Geo Coastal Group
Marine and Coastal Resource GeoSciences

VIBRACORING ESSENTIALS

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1 Introduction

Vibracoring (traditional spelling vibrocoring) has been the preferred method of seabed/aquatic sediment coring over a number of decades because it:

i. is marine adapted (i.e. dislocated from vessel movement),
ii. recovers unconsolidated sediments such as flowing sands,
iii. recovers a continuous core, and
iv. is rapid and versatiletherefore a large number of sites can be investigated economically within a short period.

Historically the main application of vibracoring was to service research into chemical and sedimentological parameters of marine/lacustrine/riverine sediments, however, in more recent times this focus has increasing been extended into include both pre-dredge contaminant and acid sulfate soil assessments, and resource (sand or mine tailings) assessments.

There is now a wide array of vibracorer types available, and therefore, it can prove quite difficult for the uninitiated to know where to start in the process of selecting a 'fit for purpose' configuration. The purpose of this discussion is to provide a path through this maze. To say that "I need a vibracorer" is like saying "I need a vehicle to travel from A to B"; in the way that a 'vehicle' may vary from a small, low-powered urban 'bubble' car to an interstate truck, vibracorers (including percussion corers) come in a vast range of power and performance characteristics. Bigger is not necessarily always better; to continue the 'vehicle' analogy there is no point commissioning a truck to run a local errand when considering the load capacity required, economics, versatility, emissions etc. Similarly there are situations were less powerful and portable vibracorers have their role, however, sophistication is always important. What are we talking about when we say sophistication? This will be discussed in more detail later in this article, but a short list includes: barrel design, barrel material, core-retainer design, frequency and frequency modulation, plus a method of both evacuating water from, and creating a vacuum in, the barrel.

2 History in Australia

The following is a brief summary from the quite long history vibracoring in Australia, which has been punctuated by many triumphs and travails.

Traditionally, marine vibracoring has been dominated by 415 vlt electric powered units because electricity can be applied over a considerable distance without significant power loss, thereby providing the capability to core in considerable water depths (e.g. we achieved 275m water depth in Rabaul in 1993). Although I am a little vague on the very early history (I look forward to any 'old boys' chipping in here) my understanding is that the first vibracorer to operate in Australia was a British-built, electric 'beast' introduced by a South Australian university in the 1960s (I have seen diagrams of this unit, and heard some descriptions of it being quite cumbersome in use). During the 1970's the design of electric vibracorers, and the seabed towers in which they operate, were substantially refined by Sydney-based researchers and operators Prof. C. Phipps and Mr. D. Fitzhenry (I was fortunate to have worked with both of these gentlemen during the 1980s) . These developments continued throughout the 1980s and by the 1990s, and there was an expansion of their numbers and distribution during this period. A commercial application of the Phipps' style electric corers was spawned out of Coastal Geology program at Sydney University courtesy of Messer's J. Hudson and D. Skeene (later joined by experienced US born operator Ms. Bobby Rice). James Cook University also acquired a Phipps model during the 1980s, and I developed an 8m vibracoring capacity during the late 1980s while attached to the Commonwealth Geological Survey. By the late 1990s Australia could justifiably claim to have developed the most effective electric vibracoring systems in the world (a claim that was well demonstrated in east coast USA programs in the early 2000's). Again, I was fortunate to have worked with many of these people and units throughout the 1980s and 1990s.

The 1990s also witnessed the introduction of light, pneumatic vibracorers. The evolution of these corers can largely be attributed corers pioneering engineer E. Braumm (Queensland), and were widely used by the Coastal Geology group of Queensland Geological Survey (A. Stephen, K. Holmes, M. Jones, D. Searle)who used them in a diving mode for research. These pneumatic 'vibrators' (discussed later in more detail) are generally quite modest in power and, while they have played a valuable role environmental/research coring, they are quite limited in their penetration capacity and application.

A third category of vibration source is hydraulic. I had the first hydraulic unit commissioned in the early 1990s for coring coastal land sequences while manager of the Coastal Geology program in the Commonwealth Geological survey. Subsequently, within GeoCoastal, we have continued to develop a series of hydraulic vibration heads and apply them to both land and marine coring with the advantage of substantially increased power (approx. 300% that of 415vlt electric systems). Another advantage of hydraulic is that it provides the opportunity to modulate frequencies which, in combination with additional power and other physical design features, has allowed us to take penetration to depths that were inconceivable a decade ago. The conventional wisdom until the current decade was that it was not possible to vibracore beyond 6-7m. This belief was driven largely by the power, frequency and configuration constraints of electric vibracoring systems. During the past decade GeoCoastal's two senior marine geologists, with over 60 years of combined vibracoring experience, embarked on a developmental path to extend the depth of vibracoring. As a result of this program GeoCoastal regularly vibracores to depths of 20m, and produces 100% continuous core that is free of downhole cross-contamination. This capability is unique to GeoCoastal and uses proprietary techniques and PEP technology which has allowed us to establish world record depths of continuous core recovery (i.e. 28m in riverbed sands complete with undisturbed pore water (for CSIRO), 43m including pore fluids in coal mine tailings ponds, and recently 32m subbed continuous recovery of gold-mine tailings in 20m water depth).

A fourth category is one that is not strictly a vibracorer, but is a close relation and is designed to work in the same style of application – the marine 'percussion' corer. Again this has been the subject of a development program within GeoCoastal during the past decade in response to the requirement for testing of stiff clay seabeds for capital pre-dredge surveys. This GeoCoastal program of marine 'percussion' corers (original CAHT series and more recently the Mako series) has raised the bar on power and penetration well beyond that possible with vibracoring.

