THE CHALLENGES OF DEEPWATER MOORING

The deepwater mooring challenge and industry attempts to develop the solution

D. Cuthill, Operations Director
M. Kobiela, Technical Manager

Trident Offshore Ltd, 34 Carden Place, Aberdeen
Introduction

The current trend for the offshore industry to move into greater water depths has led to increasing challenges for deepwater mooring. Mooring systems and their deployment are now seen by operators as a major technical constraint on the cost effective development of deepwater fields. The industry is now highly focussed on the need for technical developments in this area.

In many cases, due to the high costs of establishing a drilling unit on a deepwater drilling location, cost effective mooring solutions must be developed to make deepwater exploration viable. Similarly, for deepwater production, a cost effective and secure method of mooring the production unit is required.

This paper seeks to outline the problem areas for current (or traditional) mooring technology and methods and provide an assessment on the various industry attempts to provide solutions to those problems.
Table of contents

INTRODUCTION .................................................................................................................. 2
Table of contents .............................................................................................................. 3
MOORING SYSTEMS ........................................................................................................ 4
Catenary Systems ........................................................................................................... 4
Taut Leg Systems............................................................................................................ 6
OPERATIONAL CONSTRAINTS ...................................................................................... 7
Mooring System Weight................................................................................................ 7
Deployment Loads......................................................................................................... 8
Mooring Equipment Integrity........................................................................................ 9
ANCHORED SYSTEMS AND LIMITATIONS ................................................................. 10
Drag Embedment Anchors ........................................................................................... 10
Conventional Pile Moorings ......................................................................................... 11
Suction Anchors............................................................................................................ 12
EXISTING MOORING STRATEGIES ............................................................................ 13
Load Sharing.................................................................................................................. 13
Pre-laid Moorings......................................................................................................... 15
NOVEL MOORING STRATEGIES .............................................................................. 16
Drilled Pile Systems ..................................................................................................... 16
Suction Embedded Plate Anchors ................................................................................. 18
Modular Suction Pile .................................................................................................... 19
SUMMARY: PROBLEMS AND SOLUTIONS .............................................................. 20
Mooring System ............................................................................................................ 20
Deployment/Recovery .................................................................................................... 20
Anchors......................................................................................................................... 20
Summary of Requirements ........................................................................................... 21
Mooring systems
The various conventional mooring systems and their limitations with regard to deepwater mooring are outlined below:

Catenary Systems
A catenary type mooring system utilises the horizontal force component of the mooring lines to provide the restoring forces which maintain the moored unit on station. Any movement off station induced by environmental or other loads on the moored unit causes increased tension in the mooring and a less steep catenary. This tendency to straighten the catenary provides increased horizontal or restoring forces and the action of the catenary system under varying loads additionally provides a damping effect which removed shock loads from the system.

There are two main types of catenary mooring system, all chain/all wire systems and ‘true’ wire/chain combination systems (as opposed to wire insert systems utilised for low cost drilling rig deepwater upgrades).

Chain Mooring Systems
In deepwater, the self weight of a chain mooring system produces a very steep catenary with high vertical loads and very little horizontal loads. Any environmental forces applied to the moored unit will result in large unit offsets which may exceed the limiting parameters for the marine riser.

The high vertical component of the mooring loads also results in a large reduction in variable deck load capability.

In addition to the above, the weight of the all chain system and the associated deployment problems means that such systems are not considered for deepwater operations.

Wire Mooring Systems
Wire moorings have a much higher strength/weight ratio when compared with chain. Wire moorings produce a significantly shallower catenary profile which results in higher horizontal restoring forces. The system is commensurately ‘stiffer’ than a chain system with resultant higher peak loads because of decreased damping effects.

The reduced vertical component of the mooring load results in increased variable load capability when compared with an all chain system in the same water depth.

The reduced weight of wire systems reduces loads during deployment. However, if drag anchors are to be utilised, very little or no vertical forces are permitted at the anchor and the shallower catenary profile of an all wire mooring system results in considerable lengths of wire required to ensure an adequately grounded system.

