reach the same vertical position, alternately directed up and down, completing close to 3600 cycles every minute (3000 cycles on 50Hz).

The P-5C pressure housing is rated for operation in ocean depths down to 1,200m (4,000 ft).

Under proper voltage conditions the internal vibrator motors have a 1,000-hour operating time before requiring service and lubrication. As a rule of thumb, at 2-3 minutes per core, this means some 20,000 cores.

- DEPTH CAPABILITY \* 1,200m (4,000 ft)
- POWER REQUIREMENTS (**All 3-phase**)
  - 230v, 50/60 Hz (Low Setting = 8.5 kW, 10 amps  
Mid Setting = 9.0 kW, 12 amps  
High Setting = 10.0 kW, 16 amps)
  - 440v, 50/60 Hz (Low Setting = 8.5 kW, 4 amps  
Mid Setting = 9.0 kW, 6 amps  
High Setting = 10.0 kW, 9 amps)
- CENTRIFUGAL FORCE (1 kN = 225 lbs)
 

	At 60Hz	At 50 Hz
Low Setting =	32.0 kN	21.8 kN
Mid Setting =	40.0 kN	27.3 Kn
High Setting =	48.0 kN	32.8 kN
- VIBRATIONS PER MINUTE 3,450vpm @ 60Hz or 2,850vpm @ 50Hz
- APPROXIMATE WEIGHT
  - in air (w/o ballast & core tube) 450 lbs (210 Kg)
  - submerged (w/o ballast & core tube) 220 lbs (100 Kg)
- RECOMMENDED BALLAST (lead, scrap metal, etc.): 100 lbs (45 kg)

## MULTI-SENSOR CORE LOGGING (MSCL)

MSCL systems rapidly and non-destructively obtain high-resolution (typically 1 cm to 10 cm downcore spacing) geophysical and geochemical data from sediment and rock cores. The high-quality multi-parameter stratigraphy delivered from MSCL systems enables facies classification and soil/rock typing ahead of, or in support of a visual description. Ultimately this leads to improved laboratory test planning for any necessary destructive or advanced laboratory testing. The Geotek core logging services team follows strict calibration procedures for each core size and liner type to ensure consistency and accuracy of data collection.

Sediment or rock cores with or without metal or plastic liners up to 1.5 m long and 155 mm in diameter can be accepted. Physical, elemental and mineralogical properties can be obtained from whole or split/slabbed core samples regardless of whether they are within a liner or not. An MSCL dataset provides vital information about core heterogeneity or homogeneity ahead of destructive laboratory testing or visual logging.



## XCT: STANDARD X-RAY CT SYSTEM

TDI-Brooks has a Geotek XCT system on campus to acquire both 2D X-ray transmission images and 3D X-ray CT volumes from lined whole core, split core, or slabbed core sections. Automated rotation of lined core sections allows users to visualize and record three-dimensional structures within the cores. These rotational images are used for computed tomographic (CT) reconstructions. X-ray CT imaging provides valuable quantitative data as well as information about core quality for sub-sampling or further analyses.



# CORE PROCESSING

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Torvane and Miniature Vane measurements are typically conducted on BCs, PCs, and JPCs in the field and remolded Miniature Vane are typically conducted in the onshore lab. In summary:

- After a PC or JPC is acquired, each section is cut and the bottom cap taped to the liner on the selected section. (*NOTE: these cores virtually always have one short or long “odd” section, due to recovery length not being an exact multiple of 1 meter. The short (or odd) section of a JPC is the top section, whereas the odd section of a PC is the bottom section.*) A digital photograph is taken and a visual description of each section is recorded. The shear strength of the sediment in the top of each liner is obtained with a Torvane and then with a Miniature Vane tool, as well as in the bottom of the deepest core section. The serial number of the spring set in service is recorded on the in-service Minivane data sheet. On some samples, identified by the client representative, moisture content, unit weight (density), and remolded miniature vane tests are also conducted offshore. Unit weight tests are conducted using TDI-Brooks’ syringe method. The quantity of moisture content tests and unit weight tests conducted offshore is limited by oven space. After testing is completed, sediment samples are typically removed from the test depths in sufficient quantity to conduct moisture content, Atterberg limit, and remold tests during subsequent onshore geotechnical testing. This equates to the top 3 inches for JPCs and the top 4 inches for PCs. The resulting gap is then filled and the core section in its liner is capped and taped in an air-tight manner. The bag is air tight sealed. Both the liner and bag are labeled according to the protocols in **Table 1**.
- After a BC or XBC is acquired, a digital photograph is taken, a visual description is recorded, and the shear strength of the sediment vertically through the core is obtained with a Miniature Vane tool at 4-vertical-inch (10-cm) spacing while still in the box, unless instructed otherwise by the client rep. The serial number of the spring set in service is recorded on the active Minivane data sheet. If specified by the client, the T-bar test is run in a zone of undisturbed soil away from the Miniature vane testing. After field testing is completed, a total of three or four push-core sections are sampled using 3-in. or 4-in. diameter tube samplers. These push core sections have their void spaces filled, capped, taped in an air tight manner, and labeled according to the protocols in **Table 1**.

