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DEEPWATER MOORING SYSTEM USING CT TECHNOLOGY

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Abstract

This paper provides an introduction to a joint industry project (JIP) which plans to employ coiled tubing (CT) from the deck of a vessel to deploy and install anchor points for mobile offshore drilling units requiring deepwater moorings.

CT offers significant advantages for installation of anchor points. It is a rapid conveyance means to the seabed; in addition it can supply significant power for drilling and is a circulation means once there. It provides the means for deploying anchors to considerable depths in the seabed, as appropriate to provide the necessary retainment force.

The vessel can then immediately perform a proof load test on the mooring line to ensure the quality of the anchor point. Only if it meets the required capacity is the CT then disconnected and recovered back to the vessel to collect the next anchor assembly and mooring line. To unset the anchor point, the mooring line is pulled taut and a release tool is dropped down the mooring line, close to the seabed, to activate a release mechanism which allows the mooring line to come free.

The concept offers many advantages over conventional anchors, including:

* pin point accuracy with reference to the mooring pattern centre.

* rapid and accurate anchorage deployment to significant depths into the seafloor

* very high ratio of pull-out force to weight of anchor equipment

* reduced difficulties in transportation and handling and therefore increased safety for anchor handling personnel.

* Significantly reduced CAPEX and OPEX.

* Simple recovery of anchor and mooring line when released from rig.

Background

The development of oil fields in progressively deeper water has led to the requirement for improved anchor technology[1-5]. In particular, taut-leg moorings (TLMs) are now being increasingly used and these require anchors that are capable of withstanding substantial vertical loads. In response to this need, anchoring technology currently employed for deepwater mooring has followed two distinct development paths.

The first approach is a new generation of fluke drag embedment anchors which is capable of withstanding vertical loads. These is termed a vertically loaded embedment anchor (VLA - figure1). In its simplest form a VLA constitutes an anchor having a plate fluke and a shank which is embedded to sufficient depth in a manner edgewise to the fluke and is then loaded in a direction perpendicular to the fluke to give a high pull out capacity. It involves quite an art in its installation, and can require a significant towing distance by the anchor handling vessel (figure 2) before it can hopefully orientate itself upright and commence its embedment trajectory, penetrating the mudline to sufficient depth to be capable of carrying significant load. The final depth and geographical location of the anchor can be difficult to predict.

The second approach has been the development of the suction embedment plate anchor (SEPLA - figure 3). This combines a suction follower to embed a plate anchor that is slotted vertically into the base of the follower. The suction follower might typically be 15ft or greater in diameter and 50ft long The combined follower and plate anchor are deployed similarly to a conventional suction anchor. After being lowered to the sea floor, the follower is allowed to self penetrate. An ROV-mounted pump skid is then docked to the follower to evacuate water from the follower, thus allowing the plate anchor to reach its full design depth. The plate anchor is then released and the follower is removed from the seafloor by reversing the pump and pulling up on the follower deployment line. The plate anchor is subsequently pulled perpendicular to the load applied to enable its maximum holding capacity to be developed. The depth of embedment possible is obviously limited to the length of the follower. However, instances have occurred when it has not been possible to install the anchor to the required depth because the seabed soils are too stiff or dense to penetrate.

It will be appreciated that both of these systems employ large items of equipment which take up deck space, can be difficult to handle and have limited performance envelopes for certain seabed conditions. The goal for this project is to enable a more reliable, consistent and scientific means of installing anchor points in the sea bed at a significantly reduced cost to existing methods. The way in which this will be achieved will be by:

* Use of CT technology to achieve deeper and more reliable penetration below the seabed prior to anchor deployment, which will allow the use of smaller anchor assemblies (this will be explained in more detail in the analytical section).

* Development of geological databases and geotechnical classifications for a number of target areas.

* Development of analytical techniques and design methods to predict anchor capacities more accurately.