The wire lengths required to ensure system integrity makes this option unattractive for deepwater mooring.
Combination Mooring Systems
Moored drilling units designed to have a deepwater capability are generally fitted with (or have the capability to be fitted with) ‘true’ combination mooring systems which utilise the best features of both all chain and all wire systems. Such systems are also fitted to floating production units.

The combination system is generally designed such that the wire section forms the elevated part of the catenary, producing a shallow catenary profile, good horizontal restoring forces and optimum variable deck load capability. The chain section is at the lower (anchor) end of the mooring system and ensures adequate grounded length of mooring. As the chain has a high unit weight compared to wire, considerably less chain is required than the equivalent weight of wire.

For example, 500 metres of 76mm ORQ grade chain weighs 56 Tonnes. This is equivalent in weight to 1650 metres of 90mm wire (commensurate in strength with 76mm ORQ chain).

The use of a chain component does, however, incur a penalty during deployment. For example, in a water depth of 1200 metres with a chain component length of 1200 metres, the chain will weigh some 116 tonnes, not including the anchor and before any tension is placed in the system during deployment/recovery. This imposes high loads on the deployment vessels.
Taut Leg Systems

Taut Leg mooring systems are, in general, utilised only for permanent or semi-permanent mooring systems such as FPSOs. The reasons for this are as follows:-

Taut Leg moorings require an anchor which can accept high vertical forces. Fabrication and installation of suitable anchors, such as drilled and grouted piles, is a high cost undertaking which, to date, has been considered unnecessary for the mooring of mobile drilling units.

Conventionally moored mobile drilling units are fitted with catenary mooring systems which would require to be removed prior to mooring to a taut leg system. If the drilling unit mooring system were retained on board, a large reduction in variable deck load capability would be incurred. Removal (and subsequent reinstatement) of the drilling units standard system is a time consuming and costly operation.

The inherently ‘stiff’ mooring system produces high peak tensions which may be in excess of the design limits for drilling rig mooring equipment.

However, with regard to the above, significant advances in mooring technology have been made recently in both anchors and mooring line components.

Currently, synthetic fibre ropes and vertical lift anchors (VLA) are being used in taut leg systems for floating production in deep water. Synthetic fibre ropes are not inherently robust when compared with steel wire rope and require careful handling to prevent damage. They are, therefore, difficult to use in mobile drilling rig mooring systems, where the mooring is deployed and recovered repeatedly unless special handling equipment is provided and/or damage and replacement components is expected. An additional problem with regard to synthetic fibre rope is their bulk when compared to steel wire rope of equivalent strength. Manufacturers of synthetic ropes continue to make advances in improving the strength/diameter ratio but the higher performance materials have a significant cost penalty and the handling problem during mooring operations remains.

Taut Leg (or semi-taut leg) mooring systems may be considered for prelaid moorings for mobile drilling rigs if an acceptable low cost mooring system with an anchor which is readily deployable/recoverable can be devised.
Operational constraints

Mooring operations in deepwater require considerable planning. In shallow waters, the planning required to ensure an efficient and cost effective operation is relatively straightforward. For mooring in deeper waters, however, the levels of complexity, difficulty and associated costs increase in an almost exponential manner with increasing water depth.

For any moored unit, whether mobile or permanent, the mooring system must be secure. Stringent analysis of the proposed system will be required to demonstrate mooring system integrity and to ensure the moored unit will remain within predetermined offset limits.

Planning and analysis of the mooring system cannot be undertaken in isolation. To ensure the mooring system can be deployed efficiently and cost effectively it is also necessary to plan the deployment strategy and to identify, at an early stage, the vessels which will be utilised for deployment of the mooring system.

The primary constraints in planning mooring deployment/recovery operations in deepwater are:

Mooring System Weight
Deepwater catenary type combination mooring systems have evolved from the conventional catenary mooring systems utilised in shallow water locations. Moored drilling units with deepwater capability are, in general fitted with combination mooring systems.

