ESCUELA TÉCNICA SUPERIOR DE NÁUTICA

UNIVERSIDAD DE CANTABRIA

Trabajo de Fin de Grado

PROPOSALS FOR THE IMPROVEMENT OF SECURITY IN SPECIAL ANCHOR OPERATIONS FOR THE SETTING OF OFFSHORE STRUCTURES

PROPUESTAS PARA LA MEJORA DE LA SEGURIDAD EN LAS OPERACIONES ESPECIALES CON ANCLAS PARA LA FIJACIÓN DE ESTRUCTURAS OFFSHORE

Para acceder al Título de Grado en

INGENIERÍA NÁUTICA Y TRANSPORTE MARÍTIMO

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Diciembre-2019

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CONTENIDO

ABSTRACT

The aim of this Final Degree Project is to suggest improvements in terms of security and positioning operations in the offshore space, specifically offshore structures that are fixed to the seabed by spread anchor lines. In order to provide these improvements, this project will offer a step by step description of the operation, focusing on oil rigs, especially the semi-submersible type.

These operations are held by specialized vessels named Anchor Handling Tug Supply (AHTS), fitted with specific equipment for such activities and furthermore with the Dynamic Positioning System (DPS), whose classes and principles are also explained in further detail.

In order to describe the dynamic positioning system, the AHTS vessel *Havila Neptune's*, ship particulars, drawings and characteristics will be presented in detail.

As these activities are carried out using large mooring lines in deep waters and deploying heavy equipment, the risk in these operations are considerable. These are carried out even in rough sea states and with multiple external loads and forces. To finish, security improvement Proposals in Anchor Handling operations will be offered, so as to prevent risks, both human and material.

KEYWORDS

Dynamic Positioning, Drill, Offshore, Anchor, Anchor-Handling, Oil, Motions, Loads, Hydrodynamics, Waves, Safety.

RESUMEN

El objetivo de este Trabajo de Fin de Grado es proponer mejoras en materia de seguridad para las operaciones de movimiento y posicionamiento de anclas de estructuras Offshore, concretamente las que son fijadas al fondo marino mediante líneas de anclas dispersas. Para ello, se dará una descripción minuciosa de la operación paso a paso, centrándose en las plataformas petrolíferas, especialmente en la de tipo semi-sumergible.

Estas tareas son llevadas a cabo por buques especializados, los remolcadores de suministro y manejo de anclas (AHTS), equipados con elementos específicos para estas operaciones y con el sistema de Posicionamiento Dinámico. De éste, sus clases y principios también entraré en análisis.

Para describir el sistema de posicionamiento dinámico, se expone, de manera exhaustiva, los planos, características y los datos del buque AHTS Havila Neptune.

Al tratarse de largas líneas de amarre, grandes profundidades y elementos voluminosos, los riesgos de estas operaciones son considerables. Estas se llevan a cabo incluso con la mar hostil, conexiones de equipos pesados y múltiples fuerzas externas. Para finalizar, se exponen unas ideas y sugerencias de mejora en cuanto a la seguridad y la eficiencia de las operaciones, con el fin de la prevención de riesgos tanto materiales como humanos.

PALABRAS CLAVE

Posicionamiento Dinámico, Perforación, Alta Mar, Anclas, Manejo de Anclas, Posicionamiento de Anclas, Petróleo, Movimientos, Fuerzas, Hidrodinámica, Olas, Seguridad.

ABBREVIATIONS USED

AH: Anchor Handling.

AHF: Anchor Handling Frame.

AHTS: Anchor Handling Tug Supply Vessel.

BOP: Blow-Out Preventer.

DP: Dynamic Positioning.

DPO: Dynamic Positioning Operator.

HSE: Health, Safety and Environmental.

HLV: Heavy Lift Vessels.

IMO: International Maritime Organization.

IPE: Individual Protection Equipment.

MODU: Mobile Offshore Drilling Unit.

PCP: Permanent Chaser Pennant.

PRS: Position Reference System.

RAD: Risk Assessment Document.

PSV: Platform Supply Vessel.

SJA: Safe Job Analysis.

SOW: Scope Of Work.

ROV: Remotely Operated Vehicle.

UPS: Uninterruptable Power Supply.

VRU: Vertical Reference Unit.

CHAPTER 1: OBJECTIVES.

The main objective of the project englobes a series of ideas concerning improvements for security of anchor-handling operations in the ocean space. To do so, an Anchor Handling operation is described step by step and all the equipment that can be found on such vessels prepared for those activities.

This project has also a great focus on the Dynamic Positioning system. This system, unknown in our sea environment and operations in our country, it is a daily basis in several offshore activity areas worldwide, such as Norway, UK and the Gulf of Mexico, among others.

For a better understanding of anchor-handlers, I decided to give a full detailed analysis of AHTS vessel Havila Neptune, for the shake of better-understanding of these type of vessels.

CHAPTER 2: OFFSHORE OIL & GAS INDUSTRY BACKGROUND.

In order to study the modern offshore business and operations, it is necessary to have a look at its history, from the origin in the 1950s up to these days, as well as the evolution and development of such vessels.

Industrial advances were first stoked by coal and then by oil and gas. In the early 20th century the demand for fossil oil increased. What is more, there were many challenges to overcome if efficient and safe offshore operations were to be possible. As a result, offshore arquitecture and offshore vessels as well became more technical and equipped.

2.1 Gulf of Mexico.

The origin of these vessels may be traced to the Gulf of Mexico. What is considered by some to be the first offshore well to be drilled took place in 1936 from a platform one mile off the coast in extremely shallow water. This platform was fixed to the seabed. Although the platform was only one mile from the coast, it was necessary to transport everything to do with the well and the platform from the port of Cameron, which was 13 miles away. The drilling equipment and supplies were transported mainly by tug and barge, and the personnel and smaller items were transported by fishing vessels. Hampered by lack of radiocommunications, the offshore personnel had to rely on messages being passed by the boats running back and forth. This may have been the first offshore location where marine logistics had to be considered. (Victor Gibson, p.28, 2008).

Back to the 50s, in the beginning, such operations took place in shallow waters (less than 50m water depth) by small fishing vessels modified for these operations. Oil was transferred from the platform to shore by primitive pipelines and floating barges, known as tenders. The first offshore vessel dates from 1955 by Alden and John Laborde. (Victor Gibson 2008). But very soon they realised the advantages of deploying oil platforms and rigs in deep-water. By 1968 there were already 200 platforms offshore in the Gulf of Mexico. But moving to deeper waters meant that new and more specific vessels were necessary to fulfill such activities. The limitations of the supply and anchor handlers of the Gulf of Mexico soon became evident, because of their difficult in dealing with the weather conditions (concerning hurricanes capability to sink floating objects and to destroy the footings of jack-ups) and their inability to run anchors and tow semi-submersibles. In addition, offshore structures became larger and more technical. In that moment is when oil companies realised they need more specialized vessels for those tasks, with greater bollard pull and bhp.

2.2 North Sea

Regarding the North Sea, oil was discovered in the very late 60's, early 70's. In 1962 a number of operators began to carry out seismic surveys. Any oil found was brought to land by pipelines. When the first discover of oil was a fact (Ekofisk oil field & Phillips, October 25th 1969, discovered by Ocean Viking drilling) it was a problem to carry the oil. At that time, all subsea work was done exclusively by divers, meaning the technology for deep water operations was not yet solved. The biggest challenge was to pass the deep-water constellation called "Norske Renna", which a geological area is, going almost parallel to the Norwegian coast line with a depth up to 720 meters. This made it impossible to cross, as it would not be possible to have divers going that deep and doing the necessary tasks. What is more, right from the start the oilmen found themselves having to deal with the legendary North Sea weather.

Between 10-15 years later, exactly in 1974, another big oil reservoir was found further north and in deeper water. This pile field was to be called Statfjord oils field. Still the deep-water technology for crossing the "Norsk Renna" was not in place. The water depth had traditionally been limited to about 1500 feet as an absolute maximum. This would usually be the limit for the storage of the moorings in the chain lockers. Although many anchor-handlers of the period had the power to drag the moorings out, not many of them had the necessary drum size to store sufficient wire. As a temporary solution, it was accepted to transfer the oil from the oil rig by using oil tankers, namely shuttle tankers.

Also during the early seventies it became obvious that another type of supply vessel was going to be required, as the oil companies began to contract for the laying of pipelines from the fields being constructed in the Shetland basin to the mainland and to the Orkneys and Shetland. By 1981 there was a general increase in offshore exploration activity worldwide. During this decade the North Sea became the testing ground for offshore surface ships, systems and equipment. There was a feeling that if they could work in this extremely hostile environment they would work anywhere in the world. This was the beginning of a big era, not only for shuttle tankers, but also for offshore vessels and DP industry. (Odd R. Grinde – Arve H. Kvilhaug 2016).