3 Technical Discussion of Vibracorer Sources/Configurations/Pros & Cons

For those who do not require external assistance to get to sleep you may wish to skip this section and move directly to the "How do I select the right vibracorer for my project?" section following.

I note here that the following discussion may sound GeoCoastal-centric at times, but this is unashamedly because we have embarked on a continuous development program to enhance performance, and are continuing to do so as this article is written. The following discussion considers the 'pros' and 'cons' of various vibracore systems in the light of the various elements that combine to make an effective unit:

Power:

a fundamentally important attribute to achieve good penetration

- ***Power*** - raw power is not everything in a vibracorer – but it does go a long way to helping to achieve the result as nature rarely provides the 'ideal' sedimentary circumstances for easy vibracorer penetration. At GeoCoastal we have developed an index to rate our systems on a penetration scale. This is a 'clay penetration' or 'C' index relates to the depth in centimeters of penetration of a 2mm thickness tube into a moist stiff (i.e. mature) clay in 3 minutes (e.g. C45 = 45cm of penetration in 3 minutes). While mature clay is not the preferred sedimentary environment for the vibracorer, this gauge of penetration is a good proxy for how they might be expected to perform in a range of circumstances such as where cemented layers, or intercalated clay layers might occur.

CLAY INDEX: Depth in centimeters of penetration of a 2mm thickness tube into a moist stiff (i.e. mature) clay in 3 minutes	
Light pneumatic 'bin shaker' vibracorer	C 1
Light electric vibracorer	C 1
Rossfelder electric vibracorer[∦]	C 15
Phipps-style electric vibracorer	C 20
Small hydraulic vibracorer (GeoCoastal)	C 50
Hydraulic vibracorer (GeoCoastal)	C 100
Pneumatic percussion corer (GeoCoastal)	C 400
Hydraulic percussion corer (GeoCoastal)	C 750

[∦] Remote Estimate - other estimates and measures based on direct observation

Barrel/Core retainer:

affects penetration, core recovery, and quality control

- ***Barrel/Core retainer (core-catcher) -*** barrels may be considered from two perspectives: *i*. as they effect performance, and *ii*. delivery of core free of contamination.

  Vibracorers have traditionally used *aluminium irrigation pipe*. On the' pro' side of the equation this pipe can be stored for long periods in marine environments and is easily cut (with the right gear) for splitting and presenting core. On the 'con' side it is expensive, has a degree of additional wall friction over steel, the cutting process may introduce a contamination vector via the cutting residue and blade (depending on the parameters being tested for). Also they are prone to failure if hard surfaces are encountered (particularly with set-frequency, electric corers where they are prone to 'harmonic compression' failure. An alternative is *mild steel pipe* which on the 'pro' side is cheap, stronger than aluminium, and generally low wall friction (if pristine), while on the 'con' side may also introduce a contamination vector via hydrocarbon residues in preservative lubricants, rust, or via residue and blades during cutting. Incidentally, I have also witnessed 'harmonic compression ' failure in mild steel barrels using electric vibracorers on a hard calcrete cemented substrate. Both of these aluminium and mild steel barrels can result in the core being exposed to contamination vectors if split outside of a laboratory grade environment (which they usually are because the noise is horrendous).

Don't use PVC (or similar) liners!

As part of our Quality Management System, GeoCoastal ensures that only low friction, marine grade stainless steel ever contacts the core, does not use cutting in the process, and presents core that is not exposed until in a laboratory environment. We are working on a more advanced barrel model as this article is written.

It is not unusual for personnel who are first confronted with the barrel dilemma and who are generally unfamiliar with the fundamentals of vibracoring, to suggest coring with a PVC (or similar) liner. This seriously impedes performance, and should not be considered - unfortunately, this age-old clanger has been given a rebirth in some recent tender documents. GeoCoastal has the most powerful vibracorers operating today and would not consider inserting PVC liners.

Generally associated with the barrel is a core retaining device (commonly a multi-fingered core catcher but other exotic models also exist). Firstly, if your contractor doesn't have a core retaining device, then send them home. Arriving at an effective core retainer design for a range of sedimentary media from very soft silts to flowing sands to stiff clay is challenging, and generally the first response to failure or leakage by this device is to simply increase the stiffness of the finger material. This can be quite counterproductive to collecting that critical very soft silty layer at the top of the sequence.

Barrel evacuation / Vacuum:

If the corer proposed doesn't have a mechanism for this put it back in the shed.

- ***Barrel evacuation/vacuum -*** this relates to evacuating water from the barrel and creating a vacuum as the barrel penetrates the seabed. It is one of the more important facets of obtaining quality core; with contaminant coring in particular, the most critical recovery target is the weak, liquified mud at the very seabed. If a corer does not have a method for extracting water from the barrel then the combination of: the water head in the barrel, reduced aperture at the top of the corer restricting water escape, core retainer resistance, and wall friction, will provide greater resistance for weak sediment to enter the barrel than to flow beside. Additionally, many sequences may have softer internal layers, and these will be selectively compressed during penetration, is a vacuum creating device is not applied.

  Traditionally, this requirement has been serviced by a piston which is attached via a fixed length cable to the top of a seabed tower; as the barrel enters the seabed the piston remains static, thereby travelling up the barrel ahead of the core in a relative sense. There has been a recent introduction of diver supported coring (i.e. without a tower - refer later discussion) and I am uncertain as to how this requirement is serviced during this style of operation. GeoCoastal do not use a piston, but have other proprietary technology for achieving recovery of all mediums including these weak surface silts. Unfortunately, this requirement has fallen into the too hard basket in some systems currently in use - bottom line, if a vibracore system does not have a positive mechanism for evacuating the tube and creating a vacuum it should not leave the shed!