Such combination systems can, dependent upon component lengths/unit weights, be used successfully in water depths of 1500 metres plus in the UK Atlantic Margin area.

Although system performance is, overall, considered to be good, significant problems arise during mooring deployment and recovery due to the weight of the mooring system. Only the most highly capable anchor handling vessels can undertake the mooring operation. This limits the options for vessel selection and suitable vessels may be unavailable when required.
Deployment Loads

Catenary Systems
Mobile drilling rig catenary mooring systems are generally fitted with drag embedment anchors. The design of the drag embedment anchor requires that little or no uplift forces are generated, by the mooring system, at the anchor. This requires that the catenary system remains grounded in all conditions.

To ensure adequate length in the mooring system, it is important that the anchor is deployed to the correct range. Stretching the mooring to the correct range prior to deploying the anchor to the seabed imposes loads on the anchor handling vessel in addition to the weight of the system. Such operations place high demands on both rig and vessel winches.

Strategies such as the load share methodology, which essentially seeks to equalise the loads on rig and vessel winches by using a detailed sequence of mooring/deployment wire payouts, can be utilised to optimise vessel performance. As mooring depths increase, however, and mooring system weight increases commensurately, the choice of suitable vessels is diminishing even when load share strategies are employed.

To control cost and ensure deepwater exploration remains viable, alternative mooring strategies must be explored.

Taut Leg Systems
As previously discussed, taut leg mooring systems are not conventionally fitted to deepwater drilling rigs but are used for deepwater floating production applications.

Deployment loads on anchor handling vessels can be decreased significantly if taut leg mooring systems are used. However, due to the nature of taut leg mooring systems, drag embedment anchors (which are the most readily deployable and recoverable anchor type) cannot be sued due to the high vertical forces imposed upon the anchor.

To date, the anchors used for taut leg systems have been the conventional Pile (driven or drilled and grouted), the suction pile or the VLA. Conventional Pile moorings require specialised vessels for deployment. Suction anchors and VLA anchors have been deployed by anchor handling vessels but these have been high capability vessels.
Mooring Equipment Integrity

Deepwater moorings are generally made up with combinations of chain and SWR or chain and synthetic rope.

Due to its robustness, the integrity of a vessel's mooring chain is not generally of concern when planning a deepwater mooring operation, provided the chain is regularly inspected and renewed as required.

SWR mooring lines are reasonably robust, however, they are more susceptible to damage than chain. The cause of SWR mooring damage is generally due to wear and tear experienced during handling operations as detailed below:

- Chaser damage during deployment/recovery.
- Stern roller damage if wires are deployed/recovered from an AHV.
- Crush damage on storage reels/winch drums.
- Overstress damage due to wire being stored at less than the minimum recommended bending radius.

Other forms of damage that can be found on SWRs are:-

- “Birdcageing”, this can be experienced if suitable swivels are not incorporated into the mooring system.
- Abrasive damage due to the SWR being in the seabed thrash zone.

Most forms of SWR damage can be avoided through good design and planning, selection of suitable mooring/marine equipment and by the use of correct handling procedures.

Synthetic mooring ropes are not inherently robust and can be subject to damage during mooring deployment/recovery operations.

As with SWR, Synthetic ropes are most likely to be damaged during handling operations. Synthetic ropes are generally used with prelaid systems and are therefore, not subject to damage from chasers.

However, the ropes are bulky compared to SWR which can lead to additional problems during deployment/recovery operations from AHV. Damage can be experienced during spooling/unspooling of ropes and deployment/recovery of ropes over the AHV stern roller.

For “one off” operations such as the mooring of an FPSO/production facility, the risk of damage to the synthetic rope is minimised. However, for a mobile drilling unit moorings must be deployed/recovered repeatedly and the risk of damage to the ropes is significantly increased.
Anchored systems and limitations

Drag Embedment Anchors
Drag embedment anchors require high pre-tensioning to ensure correct embedment. This is not feasible in deepwater locations if moorings are to be prelaid unless a patent tensioning device is used. Using a tensioning device in deepwater adds significant complications and cost to the operation.

