

Portable Remotely Operated Drill (PROD)

PROD Technology

Benthic is a global leader in offshore geotechnical site investigation and geotechnical engineering, in particular the use of remotely controlled seabed drill rigs for this purpose. Designed and operated by Benthic, the innovative Portable Remotely Operated Drill (PROD) offers proven gains in efficiency, data quality and safety.

At A Glance

- PROD is a fully self-contained, remotely operated seabed drilling and geotechnical testing system, capable of operating in water depths to 3000m and investigating subsea bed depths in excess of 130m.
- The first system of its kind in operation, PROD has a proven track record of successful projects worldwide. These projects include deployments in ultra deepwater with difficult soil conditions and challenging seabed slopes.
- By switching dynamically between rotary coring, piston coring and in-situ testing with Benthic's suite of patented tools, PROD offers greater efficiency and flexibility than competing surface and subsea systems.
- Using the high-quality data generated by PROD, Benthic's team of experienced geotechnical engineers provide a complete end-to-end solution, from site investigation planning, data gathering and sample testing, to data synthesis, analysis, and foundation design.



The PROD Advantage

Efficiency

Operating directly on the seabed, PROD avoids the lengthy and time-consuming deployment of drill string, yielding immediate efficiency gains, especially in deep water. PROD can switch dynamically between drilling and testing tools in a single deployment or a single hole, allowing the device to penetrate a wide range of strata and deliver a variety of samples, from hard rock to soft sediments, without the need to recover the drill module to the vessel.

When transported between test sites, PROD can also conduct multiple borings in a single deployment from the vessel. PROD has been shown to deliver a lower cost per metre of data than other testing methods. PROD's productivity record includes up to 3x70m borings in a single day in water depths of 700m.

Quality

With the drill unit located on the seabed, PROD provides a highly stable and controlled platform, enabling Benthic's geotechnical team to make precise tool adjustments and collect extremely accurate data. In addition, PROD has been designed to produce minimal disturbance to the seabed at the point of testing and deliver undisturbed samples from the mudline, with a borehole depth accuracy of 25mm.

Safety

Safety is a key consideration in the PROD design. Controlled remotely by computer, human interaction with heavy, mechanical equipment is kept to a minimum, PROD eliminates the need to manipulate pipe sections on the surface, a leading cause of accidents. As a result, PROD has achieved an outstanding safety record in deployments around the world.

Proven Technology

Since 2000, PROD has proven itself in a wide variety of projects, including site investigations for jack-up and platform foundations, FPSO anchor spreads, subsea structures and pipelines. PROD has been particularly successful when presented with challenging conditions such as extreme seabed slopes, very soft sediments, adverse sea-states, operations in close proximity to existing platforms, pipelines or seabed structures. Its track record includes projects across the major global oil producing regions of South America, West Africa, Europe, the Atlantic and Australasia.

Environmentally Friendly

PROD produces lower environmental impacts than traditional testing methods, achieving the same volume of data with minimal seabed disturbance and fewer drill holes.

Geoscientific and Engineering Expertise

Using PROD technology, Benthic's team of experienced geotechnical engineers can generate a highly accurate dataset, adjusting the testing regime while the device is in operation to produce optimal information for each client's objectives. With extensive experience in geotechnical site investigation, data analysis and foundation design, we offer a complete end-to-end testing and design solution.



Technology

Engineered for rapid and cost-effective transport and deployment, PROD is both portable and self-contained. PROD is deployed from vessels of opportunity – chartered by Benthic or free-issued by our clients. Once on the seabed, PROD is powered and controlled by an umbilical cable from a support vessel, so it is unaffected by surface conditions, delivering higher quality data than ship-mounted systems relying on heave compensation.

PROD is controlled by a computerised system that combines operator input with proprietary software automation. Benthic's operators monitor a range of drilling parameters in real time, including bit weight, rotation speed, torque, elevator position, penetration rate, water pressure, flow rate and current hole depth, allowing them to make precise and delicate adjustments while the device is in operation.

Other features of the PROD technology include:

- Two rotary magazines holding up to 260m of sampling barrels, test tools, rods and casing, enabling penetration depths in excess of 130m sub-seabed.
- Pan and tilt cameras, allowing operators to visually monitor drill operations in real time.
- Tilt sensors and thrusters for precise positioning.
- Comprehensive in-situ testing tool suite including; CPTU, BPT, Seismic Probe, Hydrocarbon Analysis system, permanent piezometers.
- 3 independently adjustable outriggers, enabling PROD to land on uneven ground and sea-bed slopes to 20 degrees.
- Environmentally friendly drilling fluid injection to optimise borehole stability and cutting removal.