Processed core sections are stored vertically with the top end up in a cool, temperature-controlled environment and secured in order to minimize potential for sample disturbance pending their careful offload at the next port call. Upon demobilization, the core samples are carefully offloaded from the vessel by hand and/or by crane/forklift into an enclosed, refrigerated truck, secured on a padded base against shifting during transit, and carefully transported to the specified Geotechnical Lab for a detailed lab testing program.

<ul style="list-style-type: none"> <li>• <b>Piston Cores (PC)</b></li> <li>• <b>Extended Piston Cores (XPC)</b></li> <li>• <b>Jumbo Piston Cores (JPC)</b></li> <li>• <b>Extended Jumbo Piston Cores (XJPC)</b></li> </ul>	<ul style="list-style-type: none"> <li>• Digital photograph at top of each core section</li> <li>• Digital photograph at the bottom of the bottom section</li> <li>• Torvane at top of each core section</li> <li>• Torvane at the bottom of the bottom section</li> <li>• Miniature vane at top of each core section</li> <li>• Miniature vane at the bottom of the bottom section</li> <li>• Visual classification/description of soil at top of each core section</li> <li>• Visual classification/description of soil at the bottom of the bottom section</li> <li>• Select moisture content testing</li> <li>• Select unit weight testing</li> <li>• Select remolded miniature vane testing</li> <li>• Fill void space, cap and seal each core section and properly label</li> </ul>
<ul style="list-style-type: none"> <li>• <b>Box Cores (BC)</b></li> <li>• <b>Extended Box Cores (XBC)</b></li> </ul>	<ul style="list-style-type: none"> <li>• Digital photograph taken of the sediment surface with core ID legible</li> <li>• Visual description logged of the sediment surface</li> <li>• Single Miniature vane at 4-in. vertical intervals to bottom.</li> <li>• Triplicate T-bar tests continuous from surface to bottom.</li> <li>• Select moisture content testing</li> <li>• Select unit weight testing</li> <li>• Select remolded miniature vane testing</li> <li>• Insert total of three (3-in. diameter) subsample tubes and remove, fill void space, cap, seal and properly label.</li> </ul>
<p><b>Core Section Labeling</b></p>	<ul style="list-style-type: none"> <li>• Label each core section and bag sample with the following minimum information: Job Number, Core Number, Section Number, Top Depth, and Bottom Depth. In addition, draw an arrow on each core section indicating which end is up.</li> </ul>

**Table 1. Field Sediment Testing and Protocol**

## CORE ACCEPTANCE CRITERIA

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**Table 1** lists the acceptance criteria for penetration and recovery of each type of core. A second coring attempt is made when these criteria are not met, unless the Client’s Technical Rep and the Party Chief agreed that information and/or soil from the site adequately explains the decreased penetration and/or recovery. Adjustments to the tool are possibly made for such a second attempt. A second attempt is also made if the coring gear clearly malfunctioned on the first attempt regardless of apparent penetration and recovery.

Tool	Tool length	Minimum	Expectation	Maximum	Expectation	Remark
		Penetration	Recovery	Penetration	Recovery	
PC	20 ft (6.1 m)	18 ft	80% of penetration	20 ft	98% of penetration	If geophysical data or the sediments recovered in the core do not clearly explain the reduced penetration another attempt will be made.
XPC	30 ft (9.1 m)	27 ft	70% of penetration	30 ft	90% of penetration	If geophysical data or the sediments recovered in the core do not clearly explain the reduced penetration another attempt will be made.
JPC	64 ft (19.5 m)	56 ft	80% of penetration	64 ft	95% of penetration	If the geophysical data or the sediments recovered in the core do not clearly explain the reduced penetration another attempt will be made.
XJPC	74 ft (22.6 m)	65 ft	70% of penetration	74 ft	90% of penetration	If the geophysical data or the sediments recovered in the core do not clearly explain the reduced penetration another attempt will be made.
BC	1.65 ft (0.5 m)	1.1 ft (0.33 m)	1.0 ft (0.3 m)	1.65 ft (0.5 m)	1.5 ft (0.46 m) <ul style="list-style-type: none"> <li>• Bottom sealed</li> <li>• Water on top clear</li> <li>• Surface sediments undisturbed</li> </ul>	If the geophysical data or the sediments recovered in the core do not clearly explain the reduced recovery, or the bottom is not sealed or the water on the sediments is not clear, or the surface sediments are disturbed another attempt will be made.
XBC	3.3 ft (1.0 m)	2.3 ft	2.0 ft <ul style="list-style-type: none"> <li>• Bottom sealed</li> <li>• Water on top clear</li> <li>• Surface sediments undisturbed</li> </ul>	3.3 ft	3.2 ft <ul style="list-style-type: none"> <li>• Bottom sealed</li> <li>• Water on top clear</li> <li>• Surface sediments undisturbed</li> </ul>	If the geophysical data or the sediments recovered in the core do not clearly explain the reduced recovery, or the bottom is not sealed or the water on the sediments is not clear, or the surface sediments are disturbed another attempt will be made.

**Table 1. Core Acceptance Criteria**

Revised 01/20/2022