If deployed directly from a mobile drilling unit, the unit winches may not be sufficiently powerful to overcome the weight of a catenary system to produce sufficient tension at the anchor to ensure embedment.

It is difficult to define the position of embedment depth of drag embedment anchors with accuracy following deployment and they are prone to slippage. It may be difficult to demonstrate confidence in mooring system integrity under design loads and this is a primary concern for semi-permanent installations moored to a prelaid mooring system.

The type and size of drag embedment anchors must be carefully selected with regard to soil conditions. In extremely hard to soft soil conditions, drag embedment anchors may not hold.

Drag embedment anchors are designed such that they can accept little vertical tension from the mooring system. The latest High Holding Power (HHP) type anchors such as the Stevpris and Bruce Mk 4 are quoted, by the manufacturers as being capable of accepting limited uplift forces. However, it can be assumed that this characteristic of drag embedment anchors limits their use to traditional catenary mooring systems.

Drag embedment type anchors require the use of high capability Anchor Handling Vessels for deployment in deep water locations. As anchor size/weight increases to compensate for design loads/soil conditions the requirement for vessel capability increases.
Vertically Loaded Anchors (VLAs)

Vertically loaded anchors (VLAs) are a recent development and are aimed specifically at the deepwater market. The design permits the anchor to accept high vertical forces and is, therefore, suitable for high angle, taut leg mooring systems.

This type of anchor has been used successfully on a number of occasions. Deployment methodology is relatively complex and requires high capability anchor handling vessels.

Vertically Loaded Anchors are difficult to embed and require a drag force equal to some 50% of the ultimate load capacity. Embedment in cemented sand or rock is not feasible and may be problematic in stiff clays.

VLAs are similar to drag embedment anchors in that it is difficult to define the position and embedment depth of the VLA with accuracy following deployment. This may reduce confidence in the integrity of the mooring.

Conventional Pile Moorings

Conventional piles are designed and constructed for specific applications according to seabed conditions and are high cost items. They may be designed for us in catenary or taut leg mooring systems.

Deployment is effected by either:-
   a) The pile being driven into the seabed using either an impact or a vibratory device.
   b) The pile being placed into a pre-drilled hole and cemented (or grouted) in place for security.

Installation by impact driving is generally feasible in clays and sands. Vibratory driving is generally more suitable for sands than clays. Dependant upon soil conditions a drilling stage may be required to partially pre-drill the hole for the pile. The requirement for a pile hammer or similar installation device places depth limitations on the use of driven piles.

Drilled and grouted piles can be used in well-cemented soils, rock, or soils where the shaft friction of driven piles is insufficient (e.g. cemented carbonate sands).

Due to the method of deployment and the shallow embedment depth, driven piles are of heavy construction. Drilled and grouted piles can be of lighter construction.

The resistance of the pile anchor depends primarily on pile dimensions, soil strength and pile installation technique. Once deployed, the security of piled moorings is extremely good.

Conventional piles require to be correctly aligned with the direction of the mooring and to ensure the correct orientation and verticality, subsea survey
services are generally required. Driven piles additionally require the use of a good base which must be deployed to seabed and subsequently recovered.

The requirement of hydraulically or electrically driven pile driving hammers and associated equipment including a pile sleeve and a guide base greatly increases the complexity and cost of driven pile installation in deeper waters. Extreme water depth poses difficulties for the use of hydraulically driven pile hammers.

The placing of a pile into a previously drilled hole may pose considerable problems in deep-water locations.

Conventional piles are a high cost option more suited to a permanent or semi-permanent production applications (with relatively high budgets available) but they are not a viable option for utilisation in the mooring of mobile drilling units.