2.3 Currently.

In 1986 the oil price slumped to 9$ per barrel in America. The common reaction was to lay up large numbers of offshore vessels and tankers as well and to sell others. (Victor Gibson, p.110, 2008). Victor Gibson, in his book *The History Of The Supply Ship* (p. 104, 2008) says that "In 1981 the price of crude oil reached a level which was not repeated until 2004". During the first Iraq war in the 90s there was a resurgence of the oil price, but the improvement was temporary, and later the price fell back, causing consternation amongst ship-owners, especially Europeans. In 1991 the oil process slide, and in 1993 the oil was 15$ a barrel.

Of course by the year 2000 anchor-handler vessels were ceasing to be so small. Some of them are provided with helidecks so that they can crew change on the move. With the actual technology, the operation of mooring the rig takes no more than 24 hours. (Victor Gibson 2008).

Regarding the price of oil barrel, in 1996 oil prices exceed 20$ per barrel. From 1999 til mid-2008, the price of oil rose significantly. This fact was explained by the rising oil demand in countries like China, India and Latin-American. In 2005, oil price exceeds 50$, and one year later (July 13th of 2006) oil price reaches 78,40$ per barrel. At the moment, the price is around 60$.

What can be remarked is that the oil price history in the 21st century fluctuates month by month, and even with great differences per day by day. The main reasons for the fluctuations of oil prices are speculations, wars and revolutions, among other economic and political causes.

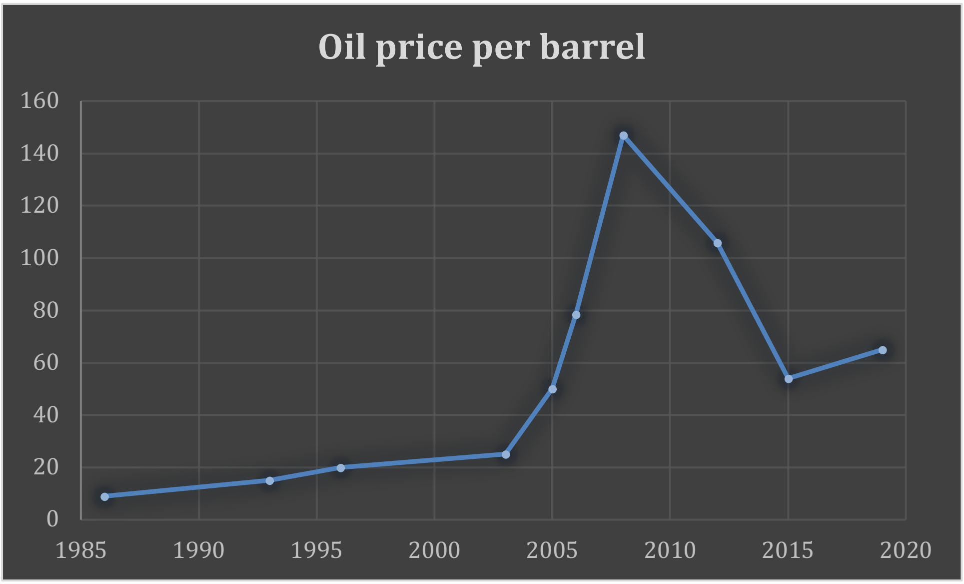

Table 1: Oil price per barrel since 1985 up to 2019. Source: Author.

CHAPTER 3: ANCHOR HANDLING TUG SUPPLY VESSEL (AHTS)

Anchor Handling vessels combine a number of functions in a single hull (that is, the use of the same ship for different tasks). We could state it as an evolution of Platform Supply Vessels (the most basic ships of Offshore Support Vessels). Commonly are designed for towing and anchor handling operations. Apart from those operations, modern AHTS vessels can carry liquid cargo in double bottom tanks, dry bulk cargoes in special pneumatic pressure tanks and equipment, such as cement in bulk, barytes, bentonite, methanol, gas-oil, fresh water, brine and oil-based mud, among others. To accomplish the operations, these vessels must be short, highly maneuverable. They are equipped with large winches (towing and secondary winches, with different bollard pull and lines, such as fiber, chain…) and a stern roller at the very edge of the aft deck. A typical operation is to recover anchors from an oil rig, towing the rig to a new location and deploying the anchors at that new location. Anchor Handling vessels are normally more powerful than other offshore vessels. Some anchor handlers are even used for trenching and ploughing operations in the sea bottom. Many of them have an ROV (Remotely Operated Vehicle) and cranes on board. These vessels are also provided with closed-circuit television cameras and several monitors within sight of the ship driving and winch-driving positions.

In the late 1970s anchor-handlers were used for all offshore purposes including the supply of materials to the platforms which were under construction. These materials include drill pipes, drilling tools, scaffolding, helicopter fuel tanks, chemicals, and food and maintenance equipment.

Some Offshore structures are placed far from shore and in deeper waters. This means mooring lines to be greater and vessels as well. Anchor Handling operations require high power, powerful winches and large wire and fiber storage capacity, deck space aft, large chain lockers for rig chains and auxiliary and additional handling equipment.

In terms of propulsion, in the past diesel-mechanical propulsion was the main arrangement. But today diesel-electric is preferable, as it offers the most environmentally effective solution. The principle behind its operation is to split the load between different engines. Power can be matched at any time to demand keeping the engines generating electrical power running at 80-90% load at which they are most fuel efficient. (Jan Babicz, p.8, 2016).

In order to reduce fuel consumption and emissions, the hybrid system is becoming more popular in new offshore vessels. Whereas the hybrid system is equal to the Diesel-electric at low load's, the hybrid system's diesel-mechanical part provides the advantage of efficiency at high load. For medium to high speed transit, the hybrid system may utilize its diesel-mechanical attributes. (Jan Babicz, p.65, 2016).

Regarding stability, they have the same parameters as supply vessels. Those vessels are permitted to have their maximum righting arm (GZ_{max}) at 15º of heel instead of 30º as required for cargo vessels. As a result, Anchor Handling ships are rigid and very stable, despite the fact that they will reach their limit already at 15º of heel. (Jan Babicz, p.65, 2016).

As Jan Babicz states in his book *Offshore Support Vessels, "*Anchor Handling is one of the most dangerous activities in the offshore industry" (Jan Babicz, p.65, 2016), regarding complicated winch operations. Not only for the exposure of seaman to environmental loads (sea, wind and current loads) but also for handling with big and heavy equipment.

3.1 AHTS equipment.

In order to take part on Anchor Handling operations, these vessels are equipped, commonly at the aft deck, with various elements to carry out an anchor handling operation, as well as safety equipment to prevent risks during operations. In order to understand the anchor handling operation, we must first look at some of the equipment used on board and look at some terms and definitions.

3.1.1 Main towing winch or Anchor Handling winch with active heave compensation.

All AHTS vessels have winches. We can say that the newer the boat is, the bigger and stronger the winches are.

The winch usually contains two smaller winches both connected to the same drive system: anchor handling drum and towing drum. These could be in front or astern of the main winch and are typically rated in the 450-600 ton range. Each winch has its own spooling gear that is used to guide the wire onto the winch drum. In order to work properly, the main winch needs to have multiple gears to allow high pulling forces at low gears when heaving in wire. (Jan Babicz, p.69 2016).

Figure 1: Main towing winch or Anchor Handling winch. Source: Wuxi Delin Marine Equipment.

3.1.2 Secondary winch with emergency release system.

A typical modern anchor handler is equipped with up to five winches. Two of them are called secondary winches and are located higher up on the ship, in an upper deck. These winches are used for storing wire and fiber rope. There should not be placed too much tension on these winches. A normal rating for these winches is 170 tons.

If a line is working on the main winch, shark jaws and towing pins (which I will enter in further detail later on) at the very aft of the after deck can be used for changing the working line from the main winch to a secondary winch, so as to store the different mooring line parts and materials (wire, chain, fiber…).

3.1.3 Gypsy or Cable lifter (Kabelar).

Figure 2: Gypsy. Source: Author.

It is used to heavy in or lower chain during operations. It is equipped with pockets with a certain size to accommodate a specific chain size. The gypsy is normally mounted on the shaft of the winch, this means that the winch drum will rotate along with the gypsy and vice versa. A regular gypsy has 6 pockets, but there are also 10 pocket versions. 76 and 84 mm are the most common sizes used during anchor handling operations.

Figure 3: Gypsy. Source: Author.

3.1.4 Shark Jaw, Towing or Guide Pins and Centering Devices.

A Shark Jaw is a hydraulic stopper used for capturing and securing the line. They are commonly remotely controlled retractable chain and wire stoppers. It enables the chain to be connected or disconnected in front of the Shark Jaw since the load of the line will be astern of it. This allows the deck crew to safely do any work and connections.

Towing or Guide Pins are “a pair of hydraulic posts for guiding towline or pennant wire” (Jan Babicz, p.72, 2016), restricting its movement. They lift from the very aft of the aft deck. Some of them are equipped with locking arms or plates (elephant’s feet, which turn inwards) that secure the chain (the towing pins and locking arms will apply downwards pressure on the chain in the shark jaws) so that it cannot come out of the shark Jaws unintentionally. These locking arms can also be used to help push the chain into the shark jaw. “Guide pins are used to contain the work wire or mooring chain within a restricted area at the stern of the vessel” (Jan Babicz, p.72, 2016). Some of them are designed to have great holding power both forward an astern, some are designed to only hold tension astern.