Geological desk study

The aim of the geological desk study is to draw together available geological and geotechnical information in target locations from project participants and from published sources such as the US Geological Survey and the British Geological Survey Deep Sea Geology Group. An initial study has been performed which includes the target areas site shown in figure 4.

Geotechnical classification

Following on from the geological desk study, the aim is to categorise the expected soils in the target areas into a relatively limited number of basic soil types. Links will be made between the geology of the target areas and geotechnical parameters for anchor design. This will enable an early assessment of the applicability of alternative anchor designs in various geologies. It is important to know, for example, whether there are likely to be hard near-surface layers that might create difficulties in deploying certain types of anchors to the required depth. Geotechnical parameters will be estimated initially and later updated with more accurate data once anchors are installed or when new site investigation data can be inputted into the database.

Anchor embedment analysis

One of the key factors in designing anchors for deep water is the efficiency of the anchor, that is the ratio of the pull-out force to the weight of the anchor (and installation equipment). Provided that they can be installed to sufficient depth in the seabed, embedded plate anchors provide the most efficient of the various generic anchor types available. Although a number of anchor types are being considered for deployment by CT, early indications are that plate type anchors are most promising. Plate anchors have been investigated for many years[7] (in particular by the US Navy) and are considered mature technology. The only real problem to date has been the installation method. A variety of techniques have been proposed (with limited success) to achieve greater anchor penetration including a ballistics deployment system, vibratory underwater hammers and the drag-embedment VLA and SEPLA systems mentioned earlier. The new proposed CT method overcomes these problems of installation.

Regardless of the installation method, the capacity of an embedded plate anchor is generally governed by two factors. At shallow burial depths the holding capacity may be governed by the weight of lifted soil, whereas for deeper set anchors the holding capacity is generally governed by the soil strength. The analysis of anchors is an area were there is relatively little modern academic work published[8]. There has been more reliance on proof loading tests, model tests and empirical theories. Some of the traditional methods of analysis which consider the weight of a lifted soil block are illustrated in figure 5. At deeper depths the pull out capacity can be estimated using the simple ‘reverse bearing capacity method’.

One of the important aims of the project is to improve the state-of-art in this area by making more use of numerical modelling. Finite element codes, for example, provide a powerful tool in assessing anchor behaviour more realistically using either a 2D axisymmetric or full 3D mesh. The power of these techniques lies in the fact that a pull-out failure mechanism does not have to be postulated or guessed in the same way as for traditional methods. The computer code generates its own, much more realistic, failure mode based on the input characteristics of the anchor and the soil. It is relatively easy using these advanced techniques to analyse more complicated soil-anchor situations (eg. layered soil, inclined anchor), whereas traditional methods tend to be limited to more simplified situations.

An example of some published work in this area[9] is illustrated in figure 6. This is for an onshore application and the anchor in this case is formed by an underreaming tool which forms a hole in the ground which is subsequently grouted (a offshore version of this anchor type is being considered as part of this project). The figure shows a 2D axisymmetric numerical representation of the anchor and a comparison between numerical and field test results. The excellent agreement obtained serves to demonstrate that numerical modelling can provide a relatively cheap alternative for assessing new anchor systems.

The aim in this project is to use the more traditional analysis methods initially and move on to more sophisticated methods for the most promising anchor systems. Numerical modelling has already been undertaken for a simple example of an embedded plate anchor and is illustrated in figure 7, which is a computer generated graphical representation of the stresses generated in the soil as the anchor is pulled upwards.

New design methods envisaged would encapsulate the analytical improvements and the aim is to produce look-up charts to indicate the anchor depth required for a given geology and required anchor capacity.

Vessel mounted hardware

All the equipment mounted on the deck of the vessel is standard coiled tubing unit CTU or mooring line hardware with the exception of the coiled tubing injector mounting frame. The operation is performed from the rear of the vessel so that release of the mooring line with floatation buoys can be performed with relative ease and safety for the vessel crew. The operation could also be accomplished on a vessel with a moon pool, but different mooring line rigging would be required. Certainly it would make the operation slightly easier from the point of view of CT operations.