PROD Specifications

	PROD 1	PROD2 and PROD3
Maximum operating water depth	2,000m	3,000m
Maximum sampling penetration depth	>125m	>125m
Maximum casing depth	40m	54m

“PROD1 performance exceeded all expectations with more than 700m of sampling, PCPT, Ball Penetrometer Testing and Piezometer installation conducted within 10 days, distributed over 8 locations 3–30km apart, in 1300m water depth.”

Tjelta, TI and Yetginer, AG, Luva deepwater site investigation programme and findings in Gourvenec and White (eds), Frontiers in Offshore Geotechnics II, Taylor & Francis Group, 2011,

Capabilities

Using Benthic’s suite of patented sampling and in-situ testing tools and site investigation methodology, PROD can take a variety of samples and conduct real-time, in-situ testing in a single deployment, including multiple samples from a single hole.

Hard Rock Coring

PROD takes rock and strong sediment cores using Benthic’s proprietary thin kerf rotary diamond core barrels and other specialised coring bits as required. After many years of coring technology development, PROD now delivers the highest core recovery in even the most challenging geologies. Each barrel is fitted with its own drill bit and used only once, allowing PROD to resume operations rapidly if a drill bit is blocked.

Rotary Diamond Core Barrel Specifications

	PROD 1	PROD2 and PROD3
Core diameter	44mm	72mm
Run length	2.70m per barrel	2.75m per barrel
Rotary coring power	100 hp	130 hp

Soft Sediment Sampling

Soft sediment cores are taken using Benthic’s patented hydraulically tethered piston core (HTPC), which exploits ambient hydrostatic pressures to deliver optimal sample quality and recovery outcomes. Independent testing has demonstrated that PROD recovers high quality samples of extremely delicate sediments from the mudline, with minimal fabric disturbance.

Piston core barrel specifications

	PROD 1	PROD2 and PROD3
Sample diameter	44mm	75mm
Sample length	2.75m per barrel	2.75m per barrel
Maximum push thrust	More than 6t	More than 8t



In situ Testing

PROD can deliver real-time data from a range of in-situ testing tools, including a standard piezocone penetrometer, Benthic’s innovative ball penetrometer, our specially designed hydrocarbon analysis system and our deepwater seismic probe for measuring shear wave velocity.

In-situ Testing Tools

	Specifications	Data output
Cone penetrometer	Diameter: 36mm Length: 2m, followed by drill rods	Cone tip resistance Sleeve friction Pore water pressure
Deepwater Cone Penetrometer	Diameter: 36mm Length: 2m, followed by drill rods	Cone tip resistance Sleeve friction Pore water pressure
Ball penetrometer	60mm diameter steel sphere attached to a 200mm long x 20mm diameter push rod	Ball tip pressure Friction Pore water pressure
Downhole seismic probe	2 triaxial geophones 2 100 joule hammers (seismic source) Sensitivity: 290mV/in/sec	Shear wave velocity Small strain shear modulus
Hydrocarbon Analysis System	Methane sensitivity: 300µmol/l – 1µmol/l	Methane concentration Gas origin Depth of intercept
Permanent Piezometres		In-situ pore pressure

Extreme Environments

PROD is unique in its ability to operate successfully in extreme and challenging environments. PROD has successfully operated on seabed slopes up to 20 degrees, in ultra-soft sediments with mud-line shear strengths at 1-1.5 kpa, as well as in extreme weather conditions. In addition, PROD has proven to be the ideal solution for site investigations in very close proximity to existing infrastructure such as platforms and pipelines.

PROD's tripod structure, accurate sensors and hydraulic positioning tools enable our engineers to keep the rig vertical even on a sloping or undulating surface. Meanwhile, PROD's specially designed large area feet allow it to land on the softest sediments without penetrating the seabed, thus guaranteeing data gathering commences at mudline.

Once on the seabed, PROD is effectively isolated from surface conditions, allowing the rig to continue working in weather conditions that would prevent a drill ship from operating.

PROD ability to land and operate near existing offshore platform whilst the survey vessel is stationed away from exclusion zone enables the acquisition of geotechnical data safely, e.g., sufficient for an assessment of jack-up rig stability.

Put the PROD Advantage to Work

With expert support, proven efficiency, superior data quality and demonstrated capabilities in challenging environments, PROD offers significant advantages over competing site investigation technologies. Contact Benthic to find out how you can put the PROD advantage to work in your next subsea geotechnical survey.

“The cooperation between NGI and Benthic produced a very efficient solution for offshore piezometer installation at Luva and the PROD proved an ideal tool for this. Never before have these installations been conducted so efficiently with no loss of equipment ...”