**Suction Anchors**

Suction anchors, like conventional piles, are individually designed and fabricated for specific soil conditions and mooring tensions. They are, therefore, relatively high cost items. They may be designed for use in catenary or taut leg mooring systems.

They also require careful alignment during deployment and are of limited use for hard soils such as corals or compacted clays.

Correct embedment of suction anchors cannot be assured prior to deployment unless a comprehensive and accurate assessment of soil conditions to the design embedment depth has been undertaken.

As with driven piles, security of the anchors, when correctly embedded, is good. They are generally designed to be recoverable but as they are designed to be location specific, there may be little value in recovery.

Extreme water depth poses difficulties for the use of hydraulically driven evacuation pumps and electric or WROV driven units may be required.

They have been used for deepwater production applications but are of limited value for exploration drilling.
Existing mooring strategies

Two primary mooring strategies have evolved to address the problems of deepwater mooring. These are:

1. The load share methodology (previously mentioned) for deployment of mobile drilling rig conventional catenary mooring systems in deep water.

2. Prelay strategies. Although these can be utilised for deployment of conventional catenary mooring systems they are, in general, most effective when allied to the new developments in anchoring. These new developments include vertical lift anchors, suction pile anchors and variants of both types.

Load Sharing

The ‘Load Share’ deployment strategy was originally developed by the Exxon Corporation for the deployment of deepwater catenary mooring systems in the Gulf of Mexico. In this area, anchor-handling vessels are generally less capable than those currently available in the UKCS area of operations.

The methodology significantly reduces the loads on vessel winches and deployment gear during the operation and allows a certain reduction in the base requirements in terms of bollard pull and winch capacity when compared with a standard deployment operation. This is beneficial in a market where access to high specification/capability anchor handling vessels may be required.

Load Share Methodology

A brief description on this load sharing procedure is detailed below:

In a combination wire/chain mooring system, the weight of the chain section per metre is significantly greater than the wire section. For example, the outer length of anchor chain of a deepwater drilling unit’s mooring system is 1200 metres of 76mm chain, with a weight 0.112 tonnes/metre, giving a total weight of 134.4 tonnes. To this must be added the weight of the anchor and, assuming a 12 tonne anchor, an all up weight in suspension below the deploying vessels stern of 146.4 tonnes. Any tension within the mooring system during deployment must also be added.

To decrease this load on the anchor-handling vessel during deployment, load sharing makes greater use of rig winch to optimise the sharing of mooring line loads between the rig and anchor-handling vessel. The basic objective is to manipulate anchor winch loads on the rig in such a way as to minimise the tension in the mooring line, thus keeping the load on the anchor handling vessel’s winch as low as possible.

The principal reason for the load sharing requirement is to minimise the weight of the outer chain section in the combination chain/wire mooring
system, this is achieved by a sequence of mooring line and anchor handling vessel work wire payouts during the anchor deployment operation. A series of calculations derived from a complex catenary programme identifies anchor handling vessel power required at each stage of the sequence, enabling loads to be shared in an equal manner between the rig winch and the anchor handling vessel.

Load share strategies have been used with considerable success on a number of mobile drilling rig mooring operations on the UK Atlantic Margin.

**Vessel Capabilities**

Larger and more capable vessels are being built which may be considered as the solution for deploying heavy mooring systems in deep water without recourse to using a load sharing strategy.

However, the load share strategy, if properly planned will also ensure that the loads imposed on mooring deployment equipment is minimised. This extends the working life of these expensive and critical components. If a detailed sequence of payouts for mooring deployment is not developed and examined then the maximum loads on vessel and equipment cannot be identified.

Vessels which are capable of deep water mooring operations are expensive to build and to charter and a mooring depths increase, the number of vessels with the capability for mooring deployment will always be few.

For conventional catenary type mooring systems, a cost spiral exists with bigger and bigger deployment vessels required to deploy heavier mooring systems to greater depths.