The initial set up shows the injector mounted horizontally, with the CT stabbed into the injector. While the assembly is mounted horizontally, the CT operator can connect the anchor, the anchor setting tool and the mooring line. This can all be inspected and tested to ensure all the equipment is functioning correctly in a relatively safe position on the deck.

The injector mounting can then be orientated vertically using hydraulic rams. Once vertical, the CT can immediately start fed into the ocean, at the same time the mooring line is fed off from its storage reel. After a predetermined length has been run into the sea, buoyancy elements are attached and clamped to the CT. These provide vertical orientation assistance for the assembly once it reaches the mudline and begins to drill or jet the anchor into seabed.

Anchor and deployment / recovery tooling

The anchor setting tool is very similar to any downhole assembly. It consists of a connector and integral release joint and a telemetry path for the tools instrumentation which are fed back to surface in real time. Two modes of anchor installation are envisaged, the first would be jetting / circulating the assembly to the required depth, and the second is to drill the anchor into more consolidated soil.

Drilling data would provide real time feedback to the surface operation and once the operator was satisfied the soil condition was suitable robust and consistent the anchor would be set. One set the mooring line could be pull tested to a proof load prior to disconnecting the CT conveyance tool.

Once the mooring line has been used and is no longer required, it would be released from the facility, i.e. the mobile drilling unit, and would be picked up by the anchor handling vessel. This would winch up the excess mooring line and once vertical over the anchor itself, would drop an actuating assembly to operate the mooring line release tool situated some distance above the seabed. A control line in that section of the mooring line to the anchor would operate the disconnect mechanism and allow the mooring line to come free.

Summary

There are strong commercial drivers in enabling 3rd and 4th generation rigs to be employed in new deepwater developments, both to increase the availability of rigs and reduce the day rate. Secure mooring is essential for them to operate in deepwater. Traditional methods identified are either :

a) Inconsistent or unreliable.
b) Expensive and time consuming to install.
c) High capital cost items.
d) Exhibit handling and safety issues.

The outcome of this project aims to deliver an anchoring system for attaching mooring lines to the seabed which is:

a) rapid to deploy and install.
b) can be set to a depth where soil strength is suitably robust.
c) very accurately positioned relative to the mooring pattern centre.
d) a low capex and opex solution.

The initial stage of the project is underway and is primarily desk-based at present. At subsequent stages of the project it is proposed to undertake model and eventually full scale field tests to measure actual anchor performance for comparison to existing practices.

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Figure 1 Medium capacity verticlly loaded anchor (VLA)