Tjelta and Yetginer (2011)



Hydrocarbon Sensing System

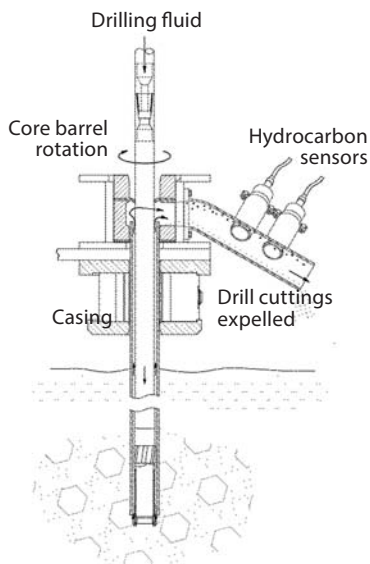
Proven Technology

Benthic's Hydrocarbon Sensing System (HSS) analyses drill returns for the presence of hydrocarbons as they pass through PROD before being vented on the seafloor.

The System, in its present form, includes two hydrocarbon sensors in line with the drill returns path. Drill returns, composed of seawater drawn from above PROD and pumped down the drill hole, mixed with cuttings created at the drill bit, also contain any gas or dissolved hydrocarbons that were held in the interstices between sediment particles.

Using tool geometry, drill fluid flow rate, and borehole progression rate, the relative concentration of hydrocarbons sensed can be used to estimate the in situ hydrocarbon composition of the material being drilled. Infiltration rate of gas into a borehole may also be estimated by water flushing and monitoring gas concentration over set time intervals.

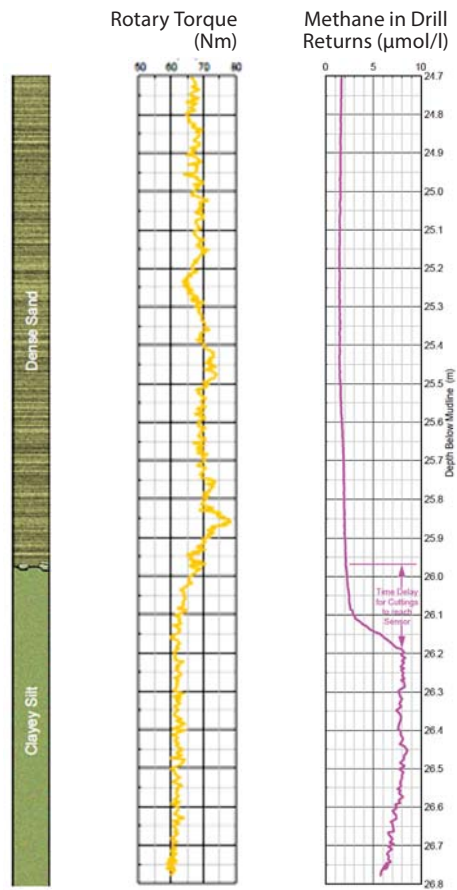
The System provides an early warning of potential shallow gas hazards and identifies the presence of methane hydrate concentrations. Gas origin, approximate concentration and approximate depth of intercept are logged versus borehole depth in real time and displayed on monitors in the control unit on board the survey vessel. Data is stored in digital format and can be combined with core logs and other in situ test data.



HSS Schematic operating principle

Technical Data

Low Range Sensor	
Type	METS
Depth Rating	0–3,000m
Temperature Range	2 – 20 deg Celsius
Methane Sensitivity	300 µmol/l – 10 µmol/l
High Range Sensor	
Type	IR-METS
Depth Rating	0–3,000m
Temperature Range	-2 – 60 deg Celsius
Methane Sensitivity	10 µmol/l – 1 µmol/l



Portable Remotely Operated Drill (PROD) Seabed Seismic System

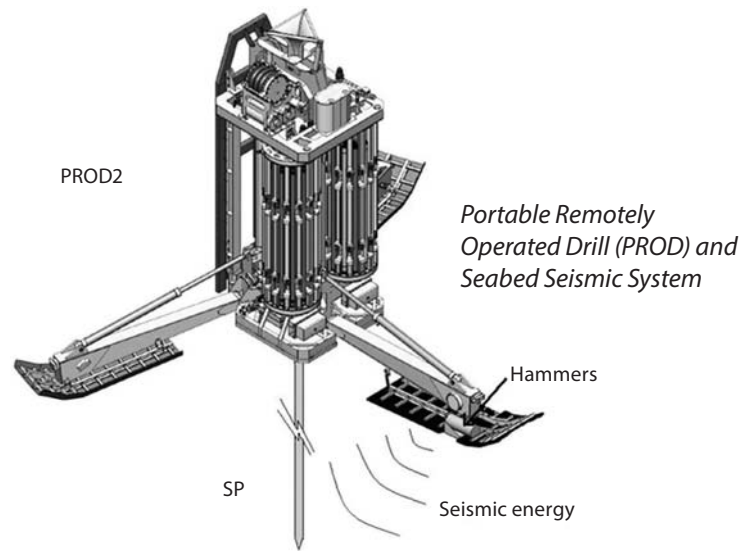
Proven Technology

Benthic's deep water Seismic Probe (SP) is an in situ seismic monitoring instrument that is deployed downhole to precisely measure the arrival times of seabed seismic waves.