**Weather Downtime**

Deploying and recovering conventional catenary systems in deep water can be protracted operations even if a load share strategy is employed. ‘Weather window’ requirements mean that considerable unproductive time (and cost) can be incurred during mooring operations. A requirement for a method of quickly establishing a drilling unit on location and subsequently departing location is required.
Pre-laid Moorings

Mobile drilling rigs are, in general, permanently fitted with a mooring system which is deployed and recovered at each location. Floating production units which remain at a particular location for a considerable period are generally moored to a permanent mooring system which site and unit specific and is prelaid prior to the units arrival.

Some merit can be found in utilising the prelay technique for conventional mobile unit mooring systems. It has advantages for certain applications but is not a universal solution. The economics of hiring or purchasing a complete mooring system may not be viable for short duration drilling programmes. In addition, retaining the complete (or partial) rig mooring system on board the unit may restrict the variable deck load allowance to an extent that makes drilling operations difficult.

Pre-Apply of Catenary Mooring System
It is extremely difficult in deep water locations to pre-tension the moorings to ensure adequate embedment of drag embedment anchors. The angle of pull provided by an anchor handling vessel will be such that very little tension will be generated at the anchor. Anchor embedment, therefore, cannot be guaranteed prior to arrival of the unit to be moored.

The requirement to pretension the mooring can be overcome if suction piles or VLA are used although VLA do require a high applied tension of some 33% of the holding capacity during setting of the anchor.

If an anchor is utilised which can accept significant vertical forces then the catenary system can be shortened or a lighter weight and shorter taut leg mooring system can be used.

Maintaining the Prelay System on Location
If a mooring system is lost to the seabed in deep water it is extremely difficult operationally and very time consuming to effect recovery.

The potential for loss of marker buoys and subsequent inability to recover and/ or connect a mooring line must always be a consideration when using buoy riser systems in such water depths.

Lay down pennants are used as an alternative to buoyed systems where the system is expected to remain deployed for an extended period. They are not an ideal solution as they are recovered by grapnel. Grapnelling operations are imprecise and in extreme water depths may be unsuccessful, especially where soft soil conditions exist which may allow sinkage of the lay down wire.
Novel mooring strategies

Drilled Pile Systems

General
The drilled pile anchorage system is a novel concept for the installation of moorings for permanent or temporary floating structures and vessels. The system is currently at an advanced stage of development and has the status of ‘patent applied for’.

The system is marketed as a reliable and high strength mooring for mobile drilling units and for FPSOs and in the rapidly growing deep-water development market. The key functional requirements for new mooring systems can be categorised as follows (in order of priority):

- Reliability (particularly for production applications)
- High lateral and vertical load capability (performance)
- Low ‘all in’ installation costs
- Suitability for a wide range of soil conditions
- Minimised project lead times

The drilled pile mooring systems document is designed to meet all of the above demands. It offers a comprehensive solution to deepwater anchoring problems which is not provided by existing systems such as suction piles, driven piles and drag embedment or vertically loaded anchors.

The potential applications of the system are broad in scope. It utilises existing technology to offer a comprehensive and cost effective solution to anchoring problems in deep water locations which are not provided by existing systems such as suction piles, driven piles and drag embedment or vertically loaded anchors.

Advantages
The drilled pile anchoring system has been designed to offer specific advantages for the installation of deepwater mooring systems, utilising either catenary or taut leg mooring systems, over the other anchoring devices.

The system utilises low cost tubular components and adapted drilling technology to allow cost effective deployment of a secure mooring termination point in shallow or deep water. The system is tolerant of soil conditions and does not require alignment – thus reducing survey costs during the planning and installation phases.

The drilled pile anchor will, in general, utilise normal drilling casing tubular components. The diameter/wall thickness of the pile will be selected according to soil conditions and design loads.

Pile length, embedment depth and mooring termination (padeye) position are varied to ensure the pile is securely embedded and will sustain the maximum
forces which will be placed upon it by the mooring system. Components are readily available, low cost items which are constructed of high grade steels.