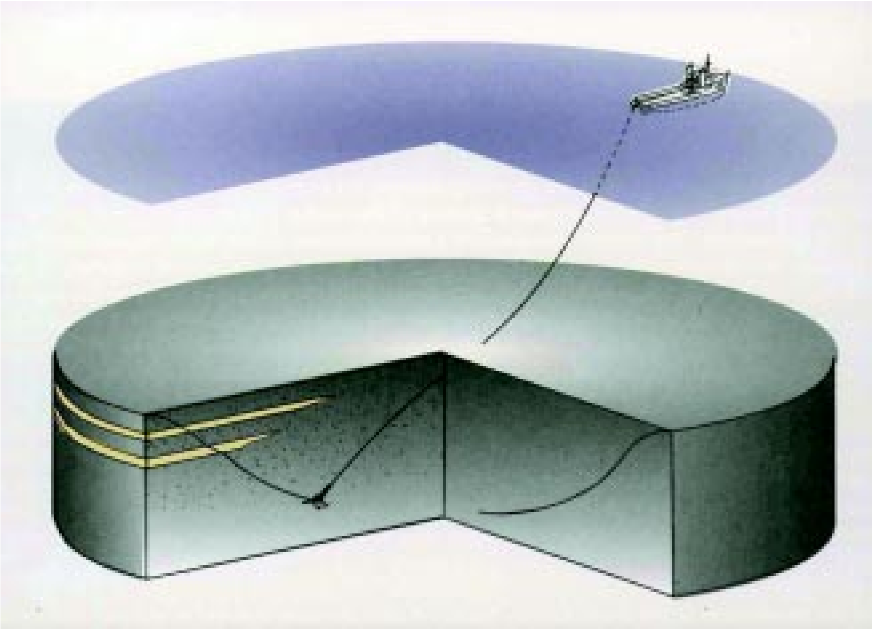

Figure 2 Typical tow tradjectory for anchor handling vessel deploying a VLA

Figure 3 Suction embedment plate anchor (very large equipment)

Area	Water depth at current development areas(m)	Water depth at planned development areas(m)	Typical seabe
Gulf of Mexico	Up to 1600	Up to 2130	River delta de pelagic clay
North Atlantic Margin		500 plus	Lacastrine cla glacial marine
North Sea	238		Lacastrine cla glacial marine
Norwegian sea		Up to 1900	Lacastrine cla glacial marine
Equatorial West Africa	Up to 1400	1525	Errigenous se tropical land
Brazil	620		Errigenous se tropical land
Offshore Australia		500-1000	Calcareous se