- ***Frequency -***

Electric vibracorers run at a set frequency governed directly by the speed of the electric motors driving them. For the larger 415 vlt units this tends to be either 1490 rpm or 3600 rpm. I have tried both of these speeds in trials and both appear to have individual advantage in different sediment types. My preference would be the lower, 1490 speed, and this tends to be the more common.

An established fact among experienced operators is that the very regular frequency of the electric vibracorers tends to result in a harmonic developing down the tube resulting in the corer wanting to sit in a single position (the same experienced operators also know a couple of tricks for breaking out of this harmonic pattern). The influence of this harmonic effect will vary according to the changing length of the barrel remaining out of the sediment. The later Phipps' model vibracorers were modified in their internal design to help overcome this frequency effect.

The ability to continuously vary the frequency is one of the great advantages of hydraulic vibration units, however, with the added power the penalty for getting some quite minor design aspects wrong can be lateral shear of some surprisingly thick steel parts. Our percussion corers run similar frequencies to conventional vibracorers, however, the harmonic question is not a consideration in this mode.

> *Frequency:*
>
> Electric systems have a very regular frequency which can lead to the development of harmonics causing penetration to stall in a favourable position.
>
> Hydraulic and percussion systems do not have frequency constraints.

- ***Configurations-***

The conventional configuration for electric vibracorers is for them to be contained within a circular seabed tower with three legs. By necessity this tower needs to be the length of the barrel + the vibration head (~7m). Once in the water this process is relatively straightforward - the tower is lowered to the seabed, the power is turned on, the vibration head drives the tube into the seabed, then the head is dragged back to the top of the tower via a winch rope to the surface (i.e. withdrawing the barrel), and the whole frame is returned to the water surface. This is where it ceases to be either easy or fun! In order to launch or retrieve a tower of 7m length with a spread of legs of some 4-5m is very difficult. This requires either the sort of large A-frame that is only found on a few large specialised vessels, or many cunning tricks (the history of coring is littered with many examples of the latter which have been applied with varying degrees of success - photographs abound of these towers slung across and alongside smallish vessels like an alien invasion). Of course, the transport of these frames to and from the port of departure is another consideration. C.V. Phipps, in particular, went a long way to developing user friendly aluminium frames that could be broken down for transport, however, these frames still present many of the same challenges in use.

A significant point to remember is that the total barrel length is restricted to what can be contained in this tower, and this has been the main constraint to attempting longer core penetrations (e.g. an 11m tower to retrieve a 10m core would be too much to contemplate unless on the scale of very large-scale, research-style vessel, and there is some doubt about the capacity of electric corers to regularly achieve that depth). GeoCoastal's offshore percussion corers operate within a modified tower design.

In exposed or deep-water (greater than 20m) situations where operations are conducted from ships with A-frames, the tower-style configurations remain the only real alternative, and consequently, 6m cores remain the realistic limit of the method.

An alternative configuration for electric coring without a tower (that to my knowledge hasn't operated in Australia) is based on a heavily weighted base frame and submerged bouys, however, I spoke to a Fijian technician who had worked with configuration and he concluded that it was problematic in other than very controlled conditions.

A further method that has evolved in recent years has been the advent of using divers in *lieu* of a tower. As mentioned earlier light coring devices have been used in this fashion in the past (and still are), however, in recent years a diving company has purchased a larger electric corer and then set out to experiment with methodologies based around divers (how do I know they were experimenting? - I had a call from a distressed client a few years back asking if I would explain to the proprietor how to vibracore). Most of my comments regarding this method stem from it introducing an unnecessary additional safety risk, however, I also find several operational aspects of this practice questionable. Both myself and our other senior geo's have a background of commercial diving (he was an dive instructor) and have considerable experience at operating equipment such as light vibracorers and jet-probes on the seabed, so have a good understanding of just how unstable this procedure can be in anything other than ideal conditions. Oddly enough this diver-based concept has been sold by claims of being able tell when the corer is vertical and being able to measure the rate of penetration. Any diver who has attempted to hold a weighty object vertically in poor visibility, current and/or swell conditions will soon draw their own conclusions on the validity of these claims. In Rabaul, PNG during the early 1990s we successfully implemented an electronic means of measuring penetration depth and tilt because high precision was relevant to the measurement of the heat flow probes we were vibrating into

Configurations:

Traditional electric systems use a large seabed tower, the deployment and retrieval of which from vessels, has been one of the long standing challenges of this method.

An alternative for lighter systems has been to substitute the tower with divers. There has been a recent move to use divers for larger systems which is regressive in many aspects, and adds unnecessary additional risk.

Geocoastal has a proprietary configuration for <20m water depth that avoids the complication of either tower or divers, and has allowed us to take continuous core recovery to unprecedented, world-record depths.

the seabed. At this time we examined the scientific merit of continuing these measurements in regard to coring and concluded that they were scientifically superfluous.

GeoCoastal's has a proprietary configuration for use in water depths of up to ~20m that overcomes many of the constraints of conventional systems and allows us to core to unprecedented depths (e.g. 32m sub-bed during 2012). Coincidentally, this system gives us the most direct measure of verticality and rate of penetration of any configuration operating today (although we continue to question the scientific logic of these pursuits).

Safety:

- working on a moving platform
- deploying and retrieving large frames on a moving platform
- lifting & suspended loads
- power sources:-415vlt electricity in a salt water & steel environments, or high pressure air, or hydraulic
- divers:- underwater with high voltage, proximity to other shipping, dangerous marine/estuarine fauna

- ***Safety***

By definition marine operations take place on an unstable platform and will therefore always have additional safety considerations ranging from basic factors such fatigue (poor sleep/seasickness with some personnel) and light lifting at the lower end of the scale, to winching/lifting, high voltage/pressure, moving weighty objects within a limited space at the upper end of the scale. It is not the intention to attempt to write a full risk assessment for each vibracoring method here (that would double the length of the document) but simply examine some of the broader fundamentals.