Figure 4: Shark Jaws and Guide Pins. Source: Escola Politécnica Engenharia Naval e Oceanica COPPE Universidade Federal do Rio de Janeiro.

The Centering Devices equipped in some ships can be used to help guide the chain or wire into the shark jaw. There are two towing pins astern of each shark jaw and two centering devices in front of the shark jaw. It is normal to have two shark jaw sets, one on each side.

3.1.5 Stern Roller

Large diameter roller placed at the stern of the Anchor Handler. When the vessel is heaving in or lowering chain or wire, the stern roller will roll at the same speed as the line, thus minimizing wear and tear on the vessel and its equipment. It can be single (mounted on the center of the stern) or double, depending on the configuration of the winches. The typical diameter of the stern roller on newer ships is approximately 4 meters.

For decking the end of the mooring line (that is, the anchor) very high tension is required. This means that the line can break or the anchor can be damaged and the anchor would then fall from surface to seabed. Recovering or deploying the anchor will be a hard task and possibly damaging subsea installations. In order to reduce the forces involved in breaking the anchor over the stern roller, some vessels include an Anchor Handling frame (AHF) at the aft of the vessel, close to the Stern Roller. This item reduces these forces up to a 50% while the anchor is gently put to rest against the frame and simply lowered onto the deck and pulled into a safe position. It can be used to lower the anchor gently into the sea as well. (Jan Babicz, p.73, 2016).

Figure 5: Installation of a Stern Roller. Source: Sotra Contracting AS.

3.1.6 Anchor

Iron or steel element provided with arms and flukes that is linked to a chain. It is set to the seabed so as to keep the vessel or the offshore structure in a fixed position, avoiding movement and displacement due to wind and sea loads. (Colección Negocio Marítimo, 2015).

Nowadays anchors are made of cast steel. There are many types of anchors used in anchor handling operations and its size is referred to by its weight in air. In the past, anchors were vast and their holding capacity was in doubt, as several times the anchor was not in the place it was supposed to be while rig shifting operations. But today, with fabricated anchors one can be sure that the anchor will hold better to the seabed, even if the job becomes a little more difficult. (Victor Gibson, p.96, 2008). When the anchor is set on the seabed, as a horizontal force is applied, it will be turned with the flukes pointing down into the seabed so that they dig down in the soil and mobilize it as resisting force. The angle of the flukes can be set at different angles (from 32 to 42 to 50 degrees) by pulling down on fluke tips with a tugger, and moving the locking pins. Different fluke angles are used for different soil conditions. If there is very soft bottom (clay or sand) higher angle will be used. If the seabed is hard, a lower angle will be set (32º). It has to be designed to satisfy all type of seabed, besides the loads that affect the anchor.

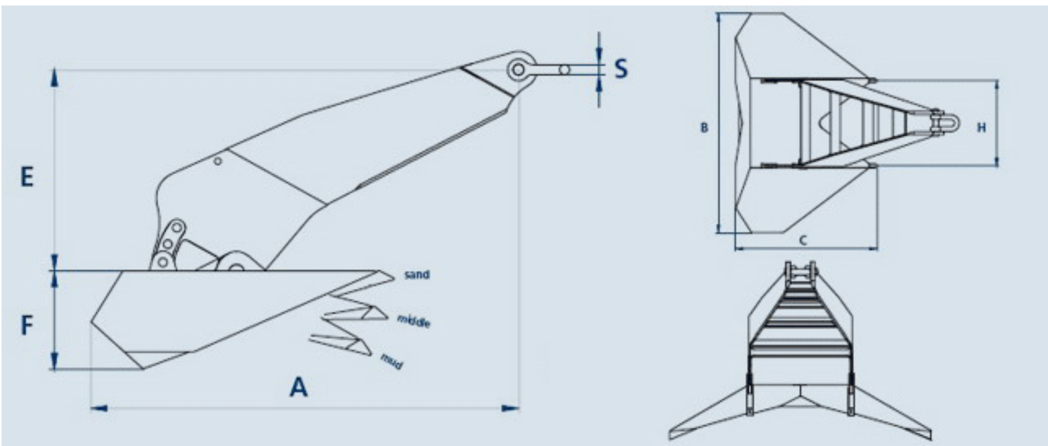

Figure 6: Different fluke angles. Source: VRYHOF.

The most common types of anchor used in anchor handling in the North sea are Stevpris mk5 and mk6. This last model has taken more and more over the previous since it has much better holding capacity, as it digs in on most bottoms. Stevpris anchors are cheap, safe and stable on deck.

Figure 7: Stevpris MK6 Anchor. Source: VRYHOF.

Pipelay barges usually use AC14 anchors. They are easy to handle and stow, dig in on the bottom immediately and are rugged, but have an ultimate holding capacity less than half of Stevpris. The relation between holding power and its weight is approximately 10:1.

Main dimensions Stevspris Mk6 dimensions in mm anchor weight in kg												
weight	1500	3000	5000	8000	10000	12000	15000	18000	20000	22000	25000	30000
A	2797	3523	4178	4886	5263	5593	6025	6402	6631	6845	7143	7591
B	3059	3870	4602	5390	5807	6171	6679	7101	7368	7625	7962	8451
C	1981	2495	2958	3460	3728	3961	4267	4534	4696	4848	5059	5376
E	1321	1664	1973	2308	2486	2642	2846	3024	3132	3234	3374	3586
F	641	808	958	1120	1206	1282	1381	1468	1520	1569	1637	1740
H	1170	1490	1781	2090	2253	2394	2610	2777	2890	3002	3138	3324
S	65	80	100	120	130	140	160	170	180	190	200	210

Table 2: Stevpris MK6 Anchor's dimensions and weight. Source: VRYHOF.

3.1.7 Lines

Traditionally and due to technological reasons, only chain was used between the anchor and the rig. Chain lines are most common lines in the offshore arquitecture. They add great strength in relation to its length. Chain lines can be easily connected by using kenter links and shackles. Chain sizes are described in terms of the diameter of the steel bar used to make the links, so 2” chain uses bar 2” in diameter, and so on.

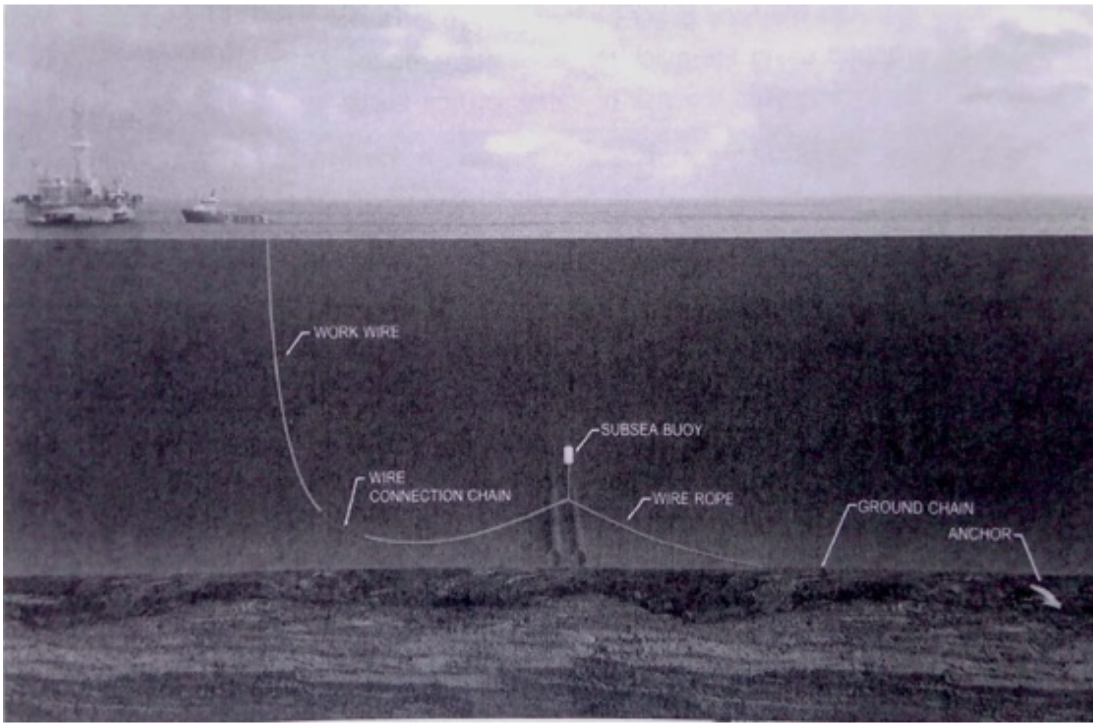

Figure 8: : Mooring line example. Source: Viking Sea Teach.

Regulations states that the safety coefficient has to be at least 5 times the maximum rated load.