Figure 4. Geographical areas of investigation

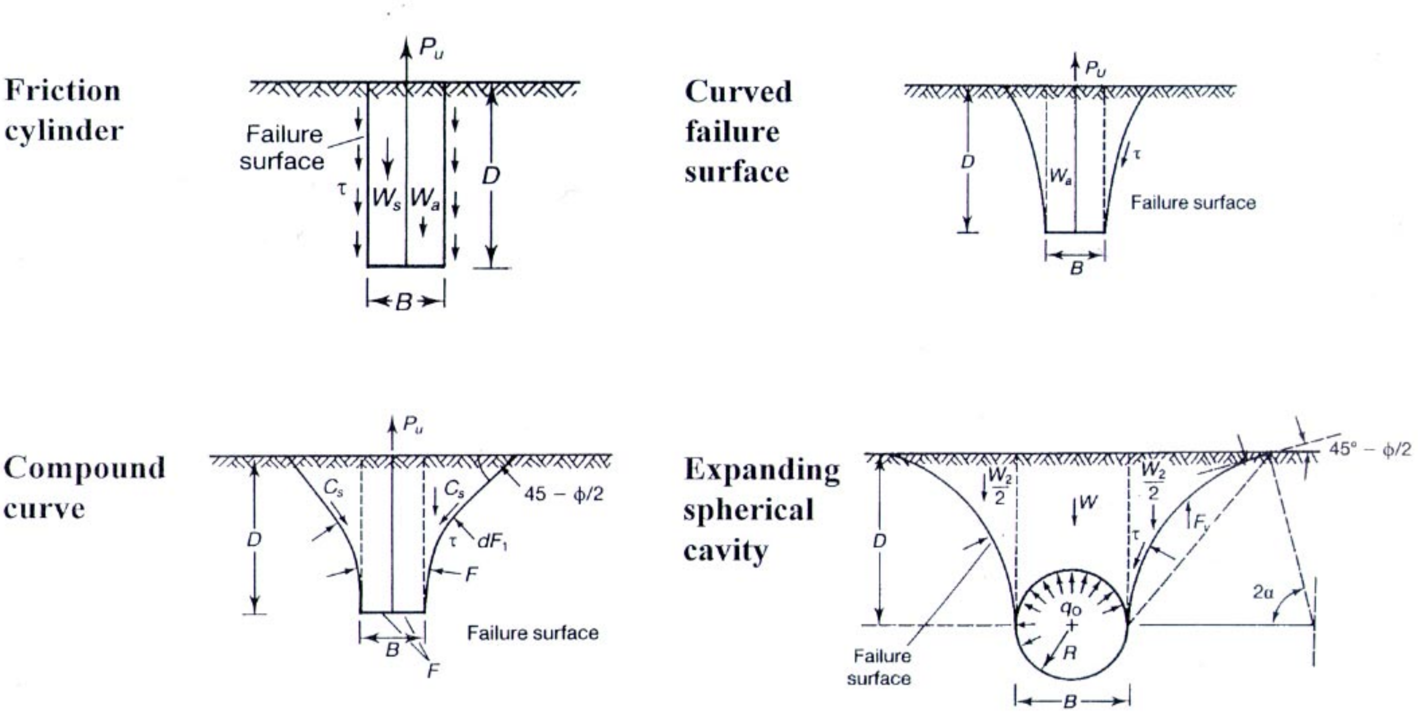

Figure 5. Traditional analysis methods