This dual geophone seismic system enables true arrival measurement of interval shear waves, which has proved to generate much more reliable shear wave velocity data and higher data quality than traditional single geophone systems.

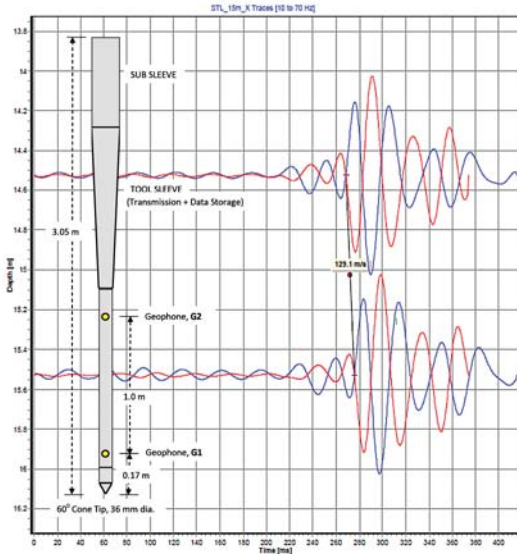
The SP houses two tri-axial geophone arrays ('G1' & 'G2') within a 36mm diameter rod, spaced one meter apart. Geophysical parameters including shear wave velocity (V_s) and compression wave velocity (V_p) are measured by penetrating the SP to target depth using Benthic's PROD drilling system, then monitoring wave arrivals generated from two opposite hammers at the sea floor.

V_s and V_p measurements by the Seismic System are used to derive important elastic soil parameters for foundation designs (i.e., small strain shear modulus, Young modulus, and Poisson's ratio). The measurements are also used for soil classification and stability assessments (i.e., earthquake soil liquefaction analysis), soil sample disturbance evaluation (i.e., through evaluation of in-situ vs. lab measurements of V_s), and calibration of other geophysical measurements.



Technical Data

Seismic Probe Technical Specifications	
Seismic Sensors	Two tri-axial geophone arrays mounted 1m apart
Geophone Sensitivity	290 mV/in/sec (type GS-14-L3)
Frequency Response	28 Hz (geophone LF roll-off) to 400 Hz (hammer energy)
Seismic Source Type	Two independent, hydraulically actuated, Iron mass-strike hammers providing opposing horizontal impulses
Source Energy	100 Joules (in each direction)
Data Resolution	16-bit (per channel)
Sampling Rate	4kHz (to a max of 16kHz) per channel
Repetition Rate	1 shot / minute (can be modified in firmware)
Shot Record	500 ms – 59 sec (programmable)
Internal Memory	32 MB (>1000 shots depending on settings)
Battery Capacity	12 hrs
PROD Seismic Probe Operation	
Probes per Deployment	3 max (current PROD prototype configuration)
Operation Rates	Typically 01 borehole per shift (12 hr)
Maximum Penetration	Depends on soil conditions, but 75m has been achieved
Data Download and processing	During seabed operation
Maximum Water Depth	Up to 3,000 m



Inboard/Outboard Shear Wave Signals

Portable Remotely Operated Drill (PROD) Seabed Ball Penetrometer

Proven Technology

Monotonic and cyclic BPT tests can be performed to provide continuous and accurate in-situ undrained shear strength and residual shear strength profiles of very soft to firm fine grained soils, especially for applications in pipeline and anchor designs.

PROD deploys 60mm diameter hardened smooth spherical ball penetrometers (BPT), equipped with individual sensors for ball resistance (q_b), and pore pressure at ball mid-height (u_b). The ball is attached to a 20mm diameter by 200mm long, high tensile push rod with friction reducing outer sleeve and is connected at its other end to a standard 36mm cone shaft that is in turn attached to an 88mm diameter, customized PROD drill rod.