The chain lowered in is stored in a tank called chain locker. When the chain comes over the gypsy, it is pulled towards the chain lockers by a chain pulling device. A chain chute is used to guide the chain into the chain lockers. The chain chute can be mounted in two different ways: between the gypsy and the chain pulling device or aft of the pulling device, depending on the ship’s winch configuration.

There are three main types of chain: short link chain, rounded link chain and ridge link chain. In order to know the length of chain lowered out, the line comes with a series of marks in the chain and shackle union. This may differ depending on the supplier of equipment, but in order to count the number of shackles being deployed, white color may be used for stud links that are near before and after the center links, that these may be in red color. The surveyor or the designated person of the company may note down the number of shackles deployed, the materials of the lines and the position of anchors or surface buoys. (Colección Negocio Marítimo, 2015).

Corrosion protection can be provided by galvanizing chain. This should be carried out in accordance with EN 10264-2:2002 or equivalent.

Nowadays some oil rigs and other offshore structures are positioned up to 1500 m depth, depth becomes a main problem, especially for the weight of chain lines. For that reason is common to have one or more sections of fiber rope insert. This is because of all the subsea installations, cables and pipes to safely span them (also by the use of subsurface buoys). These are made up of monofilament of high quality bundled. Sales pitch for fiber moorings is that they have neutral buoyancy in water.

Fiber rope lines are extremely strong, but are not that resistant to sharp edges, so caution must be taken when handling fiber rope during the operations. In addition, they are dimensionally much larger than wire for the same strength. As a result, large winches and reels are required to move them.

There are plenty of fiber lines, such as polyester, polyamide polypropylene and polyethylene, among others. The performance of fiber lines depend on several factors: strength, line linear density, temperature, abrasion and twist, among others. (OCIMF, 2018).

3.1.8 J-hook

J-hook is a tool used in the recovery of rig anchors. It is basically a large fishing hook weighing several tons that is shackled onto the end of the work wire and eased over the stern for lifting or lower an anchor line in the event of a failure of an anchor pendant line. A ROV is often used together with the J-hook to make this operation easier by verifying the hook is hooked to the line. This is not an easy task, as the J-hook easily turns around and the hook swings away from the line when heaving in.

A variation improved of the J-hook is the J-lock. It looks the same except for a track or slot in the lower part secure a chain link in the slot. This reduces the chain capability to move in the hook.

Figure 9: J-hook. Source: Sandi Pointe.

3.1.9 Grapnel.

“Grapnels are used for recovering chain and wire from the seabed” (Jan Babicz, p.78, 2016). It has 4 hooks and will catch on to the wire no matter which side it lands on. A grapnel is carried on board, with a notch cut in the flukes to take cables.

There are, however, some considerations to take whenever grappling. One must make sure that the grapnel is being pulled along the seabed in a horizontal position. In addition to the weight of the grapnel, it is vital to have enough wire length out (commonly 1,5 times water depth out). It is also essential to use slow speed both on vessel and winch when grappling.

Grappling is a very harsh method for recovering wires from the seabed and is in disuse. The wires will have to be discarded after being grappled a few times.

Figure 10: Grapnel. Source: Marine Link.

3.1.10 Chaser Ring.

Large steel cast ring fitted around an anchor chain. The chain in the mooring line goes through this ring while chasing the anchor in the seabed. If force is applied when the chaser ring is at the anchor the vessel can lift the anchor off the seabed and recover it on board.

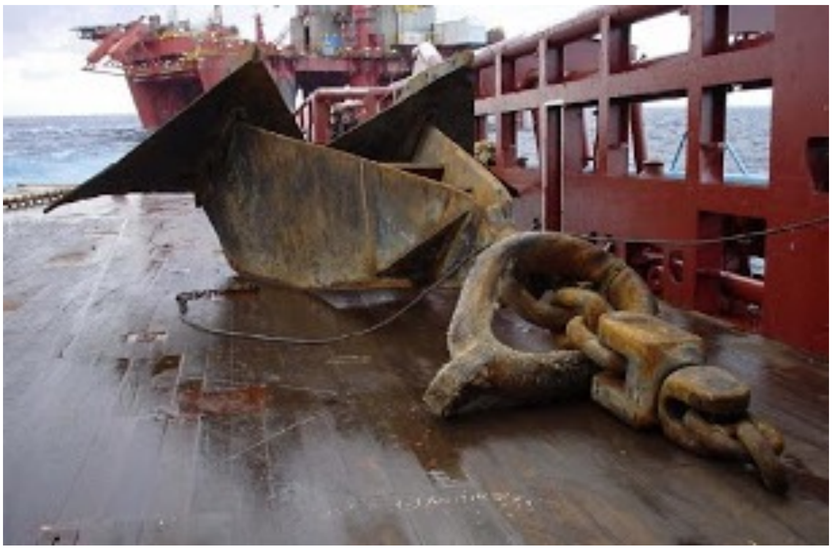

Figure 11: Chaser Ring. Source: Ebbe Holsting.

If a mooring line consist of nothing but chain, the ring can be pulled by the anchor handler vessel all the way from the rig and down to the anchor. But, when a mooring line consist of several fiber rope sections and other materials, there is normally a chaser stopper installed right before the fiber to avoid the chaser ring coming to the fiber. This can be a large metal plate or similar. The chaser ring is connected to a 60m wire Permanent Chaser Pennant (PCP).

Figure 12: Chaser Ring. Source: Bruce Anchor.

3.1.11 Kenter Links and Shackles.

Kenterlinks are composed by two pieces that are coupled next to each other by means of tabs that are embedded in recess. In the center there is a centerpiece (heart) and a bolt placed through it so as to secure the join. It is used in most operations for most connections during Anchor Handling. An advantage is that they look like a chain link when installed in a line and can therefore be run through the gypsy.

Figure 13: Kenter links. Source: Author.

Figure 14: : Opened Kenter link. Source: Blue Ocean Tackle.

As we can see in the picture below, shackles come in different shapes and sizes.

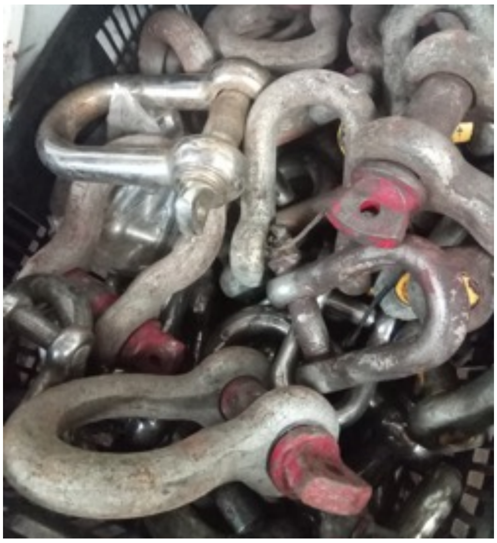

Figure 15: Shackles in different shapes and sizes. Source: Author.

They are mainly used when they are not going to be a permanent part of a mooring line. It is therefore a temporary item (except from the shackle on the anchor stock connecting the anchor and chain together and at the end of the fiber rope). The advantage of using shackles is that they are quick to connect and disconnect.

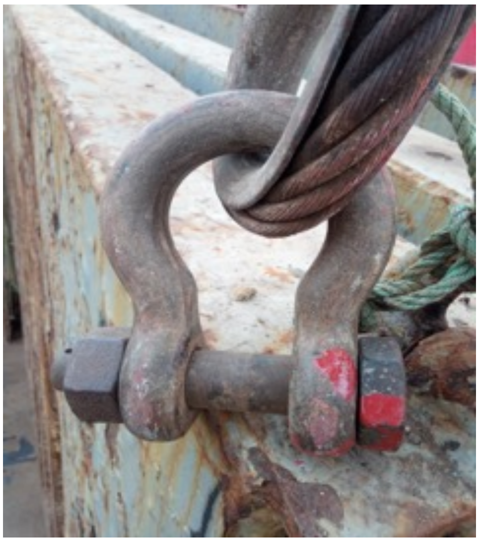

Figure 16: Shackle. Source: Author.

In addition, there are also hinge links and pear links on board most vessels. They are not used much, normally only used internally on board (it may be connected to ships work wire or else, mostly for deck jobs).

3.1.12 Buoys

Buoys come in many different shapes and sizes, and they have many uses in anchor handling operations. In the early days of anchor handling, buoys were made of steel. But if a vessel ran into a buoy, it could damage the vessel and sink the buoy. Nowadays steel buoys are being replaced by GRP and elastomer foam, despite the fact that these materials are fragile and they need to be launched carefully. The two main uses are surface and subsurface-buoys.

Surface buoys

Are typically connected to the end of a mooring line. This makes it easy for a vessel to catch the buoy and have the end of a mooring line on deck, ready to hook it up to an oil rig. A typical surface buoy has a buoyancy of 14 tons.

Figure 17: Surface buoy. Source: Balmoral Offshore Engineering.

Subsurface buoys

These are usually smaller than surface buoys and their buoyancy are more closely matched with their intention of use. A typical use is to attach it to a fiber rope in a mooring line to provide enough buoyancy to keep the fiber rope off the seabed or subsea installations (such as subsea pipes) as explained before. Typical buoyancy ranging between 2 to 5 tons.