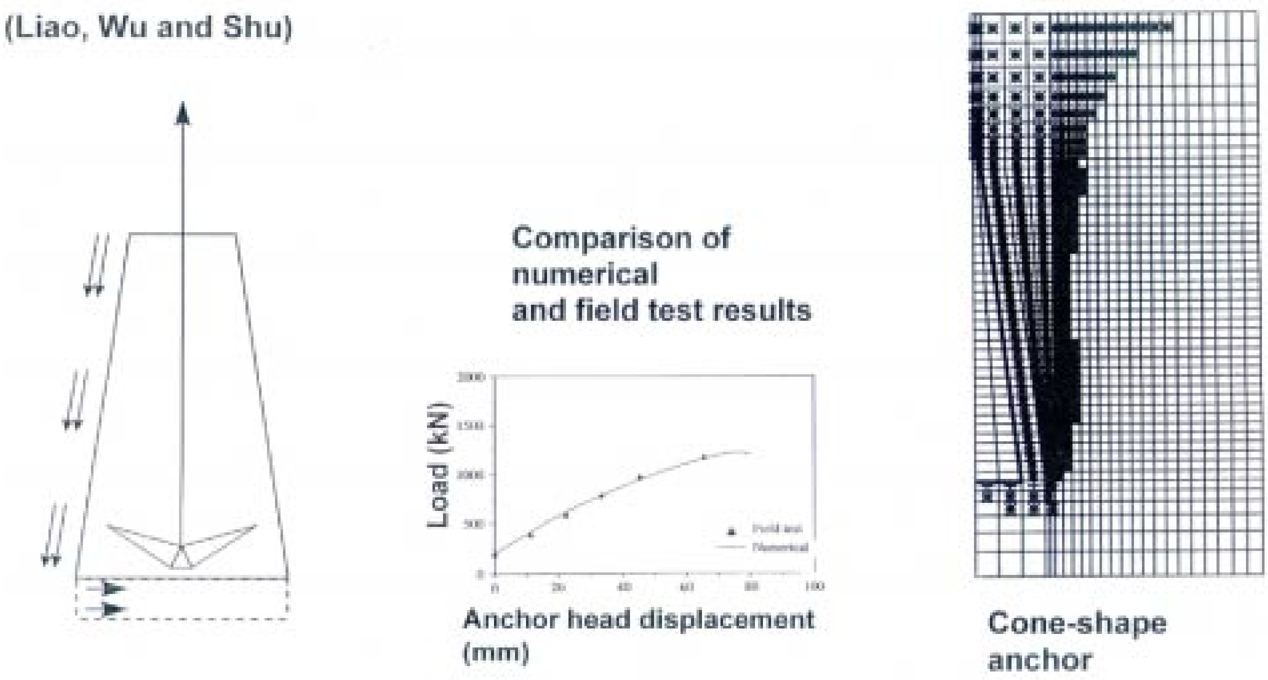

Figure 6. Numerical Analysis method

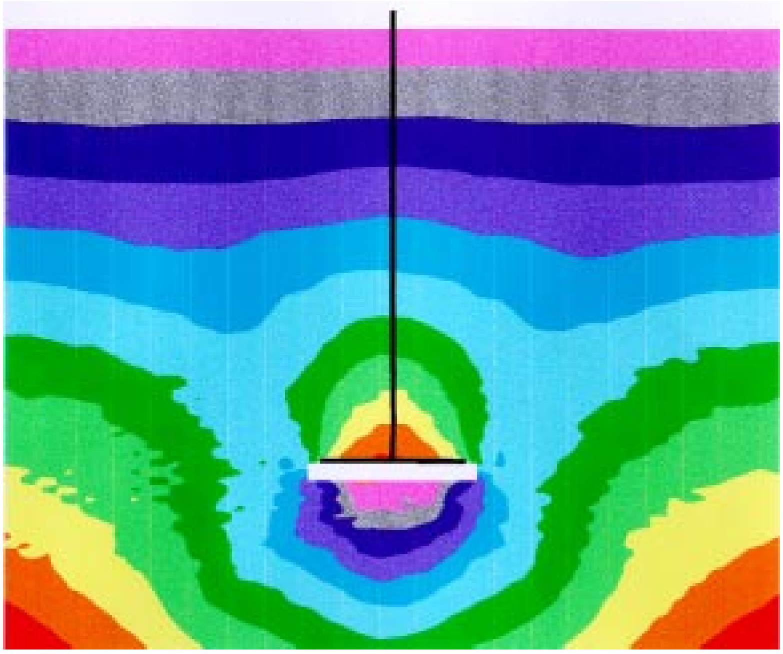

Figure 7. Finite Element Method. Shallow