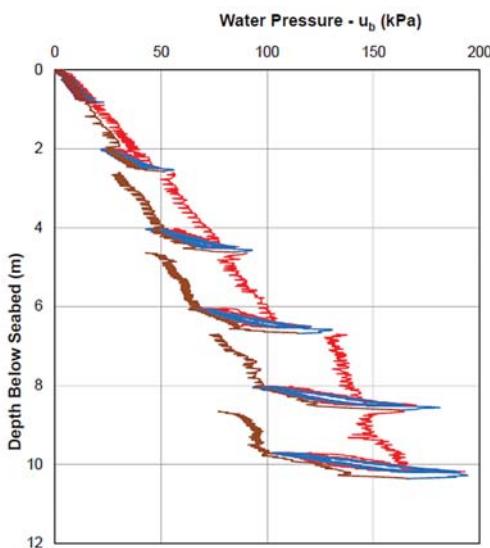
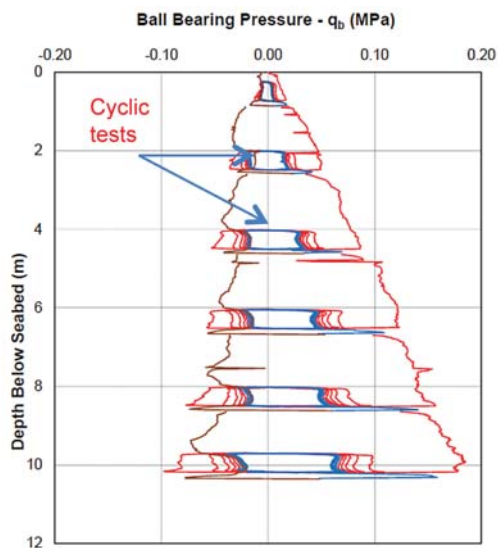
Zero reference readings are taken with the probe tip located approximately 700mm above the seabed. Sounding is undertaken at a nominal rate of 20mm/sec. Depth penetration is achieved via the addition of a drill rod, and continued application of thrust to the drill string.

During seabed sounding, 12-bit real time data is transmitted acoustically up the drill string to operator's computer. Once PROD is recovered to deck, 17-bit 'memory' data is downloaded and processed.

All cone calibrations are undertaken onboard the vessel by Benthic technicians with reference to a calibrated load cell and a pressure transducer. Calibrations for the BPT tools are conducted at the start and end of each project as well as offshore as the need arises. Monotonic and cyclic tests can be performed to provide continuous and accurate undrained shear strength profile of very soft to firm fined grained soils.

Technical Data

Ball Resistance, q_b	1.75 MPa range, accuracy <0.2% FS and resolution <0.0025% FS (50 MPa FS)
Water Pressure, u_b	25 MPa range, accuracy <0.4% FS and resolution <0.0025% FS
Penetration Rate	Nominal 20mm/sec
Real Time Data Transmission	Acoustic transmission (up to 100m drill string length)
Internal Backup Memory	Minimum 12 hours, 1 reading/sec, non volatile
Battery Life	>24 hours per probe (expended whilst down the hole)
No. of Probes per Deployment	Up to 3
Depth Control Relative to PROD	PROD carriage position system, resolution 1mm
Depth Control Relative to Seabed	PROD base plate monitored relative to seabed, resolution 25mm
Rated Water Depth	Up to 2000m
Operation Rates	Depends on soil conditions, but typically 75m or greater per operating day
Maximum Penetration	<125m below seafloor



Processed real-time and memory data available to client on board

Seabed CPTU

Proven Technology

PROD deploys 10cm² piezocones, equipped with individual sensors for cone tip resistance (q_c), sleeve friction (f_s), pore pressure (u_2), tilt angle, and temperature.

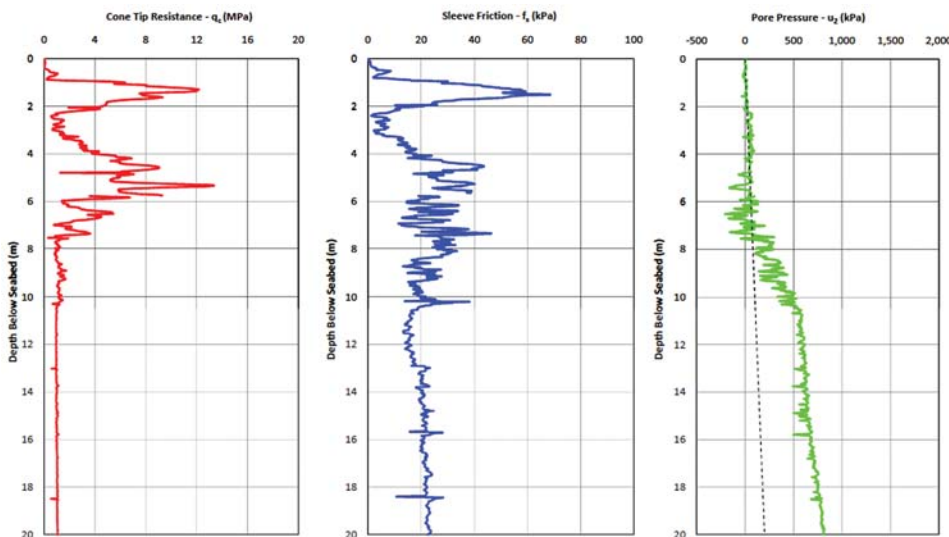
Zero reference readings are taken with the probe tip located approximately 700mm above the seabed. Sounding is undertaken at a nominal rate of 20mm/sec and continued until the end of elevator stroke is achieved (about 2.75m).