Smaller marker buoys are also used for marking specific points on the line (for example, when the line changes from chain to fiber) or to create a pick up system that enables the ROV to connect a ship's work wire to a wire or chain end lying on the seabed.

3.2 AHTS Helping aids on deck.

Deck work performed on board is high-risk, as sometimes the operations are carried out in rough seas. Equipment used during operations are very heavy and put great strain on a person. As a consequence, new safety requirements for safe anchor (and cargo) handling procedures have been drawn up. (Jan Babicz, p.74, 2016). Modern anchor handling vessels have some sort of aids or equipment on deck to help the crew with the work they are doing.

3.2.1 Triplex Multi Deck Handler.

The Triplex MDH is a large traverser crane. It removes the most dangerous working tasks on board, such as crew members using sledgehammers and crowbars, and are replaced by remote-controlled work operations all at the safe distance so that nobody is put in danger.

Figure 18: Triplex MDH crane. Source: Marine Link.

The MDH concept is based on a remote-controlled traveling gantry crane, with the carriage between cargo rail and the outer railing. It has a Palfinger crane mounted on top, a winch below for heavier lifts, a wire clamp for clamping wires that have twist in them and a manipulator mounted. The manipulator is able to disconnect shackles and kenters (even thought are seldom used because it is very time consuming). (Jan Babicz, p.74, 2016).

All equipment connected to the MDH is remote-controlled from mobile radio control panels, besides from the bridge. In addition to visual control from deck level, the operator on the bridge will be able to control and monitor the work with great accuracy via monitors connected to cameras in a closed circuit television system (CCTV). Cameras are strategically sited: one under the traveling crane and the other in the crane or manipulator arm to provide detailed close-ups. Moreover, in modern anchor-handlers the seats are placed on runners so that the operators can be positioned close to the large aft facing windows.

When working in the dark, the whole deck is illuminated by a number of extremely bright lights, usually installed above and below the aft side part of the bridge.

3.2.2 Rail mounted cranes.

Small cranes moving on top of the cargo rails. Its advantages are that they can work independent of each other and that they do not steal any view from the bridge and down on deck. While sailing, rail cranes are folded and locked forward on the deck.

The disadvantage is that they are not very strong and therefore, cannot lift and move heavy equipment on deck, such as anchors and surface buoys. Instead, all anchor handlers have tuggers and capstans installed in several strategical places on deck that are used to drag equipment along the deck.

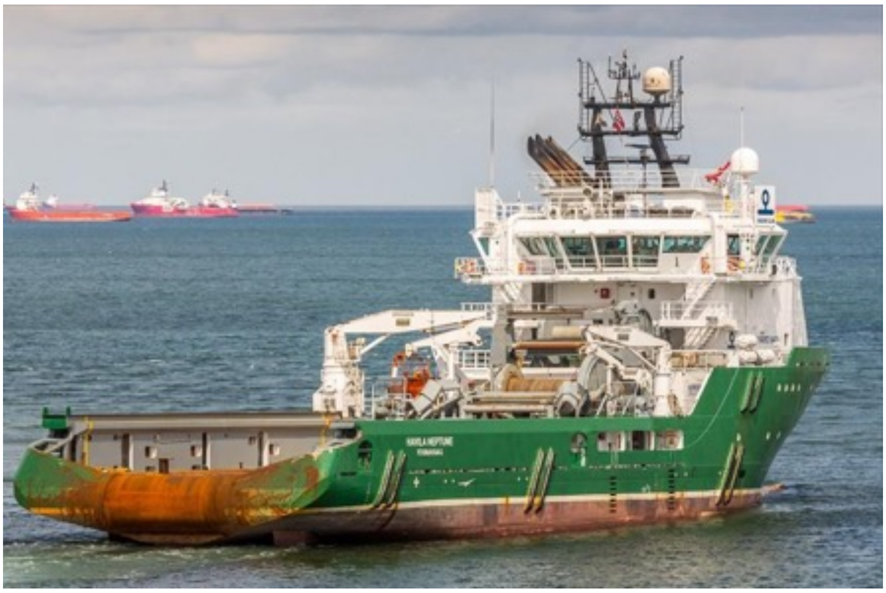

Figure 19: AHTS Havila Neptune equipped with two rail mounted cranes. Source: Alan Jamieson; Marine Traffic.

Some older AHTS vessels have a smaller crane (typically a Palfinger type crane) located at the very aft of the vessel to help lifting equipment. In addition, most vessels have one or more cranes forward of the deck.

CHAPTER 4: AHTS VESSEL HAVILA NEPTUNE

The Havila Neptune AHTS vessel was designed by Havyard Design & Engineering AS and delivered in April 4th of 2008. The vessel is equipped with DP system Class 2, which is suitable for most offshore jobs.

Figure 20: AHTS Havila Neptune by Havyard AS. Source: Ole Jakob Dingen.

Ship's Particulars	
Name	Havila Neptune
IMO no	9393400
Call sign	LACN
Flag	Norway
Port of registry	Fosnavåg
MMSI no	259133000
GT	2807
NT	857
MDWT	2671
L.O.A	74,5
L.P.P	64,8
Breadth	17,2
Draught	6,8
Total Bhp	16092
Total Kw	12000
Class	DNVGL-29122 (1A1 ICE-E & FIre Fighter I E0)

Table 3: Havila Neptune ship's particulars. Source: Author.

The Class of this vessel is DNVGL-29122. It has also ice classification 1A1 ICE-E, by Det Norske Veritas classification society. This means that the vessel is able to navigate in areas for light localized drift ice in mouths of rivers and coastal areas. It complies with 1A typical ice requirement for first-year unbroken ice. The vessel is also suitable to act as an Offshore Service Towing Fire Fighter denoted I E0. The rules for fire fighter are represented in the following tables:

Water monitor system capacities	
Class notation	**Fire Fighter I**
Number of monitors	2
Capacity of each monitor (m^3/h)	1200
Number of pumps	1-2
Total pump capacity (m^3/h)	2400
Length of throw (m) (1)	120
Height of throw (m) (2)	50
Fuel oil capacity in hours (3)	24
(1) Measured horizontally from the mean impact area to the nearest part of the vessel when all monitors are in satisfactory operation simultaneously. (2) Measured vertically from sea level to mean impact area at a horizontal distance of at least 70m from the nearest part of the vessel. (3) Capacity for continuous operation of all monitors, to be included in the total capacity of the vessel's fuel oil tanks.	

Table 4: Requirements for Fire Fighter Class I. Source: DNV Rules for Classification of Ships.

<table>
<tr><th colspan="7">Overview of additional hydrant manifolds, hose connections and nozzles.</th></tr>
<tr><td></td><td colspan="2">Number of fire hydrant manifolds</td><td>Number of hose connections at each manifold</td><td>Total number of hose connections</td><td>Number of additional hoses (1)</td><td>Number of additional hoses (2)</td></tr>
<tr><td rowspan="2">Fire Fighter I</td><td>Port</td><td>Starboard</td><td rowspan="2">4</td><td rowspan="2">8</td><td rowspan="2">8</td><td rowspan="2">4</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td colspan="7">(1) Length 15m, diameter 50mm.
(2) Combined 16mm spray/jet.</td></tr>
</table>

Table 5: Additional hydrant manifolds, hose connections and nozzles for Fire Fighter Class I. Source: DNV Rules for Classification of Ships.

For towing there is a main winch by Rolls-Royce Brattvaag with a 350t pull and 500 t brake load, with a very large wire capacity. It is equipped with secondary winches as well. Aft are two sets of Karmøy Winch shark jaws and towing pins plus the centering system for leading wires to this equipment, and a stern roller. For deck operations the vessel has two cranes: one crane Dreggen DKF 40 that can lift 3,5Tns at 10m and a cargo rail crane Dreggen DFKR100 5Tns at 15m. In terms of stability, the vessel has several water ballast tanks with a capacity of 1200m^3.

Regarding Navigation systems, it has DGPS Furuno GP-150, AIS Furuno FA-150 an Echo sounder Skipper GDS 102 a Telchart 2026 Plotter and two radar Furuno FAR-2117BB and Furuno FAR-2837S.