anchor model stress distribution

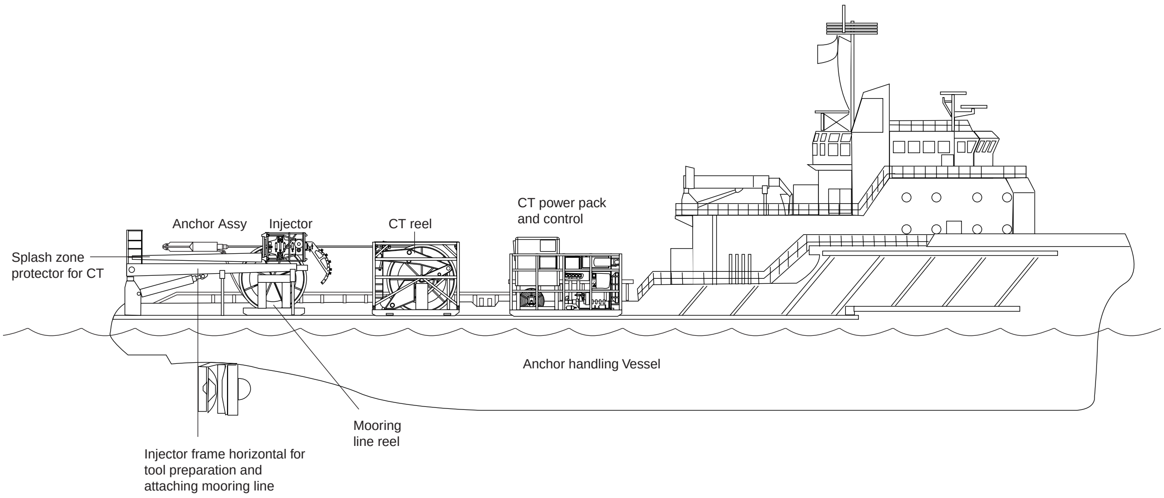

Figure 8. Vessel Equipment Oveview

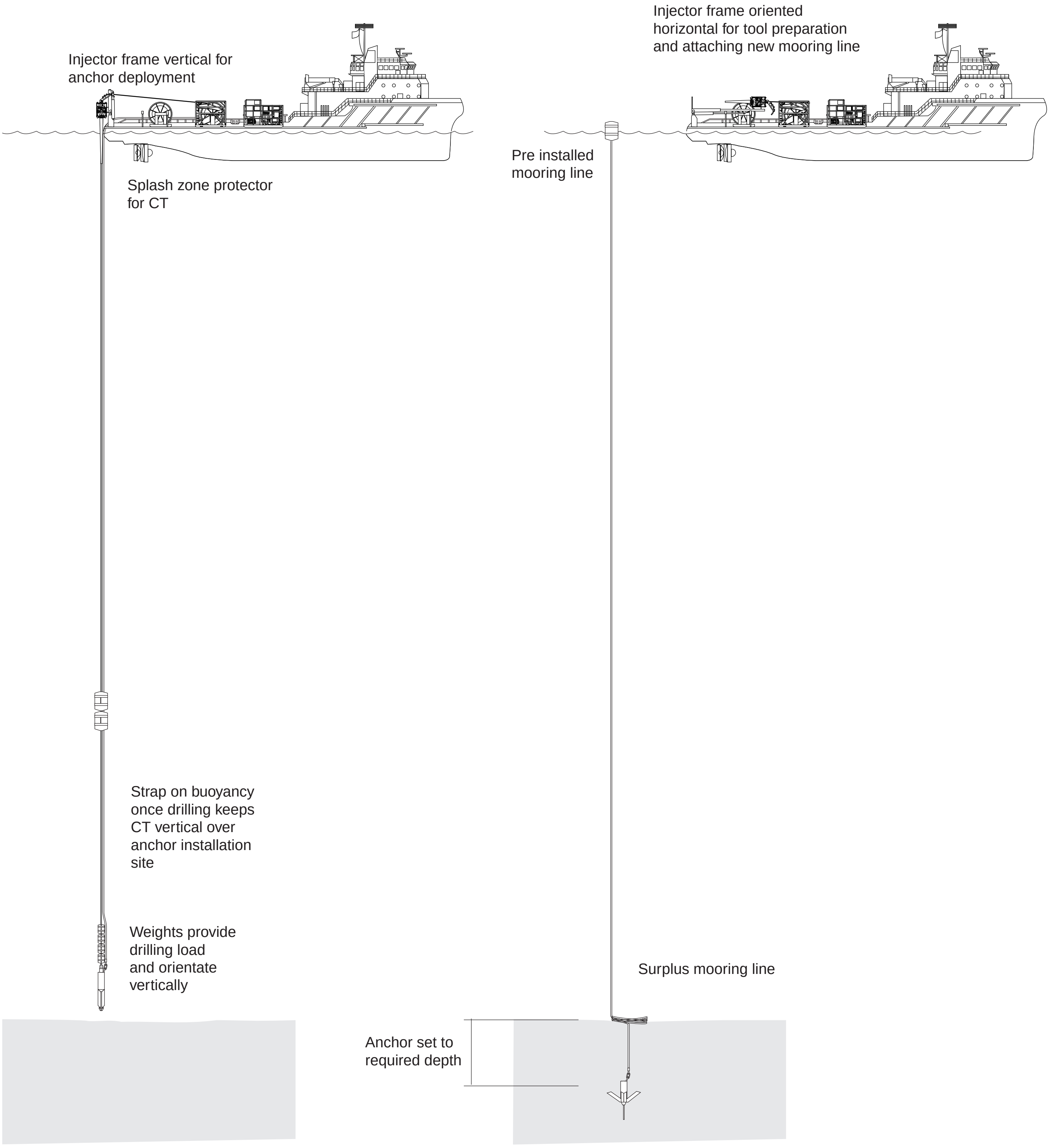