Most conventional offshore vibracore configurations use large, and *cumbersome towers* (as discussed above). These are suspended from either large A-frames or cranes, and while at least the base of the tower is in the water everything is nicely controllable. However, there is inevitably a point during deployment/retrieval where the tower is totally free of the water and suspended from a moving vessel. At this time the tower is suspended very short and, as with pendulums, swing at a higher frequency closer to the source. This is the most critical time in terms of obtaining control over the tower without risking injury to personnel. Scary Anecdotes 1 & 2→

Scary anecdote 1:

In the way on dubious methods of vibracore retrieval I witnessed a technician jumping from a vessel onto a vibracore frame in order to fold a leg - in the middle of the night, in Bass Strait, in big swell conditions!

As part of our ongoing commitment to development and safety, GeoCoastal are currently developing a revised frame and launch/retrieval procedure to streamline this procedure.

Traditionally, vibracoring in Australia has been dominated by *415vlt electric powered* corers. On the face of it the mix of electricity and water appears incongruous, however, it remains the most efficient mode for delivering of power over distance (depth). These systems have trip switches to protect personnel, and in truth I have not heard of anyone every receiving an electric shock. However, as this equipment operates in an environment of steel and salt water there needs to a strong emphasis on safe procedures. In respect to diver operator methods I would have reservations about divers holding onto steel components underwater while 415 vlts is delivered to the vibration head (something I was very cognisant of when diving to observe electric corers in steel towers in the 1980s).

High pressure air and hydraulic systems offer their own risk to surface personnel that require standard industry procedures (e.g. 'whip-checks') to overcome. Similarly, standard lifting safety procedures come into play, especially when adapting to vessels of opportunity which may be operating in a different mode than either the crew are familiar with, or the vessel was designed for.

Scary anecdote 2:

The' vibracore landing waltz' - the not uncommon dance with danger where personnel launch a (hopefully synchronised) charge at a large swinging frame to try and bring it under control during retrieval of the vibracorer.

A consideration universal to all systems is the possible severance of the power conduit if the surface vessel 'breaks away' for some reason (e.g. a sudden anchor release due to a squall) and procedures should account for this possibility. While not common, I have witnessed this on a number of occasions, and again I would question the unnecessary complication of divers in the water in such an event.

The recent advent of diver supported vibracoring raise additional concerns specific to that activity:

- in active ports divers present an additional (and unnecessary) risk where vessels work closely together. For example, we have orchestrated coring within berth pockets of active coal ports during the brief interval between when tugs remove one vessel and delivering another, with no delays incurred. In this regard I have heard reports of divers leaving the water each time a vessel travels in proximity for safety which, while commendable, would seem detrimental to maintaining productivity
- on an appropriate vessel coring operations using a well designed tower can continue in 20knot conditions and 1m+ seas, whereas diver related operations are much more restricted
- there are also obvious additional (and unnecessary) OH&S dangers associated with diver activity in regard to dangerous marine animals. The most obvious are crocodiles (previously reported as far south as the Brisbane and Logan Rivers), sharks, and a colleague of mine required emergency evacuation after being wounded by a stingray barb while providing professional diving services in the Gulf of Carpentaria
- communications between surface and divers is also obviously more 'clouded' than surface directed operations. Scary Anecdote 3 →

The recent advent of diver supported vibracoring is, in my estimation, an operationally regressive move, and one that introduces an unnecessary additional level of risk. It is refreshing to see in recent tender documents that this is a view shared by several port authorities and mining companies.

Scary anecdote 3:

I heard of an incident where a diver responding to sand leaking from the core retainer put his hand beneath the end of the tube, almost losing fingers in the process.

4 How do I select the right vibracoring configuration for my project?

4.1 Introduction

As mentioned in the main introduction, the purpose of the following discussion is to assist the uninitiated through the maze of different styles of marine vibracorer to chose one that is 'fit for purpose'. Not only will evaluation based on these parameters help define the appropriate equipment, the development of a tender scope in which these elements are well defined will help to constrain the tender price.

First, a couple of general observations on sediment quality assessments that may be useful for tender preparation:

- It is not uncommon for project managers to view the sediment quality requirements of pre-dredge investigations as a frustrating sideshow to the main event, and to therefore try to cover off on sediment quality sampling by proposing grabbing a few samples during geotechnical drilling ("let's throw the brussel sprouts on the BBQ with the meat"). At best this grossly underestimates what is required for a compliant sediment quality assessment, and at worst can introduce false contamination triggers or spread the apparent contamination footprint, leading to very substantial downstream costs. Time and again we see clients attempting to short circuit the process only to lead to a climate of antagonism with authorities, delays in getting approvals, and time for a groundswell of public discontent to grow. Remember 'fit-for-purpose' - some apparently cheaper up-front options can rapidly become very false economy. TIP →

Tip 1:

Don't try to mix sediment quality geotechnical and sampling - it just doesn't work.