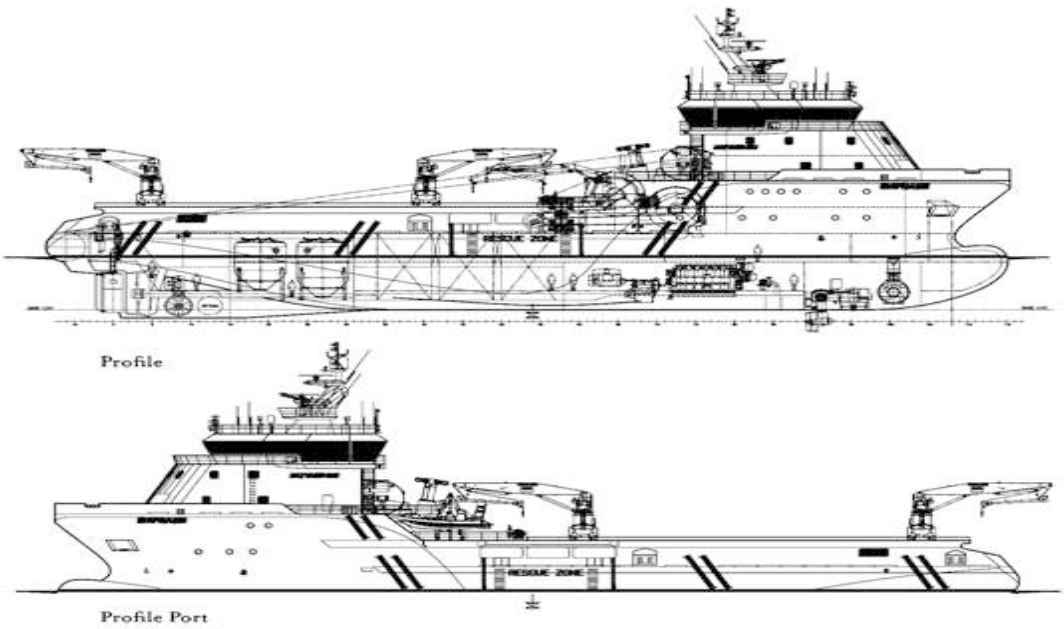

Figure 21: Havila Neptune's starboard and port profiles. Source: Ship-info.

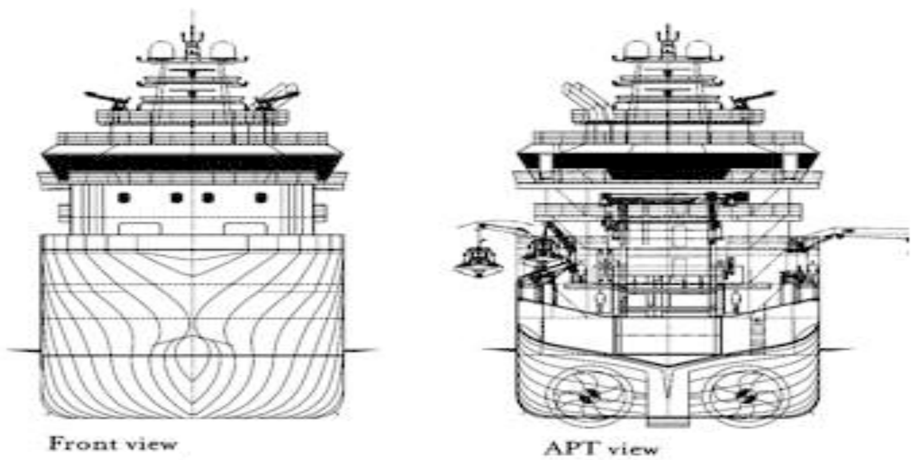

Figure 22: Havila Neptune's Front and APT views. Source: Ship-info.

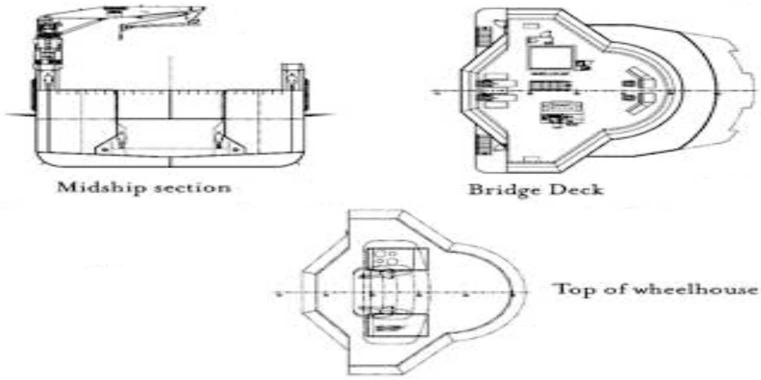

Figure 23: Havila Neptune's Midship section, Bridge deck and Top of Wheelhouse. Source: Ship-info.

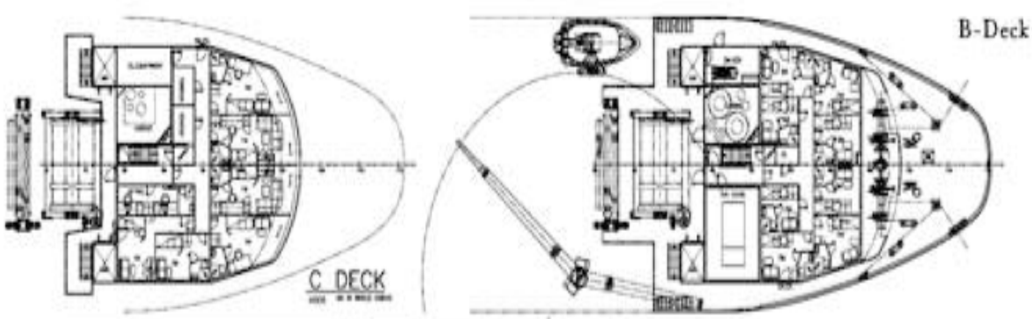

Figure 24: Havila Neptune's B and C Decks. Source: Ship-info.

Two main engines Mak 12M32C power the vessel, assisted with a bow thruster 883 Kw of Rolls-Royce KaMeWa Ulstein TT2200 DPN, a stern thruster of the same characteristics and a azimuth thruster of 883 Kw Rolls-Royce Aquamaster TCNS 73/50-180. It is also equipped with two auxiliary engines Caterpillar C18TTA of 602 Kw (807 BHP) at 1800 rpm per each. It has two gear boxes Rolls-Royce Marine 3000 AGHC-KS560.

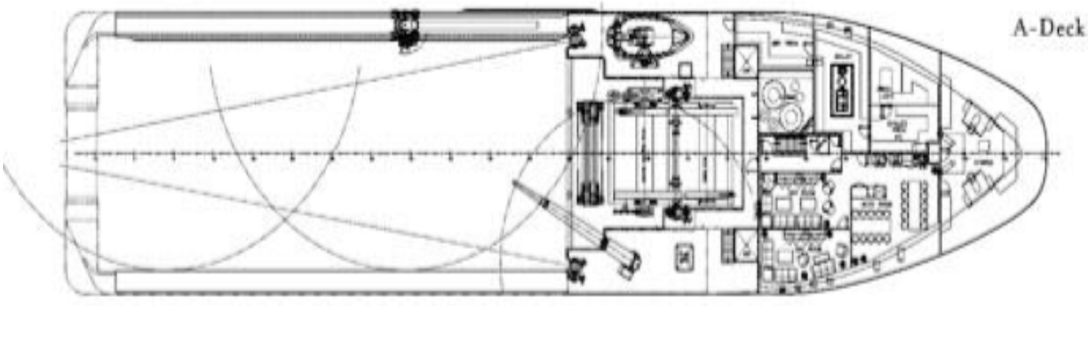

Figure 25: Havila Neptune's A Deck. Source: Ship-info.

All the normal supplies can be carried including glycol and base oil, necessary for the supply of platforms. It also has tankage for 515 m^3 of brine, 540 m^3 of mud and 220m^3 of dry bulk.

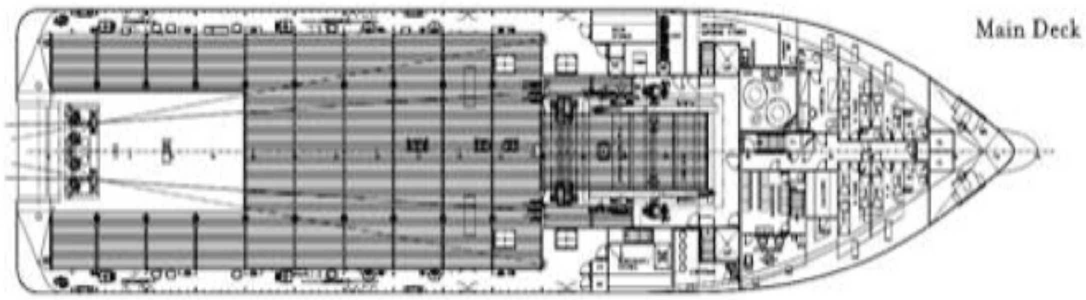

Figure 26: Havila Neptune's Main Deck. Source: Ship-info.

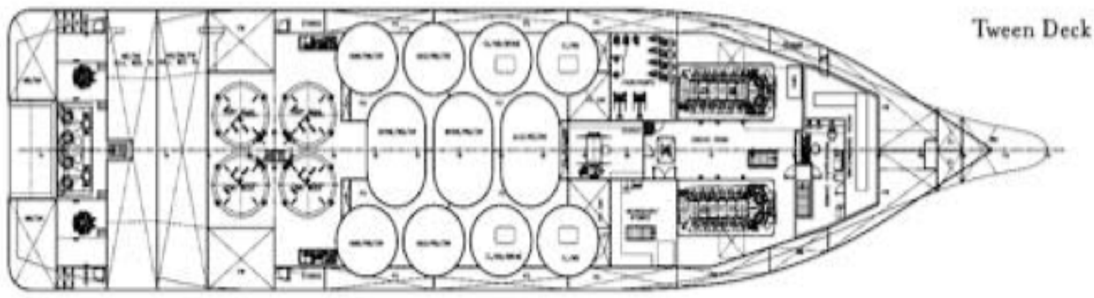

Figure 27: Havila Neptune's Tween Deck. Source: Ship-info.