Figure 9. Equipment Deployed in Ocean

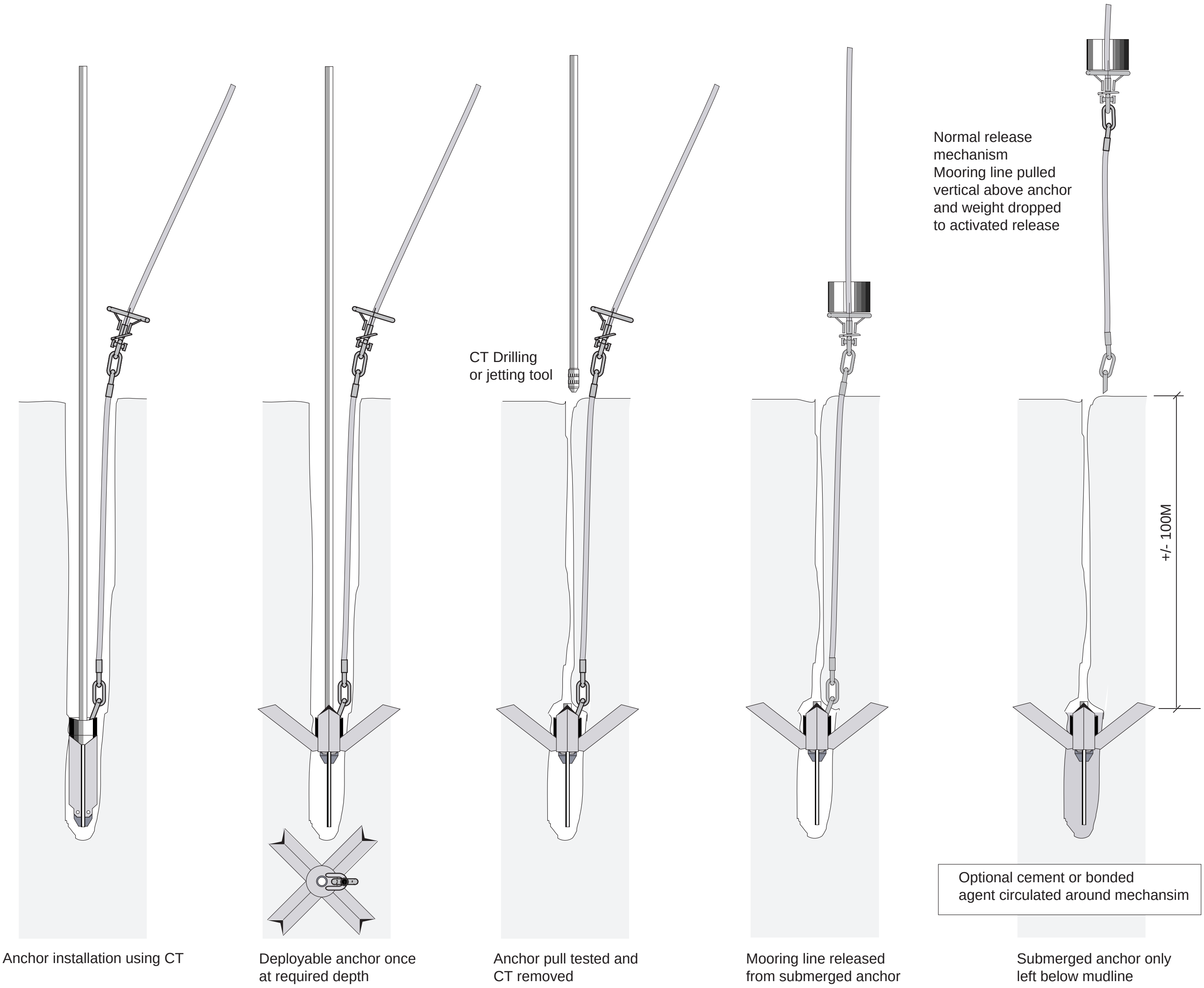

Figure 10. Anchor installation and recovery sequence