**Deployment**

The system has been designed so that it can be deployed from a conventional drilling rig (allowing options for ‘self mooring’) using standard drilling techniques or from a suitably equipped construction type vessel.

Additional potential exists for deployment by anchor handling tugs where the designs embedment depth is not excessive – e.g. present mooring systems for mobile drilling units. The anchor units are not large and it may be feasible for one large anchor-handling vessel to store on deck and deploy eight drilled piles with a second vessel employed to deploy the mooring lines.

The pile is drilled to depth whilst suspended from a running tool. When at the design depth the running tool is unlatched, retracted and recovered together with the inner drive string. The pile anchor can be installed in a single continuous operation, does not require a hole to be pre-drilled and does not require removal from the hole and reinsertion at any stage of the installation operation.

The mooring line connection point is mounted on the pile casing such that the pile does not require to be specifically orientated with regard to the direction of the mooring line during deployment. The pile may be installed with the mooring line (or the mooring line terminal components) pre-connected.

**Principal Features**

The principal features of the system are:-

1. **Reliability** is assured by the ability to install the pile consistently to the design depth in a wide range of conditions.

2. **High pile strength** (performance) for lateral and vertical loads in a wide range of soil conditions. This is achieved by the ability to penetrate into the higher strength formation. In the most demanding applications the pile may also be cemented or grouted to further increase its strength.

3. **The ability to install high performance mooring terminations** in a wide range of soil conditions minimises soils data requirements. This results in reduced overall project costs and lead times.

4. **Installation costs** are reduced as the pile is drilled to depth in a ‘single pass’ allowing rapid installation in deepwater, using proven drilling technology. The use of established drilling techniques and the insensitivity to site conditions ensures consistent results.

5. **The pile is drilled to depth without rotating the pile body**, allowing a mooring line to be pre-installed. The design includes a swivel mounted mooring termination point which negates the need to orientate the pile during installation.

6. **Construction from standard (proven) oil field drilling components** results in a reliable, low cost product and much reduced project lead times.
**Suction Embedded Plate Anchors**

**General**
An alternative to the VLA is Aker's Suction Embedment Plate Anchor (SEPLA) which is a variant of the basic VLA plate anchor. The design has been developed to reduce the costs associated with suction anchors and the difficulties associated with the installation of VLA.

The anchor is a hybrid device using attributes of both the suction anchor and the VLA. It is deployed using a suction follower (which is similar to a suction pile) with the anchor plate slotted vertically into its base. On reaching the seabed, the combination of the suction follower and anchor plate sinks under self-weight. Water is then pumped out to take the follower to full penetration. At that point, retainer pins can be removed and the follower recovered leaving the plate anchor in-situ.

Small syntactic foam buoys remain attached to the anchor plate for retrieval purposes. Load is applied to the anchor plate causing it to rotate from its vertical orientation to its final position.

**Advantages**
The primary advantages are a reduction in the high fabrication costs associated with suction anchors and a more positive embedment of the plate anchor.

**Disadvantages**
The deployment methodology essentially utilises the suction anchor philosophy and, because of this, is likely to have disadvantages similar to those of both suction anchors and VLA:-

- It is unlikely that single design of suction follower will be suitable for a range of soil conditions.
- The design may be unsuitable for very dense sand or well cemented soils.
- Specialist equipment is required for installation.
- The potential exists for problems/delays related to recovery of the suction follower following anchor deployment.
- The final orientation of the plate anchor may be uncertain.
- The behaviour of plate anchors in plastic soils where creep could occur under high static and cyclic loads remains uncertain.
- Static load testing of a plate anchor (if at all practicable) is critical. This is because failure occurs at relatively small displacements compared to drag anchors.
Modular Suction Pile

General

A variant of the conventional suction pile is offered by the Daltec suction anchor. The suction pile is essentially a two-part pile, the upper part is essentially a follower which is used to deploy the lower (anchor) section, which is typically around one third of the full length, to the required embedment depth.

The pile is installed in the same manner as a conventional suction pile. The basic lower end anchor ring will be some 2.5 metres in height with the option of additional 1.5 metre high rings.