In terms of auxiliary equipment, the vessel has an Emergency generator of 72 kW. It is equipped with two Stamford generators of 668 kVA and also two shaft generators of 3000 kVA Stamford MJR 630 LA6.

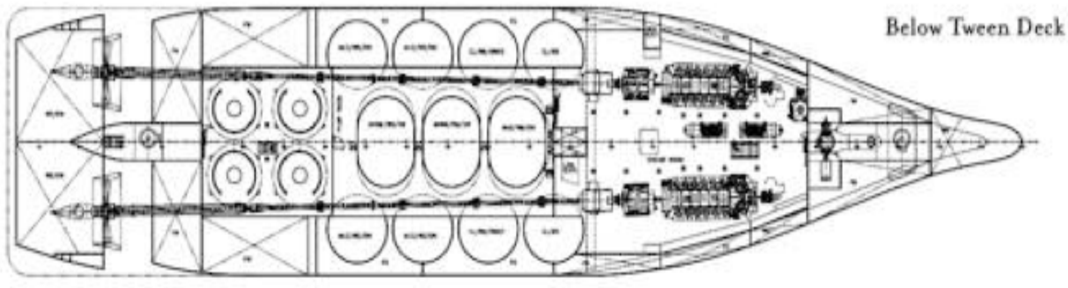

Figure 28: Havila Neptune's Below Tween Deck. Source: Ship-info.

Concerning the tween deck, its area is of 520m^2 and a deck cargo of 1000t. Below the tween deck, there are several potable water tanks, with a capacity of 725m^3.

CHAPTER 5: DYNAMIC POSITIONING.

A seagoing vessel is subjected to various external forces, such as wind, waves and currents, as well as forces generated by the propulsion system (thruster wash, especially when moving astern, which is a common maneuver during operations). If a ship is engaged in technical and precise operations and needs to stay steady in a precise position on the earth's surface (with the assistance of an electronic referencing system) Dynamic Positioning will be the solution, making the job easier and safer for the crew and for the entire operation, including other vessels in the vicinity. Therefore, dynamic positioning is a major factor for diving, ROV operations, pipe laying, subsea tasks and anchor handling, among others. Its main function is to enable the vessel to maintain a fixed position and heading, and to make changes to that position and or heading in a controlled manner. The main function is the auto positioning, but it also allows the vessel to be controlled by means of a joystick. So, the ability of this system can be defined as a system that automatically controls a vessel's position and heading exclusively by means of active thrust. (David Bray FNI, 2008)

Figure 29: Kongsber DP simulator. Source: Author.

The hearts and brains of DP systems are the computers, usually referred to as controllers. The controllers receive input data from several sensors: the wind sensor, the gyro sensor, Position Reference Systems (PRS), Satellite-based navigation systems (DGPS, Glonnas, Galileo…) and Hydro acoustic Transponders (HPR). There are also other position reference systems, but not that usual. For instance, laser-based position reference systems (Fanbeam) and hydro-acoustic position reference systems, among others.

Figure 30: Havila Aurora DP Fanbeam. Source: Author.

Therefore, the provision of a stable, accurate and reliable input of vessel position is vital to the DP system. It is not possible to control any variable until that variable can be measured. It is up to the DP operator to give sensors the appropriate weight. This means that the DP system will rely on more on one Position Reference System rather than other.

Figure 31: Havila Aurora DP control panel. Source: Author.

Anchor-Handling vessel are equipped with the DP system due to the close-in locations in which these vessels work and the associated hazards. The system may be used to advantage in manoeuvering to transfer the anchors to the tug from the barge to the rig, and in the exact positioning for the laying of the anchors and the use of ROVs.

5.1 Early Dynamic Positioning systems.

The earliest, but quite rudimentary Dynamic Positioning systems were introduced in the late 1960s. The first DP vessel in fact was the Eureka built by Sedco. But the technology did not come of age until the late 1970s and early 1980s when this system onboard Offshore Vessels improved impressively with more and better hardware and software, as it was being fitted to new vessels in large numbers. In the early days, DP was a standalone unit with one screen device with push buttons used to keep position when moored.

One individual more than any other deserves to be called the father of DP: Howard Shatto. Responsible for the systems on board drillship Eureka in 1961, enabled the first fully automatic positioning of a vessel using thrusters.

It is worth remembering the DP technology is rapidly changing in every area, developing very fast, and the learning curve has been steep. But typical installation today is a two station compound by 2 screens (one for redundancy) set up with all the operating facilities on screen. Moreover button panels are available on the desk. (Victor Gibson 2008).

Figure 32: Havila Aurora DP screen. Source: Author.

Today the typical Anchor Handling DP operation starts from a distance about 500m from the rig. In some operations, the client will require to start the operation at 1000m. DP active Joystick is used for the approach to the rig and the entire operation. The main purpose is of course to hold the position of the vessel throughout the Anchor Handling operation when needed. At 200m of the final working position, the system can be placed back into full automatic DP control. (David Bray FNI, 2008)

Vessels with DP system are provided with sophisticated propulsion systems based on azimuthing thrusters, tunnel thrusters, retractable thrusters, CP propeller and high lift rudders. The arrangement in propulsion varies on each vessel, depending on its purposes and tasks.

5.2 DP Classification

In accordance to IMO publication 1944 MSC/Circ.645, the Classification Societies have issued rules for dynamically positioned ships. These rules specify levels of redundancy known as classes. The higher the class number, the greater the level of redundancy. Classification societies (such as Lloyd's, Bureau Veritas, Det Norske Veritas, Russian Maritime Register of

Shipping…) issue vessels equipped with DP an appropriate notation. Classification societies have their own class notations that are accord to IMO classes and are equivalent as well.

Equipment Class 1 is the simplest form of DP and has no redundancy. Loss of position may occur in the event of a single fault.

Equipment Class 2 has redundancy so that no single fault in an active system (that is, thrusters, controllers, switchboards, remote controlled valves, generators and so on) will cause the system to fail. But it may occur after failure of a static component, such as cables, pipes, manual valves…

Equipment Class 3 has to withstand fire, blackout or flood in any one compartment without the system failing. Loss of position should not occur from any single failure, including a completely burnt fire subdivision or flooded watertight compartment.

Even in case of very severe damages on DP system and its compounds, new vessels are equipped with Uninterruptable Power Supply (UPS). This is a low-voltage system that ensures secure power supply to DP control elements and other vital functions, giving at least 30 minutes to stop operations safely. Normally features a battery back-up facility.

DP Class 3 is recommended to be used in critical operations were a loss of position could cause severe injury or death, maritime pollution or material damages.

SUBSYSTEM OR COMPONENT		MINIMUM REQUIREMENTS		
IMO Equipment Class		**1**	**2**	**3**
POWER SYSTEM	Generators and prime movers	Non-redundant	Redundant	Redundant, separated compartments
	Main Switchboard	1	1 with bus tie	2 with normally open bus ties (separate comparments)
	Bus tie breaker	0	1	2
	Distribution system	Non-redundant	Redundant	Redundant, separated compartments
	Power management	no	yes (DNV LG, ABS)	yes (DNV LG, ABS)
THRUSTERS	Arrangement of thrusters	Non-redundant	Redundant	Redundant, separated compartments
CONTROL	Auto control (number of control computers)	1	2	2+1 (alternate control station)
	Manual control (joystick with auto-heading)	yes	yes	yes
	Single levers for each thruster	yes	yes	yes
SENSORS	Position Reference System (PRS)	2	3	3, 1 connected to an alternative control station
	Wind	1	2 or 3 Classification Societies	3
	Vertical Reference System (VRS)	1	3	3
	Gyro	1	3	3
UPS		1	3	2+1 in separate compartment
Alternative control station for back-up unit		no	no	yes

Table 6: IMO DP redundancy requirements. Source: IMO.