Further depth penetration is achieved via the addition of a drill rod, and continued application of thrust to the drill string. During seabed sounding, 12-bit real time data is transmitted acoustically up the drill string to operator's computer.

Once PROD is recovered to deck, 17-bit 'memory' data is downloaded and processed. All cone calibrations are undertaken onboard the vessel by Benthic technicians with reference to a calibrated load cell and a pressure transducer. Calibrations for the CPT tools are conducted at the start and end of each project as well as offshore as the need arises.

Technical Data

Cone Tip Resistance, q_c	50 MPa and 100MPa ranges, accuracy <0.2% FS and resolution <0.0025% FS
Friction Sleeve, f_s	1MPa range, accuracy <0.2% FS and resolution <0.0025% FS
Pore Water Pressure, u_2	25 MPa range, accuracy <0.4% FS and resolution <0.0025% FS
Tilt Sensor	0-40 deg. range, accuracy = 0.5 deg., resolution = 0.1 deg.
Penetration Rate	Nominal 20mm/sec
Real Time Data Transmission	Acoustic transmission (up to 100m drill string length)
Internal Backup Memory	Minimum 12 hours, 1 reading/sec, non volatile
Battery Life	>24 hours per probe (expended whilst down the hole)
No. of Probes per Deployment	Up to 3
Depth Control Relative to PROD	PROD carriage position system, resolution 1mm
Depth Control Relative to Seabed	PROD base plate monitored relative to seabed, resolution 25mm
Rated Water Depth	Up to 2000m
Operation Rates	Depends on soil conditions, but typically 75m or greater per operating day
Maximum Penetration	Up to 120m below seafloor



Processed real-time and memory data available to client on board

Soft Sediment Sampling

Soft Sediment Sampling Capability

PROD contains a number of unique features that enable it to recover very high quality samples in extremely soft sediments. The PROD system, coupled with Benthic's proprietary Hydraulic Tether Piston Core barrels, enables:

- Preservation of soil fabric / structure;
- Preservation of pore water within samples;
- Zero mudline disturbance both prior to and during sampling;
- Precise borehole depth measurements; and
- Measurement of dissolved hydrocarbons.

Proprietary Piston Core Barrels Recover Highest Quality 'Undisturbed' Samples

The currently operational PROD1 unit can recover 44mm diameter samples continuously to a depth of 100m, in water depths to 2000m. The new generation of Benthic's drilling systems, designated PROD2 & PROD3, recover 75mm diameter cores with a continuous sampling capability to 85m depth, in water depths to 3000m.

PROD's patented hydraulically tethered piston coring (HTPC) system has been refined over a number of years, paying close attention to industry best practice, in particular the design of the cutting shoe and the controlled manner under which coring occurs. PROD's HTPC is field proven to recover very high quality samples in soft sediments, as determined by a number of studies including assessments based on the NGI 'sample disturbance criteria', and petrographic examination of soil fabric at microscopic level.

Soil Fabric is Preserved

Figure 1 is a photomicrograph, which formed part of a petrographic study to assess fabric disturbance of a number of soil samples recovered by PROD, offshore Western Australia, in 550m water depth. The soil recovered was predominantly carbonate silt, and comprised extremely delicate, thin walled shells. Little to no fabric disturbance was evident for any of the samples examined. This result is in contrast to other sampler systems that impart significant damage across a large portion of the cross section.

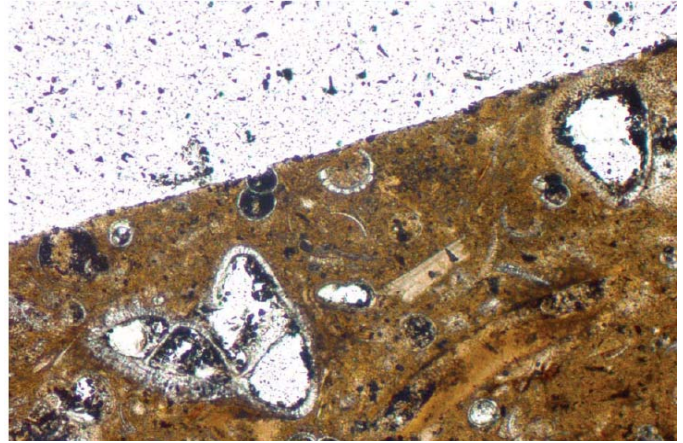


Figure 1 – Photomicrograph showing negligible sample fabric disturbance

Soil Sample Quality is Amongst the Best Available

Figure 2 presents the results of a PROD sample quality assessment undertaken using the NGI method for evaluating 'sample disturbance'. This method measures the change in void ratio (Δe) as a soil sample is reconsolidated back to its estimated, in situ stress state (p_o'), under triaxial stress conditions. Via estimation of the in situ voids ratio (e_0), the ratio $\Delta e/e_0$ is calculated. According to NGI, samples with a very low $\Delta e/e_0$ value are of high quality, and those with a higher $\Delta e/e_0$ value are of lesser quality.