For recovery, a ‘stepped extraction’ approach will be used to minimise recovery loads. The anchor rings will be connected by a system of tension chains and shear pins which allows them to be recovered one at a time. A vertical pull on the recovery bridle initiates a sequence which separates the connections between the modules. The first module is then raised to the mud line at which point the tension chains become taut and separate the next module which is then raised to the mud line. This process continues until all anchor ring modules have been recovered. However, recovery of the suspended string of separated anchor rings to a work vessel deck may be problematic.

The connection and disconnection of the module sections appears to require relatively complex engineering. Connection and disconnection is effected by a system of tie rods, link plates, shear pins and spring strips. The use of an alignment frame is required for initial pile preparation prior to deployment and this has been developed for additional use as a deployment frame. Orientation of the anchor may be required during deployment.

Advantages

The advantages of the system are similar to those of the suction embedded plate anchor system in that the high fabrication costs associated with suction anchors is reduced. The modular nature of the system will also allow suitability for a wider range of soil conditions.

Disadvantages

- The design may be unsuitable for very dense sand or well cemented soils.
- Specialist equipment is required for installation.
- The potential exists for problems/delays related to separation/recovery of the suction follower and subsequent separation/recovery of the anchor rings due to the relatively complex engineering.
Summary Problems and solutions

Mooring System
The basic requirement for deepwater mooring systems is minimum weight. Mooring systems must also be designed to minimise the storage requirements for mooring system components. The size and length of components must be minimised for the water depth under consideration.

Catenary type systems require considerable quantities of heavy equipment whereas taut leg type mooring systems utilise lightweight components such as steel wire rope and synthetic rope.

As an alternative to taut leg systems, consideration can be given to catenary systems which develop vertical forces at the anchor. This minimises the length and weight of the mooring system and may reduce mooring system and deployment costs.

Deployment/Recovery
Deployment and Recovery of the mooring system must be achievable under minimum load and from a wide range of vessel types. This broadens the scope of deployment options and minimises deployment/recovery costs.

Deployment of conventional catenary type drilling rig mooring systems in deep water imposes high loads on deployment vessels. The requirement for high capability anchor handling vessels can have a large cost implication for this type of operation. Prelaying catenary systems can reduce vessel and rig costs but, for mobile drilling rigs in deep water, such cost savings may be more offset by the costs associated with hiring or purchasing the prelaid system.

Permanent (or semi-permanent) production vessels are not generally fitted with an onboard mooring system and must be provided with a prelaid mooring system. The costs associated with mooring such units can be optimised by the correct selection of mooring system. Taut leg mooring systems require shorter and lighter components when compared to catenary type systems for the same given water depth. This reduction in weight and storage requirements may broaden the options available for the prelay vessels and provide cost benefits.

Anchors
The ideal anchoring device must be capable of accepting significant vertical loads to allow the use of taut leg mooring systems.

This requirement would indicate the use of conventional piled moorings, suction piles or VLA.

However, the above anchors, whilst good in some applications are not universal solutions. Each had disadvantages or limitations for deepwater mooring applications.
Summary of Requirements

To provide a solution for the problems and difficulties associated with deepwater mooring, the primary objectives are:

1. To develop a low cost and secure anchoring system for deepwater mooring applications. The anchoring system must be:
   - Low cost.
   - Easily deployable.
   - Suitable for all soil conditions.
   - Suitable for both permanent and temporary mooring applications.
   - Suitable for both catenary and taut leg mooring system designs.

2. To develop a cost effective and flexible deployment strategy for deepwater mooring applications. This will include:
   - The flexibility to utilise a wide range of vessel types.
   - Rapid deployment and recovery of moorings in deep water.

The drilled pile system may be the ideal solution to deepwater mooring problems. The design has good potential for considerable savings in time and cost during such operations, especially when used in conjunction with a lightweight prelaid system and, for mobile units, a quick disconnect methodology.