- We have noted in some recent tenders that, rather than the client having a Sample Analysis Plan (SAP) professionally prepared to direct the tender scope, they throw this out to the market to solve within the tender process. This isn't clever for a number of reasons; mainly because the market will, in all likelihood, come back with a confusingly wide array of responses from the totally inadequate "I'll win by having the cheapest price - we'll do it by desktop study" to the "everything and the kitchen sink" over-catered assessment. As a consequence the client then needs to commission the equivalent professional to the one who should have prepared the initial SAP to sort through the mire, or risk picking a tenderer from the multitude and hope for the best. Even after this the client will still have to pay for a professional SAP to be produced at some stage. Not only has there been no gain in the process, in all probability, the tender prices will have blown out due to the added risk of the vague scope. TIP →

- *Marine operational costing* should not be compared to land-based investigation costs. There are a number of unique costs involved in the development, maintenance and storage of highly specialised marine equipment for intermittent use. This specialised equipment can bring great benefit to marine programs when applied. In particular, the collateral costs of inappropriate equipment in generating standby charges and greater interruption to port productivity are often poorly accounted for. Another big 'sleeper' cost to the Contractor, and potential high risk to port authorities, is insurance cost. The standard for a serious port contractor in 2013 should be $US 0.5 billion - what will it cost if the port is shut down due to an accident? TIP →

- *Pricing structure* -in the way that costs are different between land and marine based systems - so too should be the pricing structure. For example, per metre coring rates are totally inappropriate in a marine coring situation where the overwhelming portion of time is spent positioning the vessel or platform (usually involving complex multiple anchoring) and deploying and retrieving gear. With a good system the rate that metres are penetrated can be literally measured within seconds when the corer is actually turned on. Also there are too many unknowns in the subsurface stratigraphy (e.g. heavy clays/indurated layers/rock) for a contractor to cost on a metres recovered basis. Over a number of years we have established that a per hole rate or per total job rate with standby on the outside is the most successful structure (the latter is our preference). This structure provides a positive incentive to drive the program along (within the bounds of maintaining safety) which is in everybody's favour, particularly as it reduces a project's exposure to standby risk. TIP →

Tip 2:

A professionally-prepared, pre-tender Sample Analysis Plan will benefit the tender process and constrain tender prices.

Tip 3:

Expect the cost of specialised marine equipment to be higher than land-based equivalents, but can bring great efficiencies to marine projects, especially when standby and port interruption is considered. Is your contractor adequately insured? - $US0.5 billion in 2013.

Tip 4:

Price marine coring as per site completed, of as whole of job price, but leave standby costs on the outside of this price.

- *Standby* - standby will always be a risk cost with marine operations, however, it is more beneficial for the client to take on this risk and budget for it - if you ask the contractor to account for it they will invariably overcompensate as it is totally out of their control. Standby is still a poorly understood facet of marine operations - particularly in more recent times where consultancy firms that have not had a long history in marine operations are increasing dabbling in pre-dredge assessments. Often between the 'hurly burly' of recovering from the extended Christmas/New Year holiday season disruption, and the impending end-of-FY accounting crisis, plus board meeting deadlines etc., scant regard is paid to the time of year and weather conditions when commissioning works. Schedule a marine program at the wrong time of year? - then expect substantial standby cost. Commonly the Contractor is made out to be the perpetrator of this cost overrun, and is made the scapegoat for poor planning. For more information on standby TIP →

Tip 5:

Choosing the right time of year to conduct marine operations will greatly reduce standby costs.

Land-based drilling equipment in a marine setting:

I have deliberately not considered standard rotary drilling techniques in the following discussion because, although they have obvious penetration capability, they are generally a very poor choice for recovery of sediments for either ASS or contaminant samples, particular in a marine setting. Scary Anecdotes 4 & 5→

Likewise we have not considered Geoprobe rigs in this evaluation as they are largely a land-based option.
They do not work well in a marine situation where there is any significant water depth as the drill stream needs to be contained, and these rigs need to continue to re-enter the hole several times to achieve depth (we know - we used to have one!).

Scary anecdote 4:

As a sobering example, we were called in after a client had spent a month of time and approx. $1 mill dollars on a jack-up mounted rig trying to recover samples in soft silt/clay and sand sediments. Other issues aside (such as quality control), the rig operators had all sorts of excuses as to why they weren't getting recovery - in our first coring run we pulled a 98% recovery core from right next to their platform, and later heard reports of 'tears of joy' from the boardroom.

Scary anecdote 5:

A client brought us the results of an attempt at an economic ASS assessment conducted via continuous augering by a local geotech. company after it was rejected out of hand by the regulator.
Because both the fundamental sampling method and the geotechnical company's ability to interprete the results were both badly compromised, these guys managed to make it appear that acid sulfate that was present through the entire sequence. In fact, the regulator had done the developer a favour by sending this assessment back ; as it stood the report made the site appear to be a sort of Acid Sulfate Disneyworld, and the remediation bill would have been astronomical. Was the client pleased? - no!

4.2 Selection of a Marine Coring System

The following is a check list of a few of the factors that should be considered when making a choice of marine coring systems.

4.2.1 Nature of the material

a. sand to medium gravel - sand and sand/gravel mix within the grain-size range 75 µm to ~20mm fit the general target recovery range for vibracoring.

Flowing saturated sand is the primary province of the vibracoring method which works on the principle of liquefaction and gravity, however, percussion corers with the right frequency also work equally well in this medium.