Data measured during the course of testing the PROD samples are included on this figure, together with other data currently available in the public domain. The tested PROD samples plot in the 'very good to excellent', 'good to fair' categories as defined by NGI. The PROD dataset is at least as good as other high quality sampling methods, such as block sampling and the DWS (Deepwater Sampler).

Portable Remotely Operated Drill (PROD)

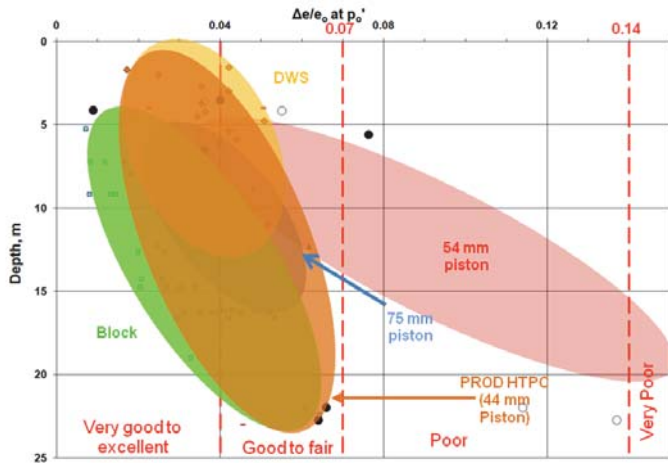


Figure 2 – PROD Piston Core Samples – Highest Quality according to NGI Criteria

Of note in Figure 2 is the demonstrated capacity of PROD to recover piston cores of equivalent quality to block samples*, and at greater depths below the seabed than able to be achieved using alternative, 'single thrust' coring systems.

* The block sampler data presented in this figure was acquired from an onshore testing site, and is not considered to be a practical method for recovery of high quality samples in marine environments.

Soft Sediment Feet Enable Precise Mudline Definition & Negligible Artificial Surcharge at the Test Site

PROD has been designed to land and remain stable on extremely soft sea beds. This capability has been demonstrated at numerous deepwater, soft soil sites, since 2005. PROD's footings have been designed to land on sea beds with shear strengths as low as 1 to 2 kPa.

Figure 3 illustrates a schematic of PROD's external leg footings, and the sequence involved in landing and levelling PROD, on a soft soil seabed.

During initial landing, the leg footings are deployed well beneath the machine, and provide sufficient bearing capacity to ensure the central zone beneath the machine does not intercept the seabed. Subsequent to landing, a catenary is formed in the umbilical to completely isolate PROD from vessel movements. PROD is then lowered on hydraulic actuators, in a controlled manner, until the central baseplate is at the seabed.

In this way, upper seabed disturbance associated with initial landing on a very soft seabed is completely avoided. Sampling commences precisely at the natural water/soil interface. Regular monitoring of the height of PROD relative to the seabed ensures that borehole depth accuracies within 25mm of actual are achieved.

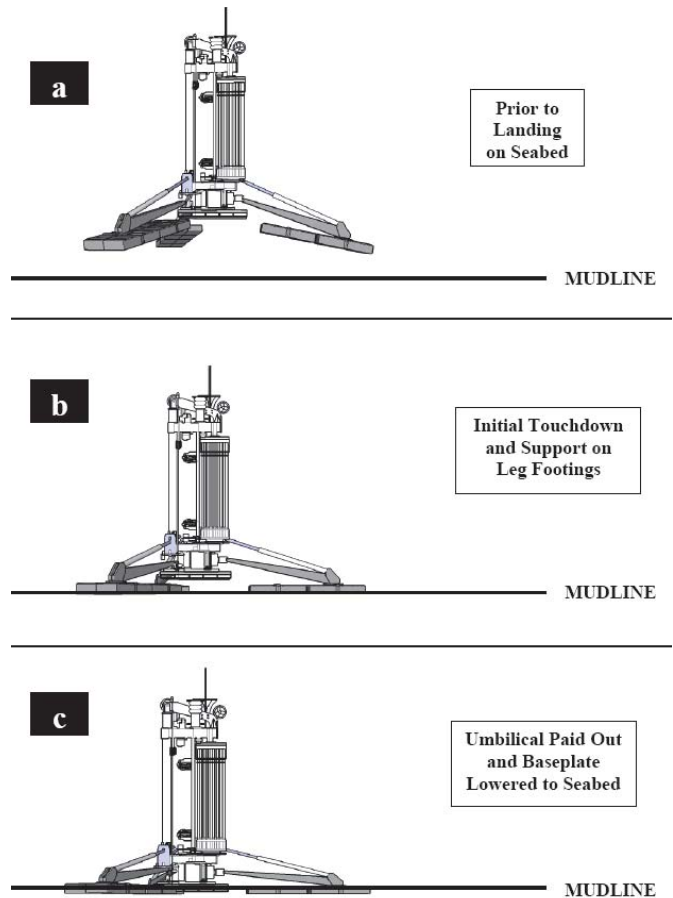


Figure 3 – PROD's external leg footings – provide stability without seabed disturbance