In the natural world conditions are rarely as kind as we would like, and sand sequences rarely fit the ideal. Here are few variables that may lead to reconsideration of the unit required: *i*. are there any mature clay layers within the sequence? (a geologist may be able to offer advice here as this is largely age-dependant) - if so move to percussion systems, *ii*. are there likely to be any hard (indurated) layers within the sequence such as 'coffee' or 'calcrete' ? (again ask a geo.) - move to either powerful vibration or percussion systems (without any shoulders in the drill stream), *iii*. is the main sand body well sorted at either the fine sand at the fine end of the grain-size spectrum or the medium gravel at the coarser end of the spectrum? - again move to either powerful and variable vibration (i.e. electric systems with their set frequencies are not recommended for fine sand) or percussion systems, *iv*. is there a depth of dry sand to penetrate? - again move to either powerful and variable vibration (i.e. non-electric systems) or percussion systems, v. if operating on land, is there a depth of overburden over the sand? - if so either move to percussion based systems, or bring in an auger rig to remove the overburden from holes first

b. 'marine clay' - soft to firm, sticky to moderately plastic, dark grey, silt/clay (commonly containing shell fragments and/or organic residues). This material is: *i*. commonly encountered beneath coastal plains and inshore sedimentary sequences, *ii*. of Holocene-age (<10,000 years old), and has not been exposed to normal surface soil forming processes (i.e. subaerial pedogenic) processes - so is more correctly a 'sediment' rather than a 'soil', *iii*. is often colloquially, and incorrectly, referred to as 'marine clay' by engineers because of its shell presence; it is in fact more correctly 'estuarine-basin silt clay', and *iv*. generally forms as a deep-fill sequence in the large estuaries that formed as valleys were flooded in the last major sea level rise (we have encountered greater than 13m thickness of this material more than 60 km inland from the present shore).

This is not the ideal sedimentary medium that vibracorers were designed to recover because if does not react well as a liquified medium. Corers are affected by wall friction and consequently lower powered units ultimately become 'bogged'. However, our more powerful vibracorers have had good success in recovering great depths of continuous core in this material (>18m) as they have the ability to keep the barrel moving up and down in this medium. Other aspects of barrel material and design, plus core retainer design, can be quite critical here as well.

Often recovery of very soft, and fluid surface silts is the most critical component of contaminant and acid sulfate soils programs - IMPORTANTLY, whichever systems is proposed, it must have a means of evacuating water from the tube and/or creating a vacuum, or not be considered as viable.

c. mature, stiff, plastic clay - often in new excavation/dredging scenarios there is an unconsolidated or weakly consolidated, younger (Holocene-aged) sequence of sands and 'marine silt/clay' overlying an older, mature, stiff clay substrate.

Depending on the site and the overall 'mission' there generally needs to be, as a minimum, capture of the entire Holocene-aged, unconsolidated sequence, plus a minimum capture of 0.75m of the stiff, consolidated clay substrate underlying. The scientific logic of the latter being: *i*. there is a now well documented phenomenon of ASS inheritance from younger sediments above into this upper rind of old substrate, *ii*. testing of this upper zone will also indicate whether there has been any significant penetration of recent contamination into these generally low-transmissivity sediments, and *iii*. providing enough sites are conducted, then a reasonable statistical evaluation of naturally occurring contaminants and material types within this old substrate can be achieved. Generally, within the context of larger marine developments it is logistically unfeasible to continuously core to great depths into mature, stiff, clay/weathered sequences. Such a requirement would involve a large and prohibitively expensive two stage process of: *i*. marine vibracoring/ percussion coring to take out the unconsolidated section which drilling cannot successfully recovery with any integrity, then *ii.* a program of jackup-platform based drilling to recovery the deeper stiff sequence. Considering we have conducted surveys with hundreds of sites (~700 sites in one program), this would be unrealistic to achieve at every site. Some regimen of select deeper recovery of samples at a spread of sites in conjunction with geotechnical investigations may be arrived at in discussion with regulators, however, this should be strictly overseen by a trained environmental scientist/technician as quality control of samples in respect of handling and exposure to contamination vectors is unfamiliar territory on most conventional rigs.

If there is a requirement for sampling into a primarily mature clay seafloor (or land sequence) as is commonly the case for capital programs, then heavy percussion coring systems are the only choice (refer Clay Index Table in Section3).

d. mine tailings - these sediments are 'manufactured' in mine crushing plants or ball mills, and are generally discharged into ponds from a single or limited number of points. Accordingly there characteristics may be quite variable within a single repository, and consequently their penetration characteristics the most difficult to predict. They may vary in the following way: *i*. be wet or dry (dry being very significant if a low-powered vibration source is proposed), *ii*. related to this 'wet' or 'dry' question is the choice of coring platform proposed; within a single tailings repository we have encountered total water coverage at one end, dry and accessible by low ground pressure platforms at the other, and transitional between these two states in the middle(i.e. 'soup'), *iii*. in delta-like fashion sediments may vary from coarser near the discharge source to finer at the distal front, *iv*. be quite layered (i.e. in coal tailings there may be very fine 'liquorice' layers) intercalated within the sequence, *v*. be very angular (which, in combination with certain very well sorted grain sizes, can lead to very particular characteristics under the influence of vibration).

As stated above the penetration characteristics are often quite difficult to predict, however, often the logistics of getting to remote sites, accessing ponds, and inducting staff etc. are quite onerous and costly, so selecting a lower-end performance/lower-cost option here could prove to be substantial false economy.

4.2.2 How deep do you need to go?

This is relatively straight forward; where ASS is involved the depth of 100% continuous, undisturbed core recovery that is free of downhole cross-contamination required is 1m deeper than maximum excavation, and for contaminants the same requirement should be to at least 0.5m below maximum depth. For JORC assessments the requirement is to go to the base of resource if possible.

We have seen a few recent examples of where tender scopes specify depths of sampling required to 10m and beyond, and the mysteriously a configuration that is not capable of recovery to that depth is commissioned? As discussed above in section 4.2.1 c (mature, stiff clay) there may some justification in discussing with regulators the extent to which coring into older mature sequences is required, but there is no excuse for not coring Holocene-aged, sand and 'marine/silt' clay sequences to the depth required (at least to depths of 20m LAT in port situations) as the technology to achieve this has been demonstrated repeatedly and regularly in the past decade. ***Whereas the risk of introduced contaminants reduces with depth, geologically the risk of PASS commonly increases***.

It is not uncommon for the newly initiated to have a sudden 'light-bulb' thought that they will achieve depth by vibracoring within a drill casing (yes-many of us have already trod that path).

This method:

i. while moderately successful in silt/clay sediments, is very problematic in sands,
ii. *ii.* leads to unnecessary duplication of rigs, *iii*. in the marine environment is fraught with all the same problems of conventional rigs on floating platforms.

Bottom line - it is a more complicated, and unnecessarily expensive, second-rate option.

4.2.3 What volume of sample do I need?

This varies according to the program, however, in our experience of a great many programs a good level of sample is: *a*. 5.5 ltr/per lineal metre in the upper metre, *b*. ≥ 3.5 ltr/per lineal metre from 2-6m, and *c*. ≥2.5 ltr/per lineal metre beyond 6m.

4.2.4 Water depth?

Water depth is a critical aspect of selecting a configuration. At GeoCoastal we have designed our more powerful pneumatic-percussion and hydraulic capacities to work within water depth ranges to 35m MSL which generally covers depths relevant to ports and associated assessments.

The reason that vibracorers have traditionally been electric is that this is a power source that can be delivered over great depth through a narrow conduit (i.e. cord) and without significant power loss. Pneumatic and hydraulic cease to be viable options at water depths beyond ~35m. On the 'pro' side, commonly at depths of 35m or beyond sediments commonly become more suited to electric vibracoring. Electric corers remain the only really viable choice at depth.

4.2.5 Exposure to weather/sea conditions?

It pays to do some homework about average weather and sea conditions in the area proposed, and at the time of the year proposed. It is not uncommon for an undersized vessel to be selected which leads to safety issues and is generally poor economy when the final bill including standby is calculated. Scary Anecdote 6→

Jack-up barges are a bit of a myth in terms of their insulation to standby. They are only as good as their ability to have staff transferred safely from vessel to platform and *vice versa*, or their abilty to move from one site to another in the incident sea conditions. If your platform is not big enough to land personnel by helicopter, then they are at a substantial disadvantage to well designed large vessel operations. Jack-ups may be a necessary evil for deep geotechnical drilling with conventional land-based rigs, but they are an expensive and unnecessary encumbrance to marine program Scary Anecdote 7→

4.2.6 Is the program in an active port or shipping area?

The key elements here are safe and flexible, low intervention configurations. Don't use jack-ups or heavy barges with cumbersome multiple anchoring requirements. Don't use conventional style drilling that requires a long time on each site. Don't use divers. Put Insurance on your shopping list. TIP →

4.2.7 Sample acquisition Quality Control

Again quality control of chemical contamination vectors is not familiar territory for most conventional drilling systems, and effort should concentrate on specialised rigs designed for continuous core recovery free of downhole and surface contamination. There has been a great emphasis in Sampling Guidelines on laboratory standards, but much less in regard to the standards of truly representative sample acquisition methods conducted with good quality control. This has always been a difficult ('too hard') area to tackle, but if you get it wrong at the sharp end, then everything that follows is compromised.

R + EA + ESS = EER

(Rubbish + Expensive Analysis + Expensive Scientific Synthesis = Expensively Enhanced Rubbish).

Check that you contractor has Quality Management procedures in respect to the collection and handling of samples before they hit the sterile laboratory bottles.

Scary anecdote 6:
GeoCoastal were asked to tender on a program in an exposed port. We did our homework on weather/ sea conditions and rang local tug masters.
A small cheaper vessel was selected by the client. Result by all reports was a chaotic and totally unproductive fiasco.
GeoCoastal was then commissioned to repeat the program. Result: 120 cores retrieved and processed in conditions of up to 20 knts with no standby

Scary anecdote 7:
At one location we were still coring on a Sunday in building conditions where operations on a nearby jack-up had been abandoned since the previous Thursday.

Tip 6 **Is the program in an active port or shipping area?**

Safe, flexible, low-intervention:
- don't use jack-ups or heavy barges
- don't use conventional style drilling
- don't use divers
- put insurance on the top of your list

4.2.8 How many staff do we need to process samples in a marine program

It is not unusual , again in the name of cost saving, for clients to porpose supplying two personnel to process cores during a contaminant/ASS program. This is a common micalculation we see again and again, with the inevitable result that the poor personnel involved are left with core up their ears and working long hours to try and catch up. In desperation they will try to get the Contractor to slow down with two possible results:

1. if on hourly rate then the cost incurred by the extension of ship and operational time to cater for this is huge compared to the cost of simply having supplied a third person intially, or

2. the Contractor is on a 'per hole' rate and would incur very substantial cost to accommodate this miscalculation.

Bottom line - 3 personnel is the minimum required in our experience, to maintain quality control and sanity.

A quick final note - something we see all the time are clients who, when faced with the financial reality of marine operations (and everything that entails), apply all their depth of engineering experience to coming up with their own simple and cheap solution. This is an instinctive reaction with engineers, and occurs particularly where an apparently modest objective such as 2m of core is required (this can be more difficult than 6m depending on circumstances). We have been watching this creative process for a combined >60 years - we wish you good luck, and will see you a bit further along the learning curve. As a final scary anecdote - in the late 1980s I saw approximately $75,000 spent just working out that a technician was wrapping a couple too many wraps of duct tape around one part of a corer!