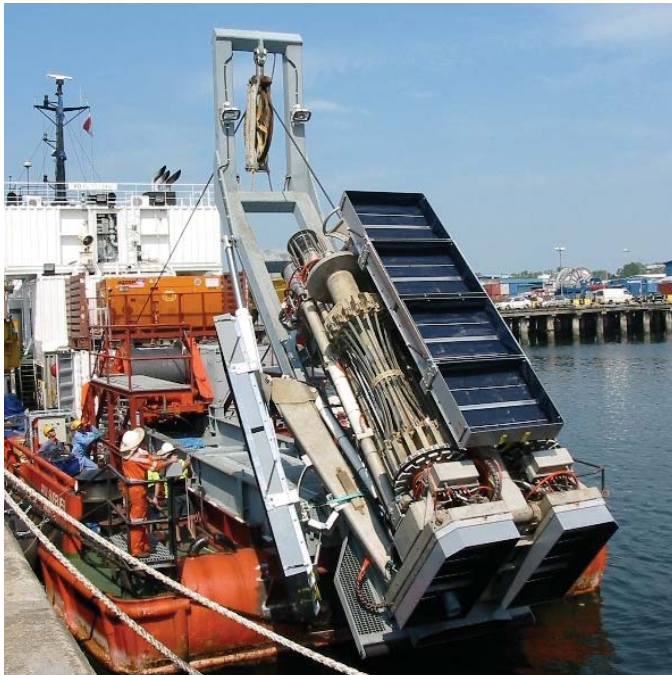
Detailed Site Investigation at Maari

Excellent Sample Recovery In Soft Clays and Sand

January 2006

Benthic Geotech recently completed safe and successful drilling, sampling and insitu testing at the Maari field, Cook Strait, New Zealand for OMV New Zealand Ltd. The project was completed with negligible equipment down-time due to breakdown or maintenance.

The investigation provided geotechnical data for foundation design to support a new well head platform. Sampling and CPT testing was undertaken at 24 locations to represent an area appropriate for the gravity based foundation.



Trial launch from ROV Supplier

Project Details

Date	Dec 2005 – Jan 2006
Location	New Zealand
Vessel	53m DP1 ROV Supplier
Geology	Soft clayey SILTS overlaying medium dense SANDS
Description	Multiple borings to a max depth of ML-34m with continuous sampling and continuous CPTs

Significant Achievements at Maari Using PROD

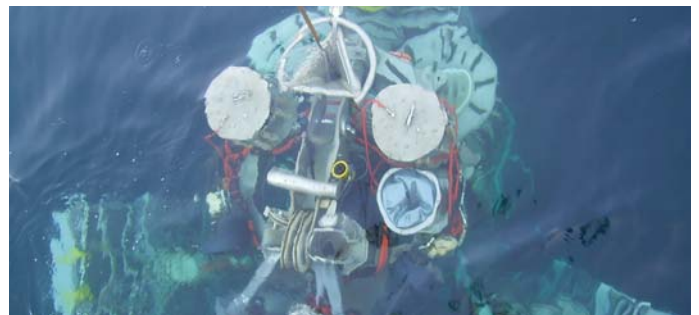
PROD provided a number of extra benefits to the client. These included:

- Detailed and accurate characterisation of surface soft soil layers. Supported on its broad skirted footings, PROD imparted negligible disturbance to the soft seabed enabling accurate definition of the thickness of the soft silt layer at seabed, and good depth control of the drilling operations.
- PROD's piston sampling system recovered near continuous 2.75m long samples. Exceptional sample recovery was achieved in all materials, including clean sands. The high quality samples enabled the layered nature of the materials to be clearly observed.

Excellent productivity was achieved. The 24 investigative holes were carried out in only 8 deployments of PROD. CPT testing at 17 locations delivered 180m of 18-bit CPTu data. Sampling at 7 locations, using the unique combination of controlled piston and the newly designed core catcher, resulted in 114m of silt and sand samples being obtained, with full recovery in both silts and sands. All work was completed in five days total operating time.

OMV's representative on board commented: "PROD is the ideal tool for this type of gravity structure with skirted foundations at this site. The productivity, reliability and sample quality of the PROD system well exceeded our expectations."

The foundation design consultant said: PROD's ability to clearly identify the soft surface layer and the softer lenses within the dense sand has been very helpful to the detailing of our foundation design."



PROD on its way to the seabed