5 GeoCoastal Development Program

5.1 2013 Schedule

Item	Status
1. Adaption of 'Crab' barge to extend depth of coring capability	Completed March and successfully trialed to 13m subbed
2. Modifications to 'Crab' barge to speed multiple anchoring capability	Completed April
3. Development of *revolutionary new barrel design for contaminant coring*. This barrel will: *i.* provide easy delivery of high integrity cores free of cutting residue, *ii.* seal the core against possible site or transport contamination	Engineering drawings completed March Prototype manufacture/trialing - June
4. Development of revolutionary new configuration for contaminant coring. This design will deliver: *i.* an improved capability for recovery of high quality/high volume sample in the upper sequence , *i.* greater control over deployment and retrieval	Engineering drawings completed April Fabrication/trialing - August/September

6 Appendix

6.1 Standby

As noted previously standby is still a poorly understood facet of marine coring after many decades of commercial operation. Here are a few of the 'mythunderstandings':

- probably the most common mistake is the failure to allow for standby in the original budget. Although it can vary substantially an allowance of ~20% time or ~15% of the operational phase budget is a guide
- picking the right time of year should be a 'no brainer', but as mentioned in earlier discussion decisions are often driven by board room and finance department agendas with little reference to real-world logistics
- choosing the right, marine adapted equipment will substantially reduce exposure to standby. One of the big miscalculations can be the selection of less powerful/sophisticated configurations and smaller vessels which are more poorly weather adapted in order to save money, only to discover that this operation is on standby for double the time - false economy and poorer results
- I have mentioned earlier the inappropriateness of conventional drill rigs for recovery of marine sediments but, associated with this is the myth that 'jack-up' platforms are more weather resilient and therefore less standby will occur. The limiting factor on 'jack-up' barge operations is the ability to get staff safely on and off, plus to be able to move from site to site safely. Because of these restrictions a 'jack-up' platform will be on standby a long time before an appropriate sized shipboard operation (days in some of our experience). I have sat in boardroom meetings where board members have struggled to grasp that the 'jack-up' platform they chose is costing them big dollars in standby - bottom line, unless your jackup platform is big enough to fly staff in and out by helicopter and accommodate them onboard, it is still standby vulnerable
- standby may occur at any time within the proposed operational window including right at the start. Unfamiliarity with this can cause considerable anxiety among clients if standby occurs at the start of the program before any progress has been made, and this anxiety not uncommonly leads to quite irrational requests to the effect 'can't you tuck your ship, crew, coring equipment and coring staff into the cupboard out of sight and at no charge until the weather improves' (i.e. demobilise everything and remobilise again a week later). Unfortunately the real world answer is: no - often mobilising means the coordination of a shipping and coring equipment schedules 2-3 months into the future. Once mobilised the vessel and associated operation is like a large taxi - the meter is running, and this is why the right level of equipment and experience is so important
- whereas standby thresholds are generally specified individually (e.g. wind 17 knts), it is often the case that combinations of circumstances dictate whether operations can safely continue. An example is the time in the program when standby conditions occur - if conditions build midway through the program when the coring operation has been comfortably interfaced with ship's operations and crew and coring staff are familiar with their roles, then the thresholds may be stretched. However, should adverse weather/sea occur at the very start, then it would be unsafe to commence in the same level of conditions. Another example is that for the same wind and sea conditions, it may be safe to operate in the phase of the tide where sea and currents are in the same direction,

whereas it can become quite unsafe in the other phase of the tide where they are opposed and conditions 'sharpen' up

- In the way that the vessel may be delayed by standby conditions during the subject program, it may also be delayed by standby in the preceding program , and therefore, the commencement date may be delayed. This is a fact of life in marine contracting to which the more flexible, land-based personnel must adjust. This concept is captured in the standard marine contract (*Supplytime 89 Uniform Time Charter Party for Offshore Vessels*) no "party shall be liable to the other for any losses incurred by reason of the non-delivery of the Vessel or the Cancellation by the Charter Party" providing the Owners have exercised due diligence
- The application of marine standby –the way we express it at GeoCoastal: 'standby applies where: *a*. the vessel is at the wharf (e.g. weather conditions exceed standby conditions or ship movements delay the commencement of operations) or, *b*. the operation is paused at sea by one of the conditions in the standby table. If our vessel is trying to establish a site beyond standby conditions (i.e. in order to maintain project productivity) and fails due to conditions this period is charged at operational rates'. This last part is important and relates to earlier discussion of having a fixed rate either 'per hole' or 'per job' rather than 'per hour' or 'per day'. This provides an incentive for the Contractor to push the limits of standby conditions within the bounds of safety, rather than lapse into standby immediately a threshold is exceeded. This is the period when there is the greatest risk of damage to equipment and fatigue of personnel can occur, and therefore there needs to be an agreed operational rate as an incentive to the Contractor to strive to maintain productivity in these trying conditions (if successful, then the 'per hole' rate takes precedence). Sometimes 1/3rd of productivity might be achieved beyond strict standby thresholds.
- Downstream or 'flow-on' standby – marine operational standby has a flow-on effect to all 'downstream' components of site operations (e.g. on-site laboratory functions, management and travel oncosts). The proportion of time related to this 'downstream' standby may not be directly proportional to that incurred in the marine standby
- The challenge for a Contractor is to complete a program on, or preferably ahead, of schedule (again within the bounds of maintaining quality control and safety). It is therefore unreasonable for the client to say "seeing as you're ahead of schedule we would like to interface additional program at no further cost". This is not the deal that the Contractor signed up to, and a massive dis-incentive

Conclusion

Standby remains one of the untidiest aspects of marine contracts. Everything about marine operations is costly, and pushing standby to the forefront when considering the selection of equipment/vessel combinations and the experience of Contractors will plug one of the major causes of cost leakage. Also establishing clear contractual lines of understanding on standby between Contractor and Client is important to a cohesive program.