Pre DP operational Checklist

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Time	12 : 41	Date	31 / 07 / 2019	Water Depth	42094 m
Wind Speed	13.6 kts	Wave Height	m	Current	0,2 kts
Wind Direction	050 º	Wave Direction	º	Current Dir	031 º
Work description received and understood		O			
Active Nav. Lights / Day signal					
Explain escape route from working location					
Comments					

Communication Tests

VHF	O	CH		UHF	O	CH		Phone	O	Talk Back	O

Thruster Control; Test of transferring command between modes

Manual to DP	✓	DP to Independent Joystick	✓	DP to Manual	O

Independent Joystick setting and tests (without DP (before activating DP))

	Enabled	Preference	Used	Comments
Gyro 1	✓	✓	✓	
Wind 1	O	O	O	

Functional in all three axes	O	Auto Heading Tested		O	Wind Compensation Enabled		O
Joystick Settings		Thrust	Full	O	Reduced		O
		Precision	High	O	General	O	Low O

	Bow Thr 1	Bow Thr 2	Bow Azi	Port Aft Azi	Stb Aft Azi
Running	O	O	O	O	O
Ready	O	O	O	O	O
Enabled	O	O	O	O	O

Outstanding maintenance regarding DP and vessel manoeuvring systems
(Example emergency stop of thrusters)

DP Hardware Controller / RCU 501 Main System

	Running	Online	Master		Day	Month	Year
Controller A	O	O	O	Last Reset			
Controller B	O	O	O	Last Redundancy integrity test			

Figure 33: Pre DP Operational Checklist (I/IV). Source: Author.

Pre DP operational Checklist

Page 2 of 4

Sensors on DP

	Enabled	Preference	Used	Comments and deviation
Gyro 1	✓	✓	O	
Gyro 2	✓	O	O	
Gyro 3	✓	O	O	

	Enabled	Preference	Used	Comments and deviation
VRS 1	✓	✓	O	
VRS 2	✓	O	O	
VRS 3	✓	O	O	

	Enablend	Preference	Used	Comments and deviation
Wind 1	✓	✓	O	
Wind 2	✓	O	O	
Wind 3	✓	O	O	

Draught	Sensor	✓	Pre sett / Manual	O		m

Tension Measured	Force	O	Azimuth	O	Elevation	O
Tension Manual	Force	O	Azimuth	O	Elevation	O

Thrusters on DP

	Bow Thr 1	Bow Thr 2	Bow Azi		Port Aft Azi	Stb Aft Azi
Running	✓	✓	✓		✓	✓
Ready	✓	✓	✓		✓	✓
DP Enabled	✓	✓	✓		✓	✓
Connect to SWBD			Lowered	O		

DP Position Reference systems

Position Reference systems			Origin	Enabled	Monitoring	Mobile	Diff. Used	Transponder Channel			
GPS 1			✓	✓	✓	O					
GPS 2			O	✓	✓	O					
GPS 3			O	O	O	O					
HPR 1	Lowered	O	O	O	O	O					
HPR 2	Lowered	O	O	O	O	O					
Fan beam			O	O	O	O					
Radius			O	O	O	O					

Figure 34: Pre DP Operational Checklist (II/IV). Source: Author.

Pre DP operational Checklist

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Bus Tie breakers

	A1-B2	A1-A2	A2-A3	A3-B1	B1-B2	B2-A1
Open	0	0	0	0	0	0
Closed	0	0	0	0	0	0

Power

	Generator 1	Generator 2	Generator 3	Generator 4	Generator 5	Generator 6	Generator 7
Running	✓	✓	0	0	0	0	0
Online	✓	✓	0	0	0	0	0
Standby	0	0	0	0	0	0	0

DP Joystick

Functional in all three axes	✓	Auto Heading Tested	✓	Environmental Compensation Enabled		0
Joystick Settings	Thrust	Full	✓	Reduced		0
	Precision	High	✓	General 0	Low	0

Alarm

	Alarm	Warning		Alarm	Warning
Position / Cross	4 m	2 m	Roll	3 º	— º
Heading	3 º	1.5 º	Pitch	3 º	— º
Heav	1 m	— m	Consequence analysis / DP Class		
DP Alarm Printer	✗	Active Alarms	No ✓	Yes*	0

*If yes add the alarm(s) text in "other comments" below

DP Class 3 Operation

DP Hardware Controller / RCU 501 Backup System

In Use	0	Runinig	Online	Master		Day	Month	Year
Controller A		0	0	0	Last Reset			
Back System setup equal to Main System					0	Back Monitoring Checked		0
Transferring Control		Switch		0	0	Water tight doors checked		0
		Main System		0				
Comments								

Figure 35: Pre DP Operational Checklist (III/IV). Source: Author.

Pre DP operational Checklist

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After a settling time on DP for more than 20 minutes considering the following before starting the operation and make comments

Online Capability plot	
Weather forecast	
Gain Setting	
Thruster Allocation Setting	
Other Comments	

Signature and date
DP Operator

Signature and date
Watch Keeping Officer

Figure 36: Pre DP Operational Checklist (IV/IV). Source: Author.

The Redundancy term has its own meaning. For DP class 1 a single controlling computer is adequate, but for class 2 two parallel identical controllers are installed. Each one runs independently in parallel, receiving the same feedback data and performing the same computations as well. One is online while the other is the back-up. It ensures that the system can continue to function after the loss of any single element or subsystem. We could describe it as the ability to maintain or restore its function when a single failure has occurred. Therefore, the aim is to prevent a catastrophic failure (loss of position and/or heading) and what it entails. Redundancy is of vital importance, as in many operations the DP ability is essential for the safe suspension of the job and ship's exit from the area. In effect, redundancy arrangements within the DP system provide a time-frame within which the operation can be safely suspended and the vessel can move to a position of safety after the failure of a critical component.

Several ways of providing redundancy are available. The commonest is to provide back-up or standby facilities in the DP system control computers or processors. Redundancy can be achieved by having two processors, one online and the other on hot standby. A further requirement is a bumpless transfer between units. That means if the online processor fails, the standby unit takes command automatically without any change in the vessel status, including position and heading. After an event of this kind, the vessel is still under DP control and can move to a position of safety. It is achieved in controllers, position and heading, and in propulsion. (David Bray FNI, 2008).

5.3 Degrees of freedom and motions. Loads.

In order to study the sea loads and motions acting on ships and offshore structures caused by wind, current and waves, it is necessary to state some basic assumptions. (Egil Pederson, 2014).

- The sea water is assumed to be incompressible and inviscid fluid.

$$\mathbb{v} = \nabla * \varphi \qquad (\nabla * \mathbb{v} = 0)$$

- The fluid motion is irrotational when the vorticity vector is zero $\omega = \nabla * \mathbb{v} = 0$ everywhere in the fluid.
- Wave height is much (an order of magnitude) smaller than wave length. $|\zeta \ll \lambda|$
- There is no viscosity. This means that there is no friction within molecules.
    - In the fluid domain, we can state that $\nabla^2 * \varphi = 0$

The complete mathematical problem of finding a velocity potential of irrotational, incompressible fluid motion consists of the solution of the Laplace equation with relevant boundary conditions on the fluid. Velocity potential has to satisfy the Laplace equation:

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial z^2}=0$$

For a fixed body in a moving fluid we have the body boundary condition:

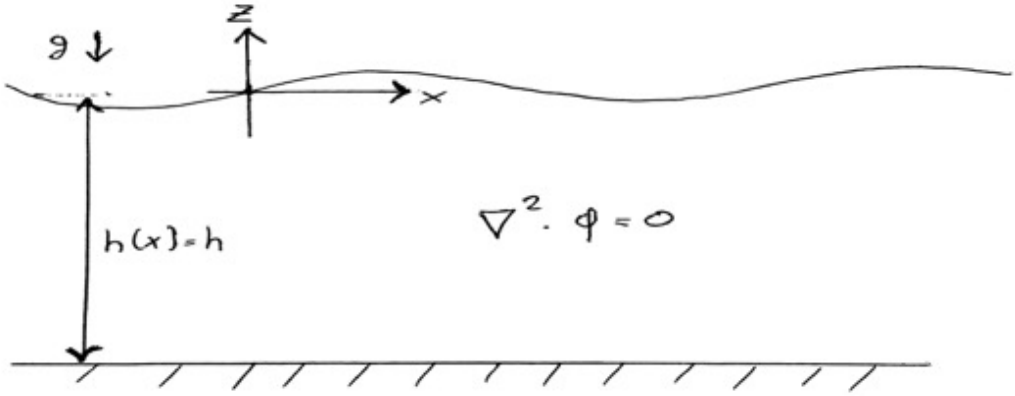


Figure 37: Boundary conditions. Source: Author.

$\frac{\partial\phi}{\partial n}=0$ on the body surface.

In this equation, $\partial/\partial n$ denotates differentiation along the normal to the body surface. We will define the positive values normal direction to be into the fluid domain. This equation defines impermeability. No fluid enters or leaves the body surface.

By assuming a horizontal or flat seabed there is no normal water motion or speed. The free-surface condition is used together with the Laplace equation and the sea bottom condition: $\left.\frac{\partial\phi}{\partial z}\right|_{z=-h}=0$

Where h is the mean water depth.

The dynamic free-surface condition is that the water pressure equals air pressure at sea surface. From the Bernoulli's and Euler pressure equations we have:

$$p+\rho gz+\rho\frac{\partial\phi}{\partial t}+\frac{\rho}{2}\mathbb{V}*\mathbb{V}=C$$

Or to simplify the equation:

$$\frac{p}{\rho} + \frac{1}{2}|\nabla\phi|^2 + g\xi + \frac{\partial\phi}{\partial t} = C$$

Assume the z-axis to be vertical and positive upwards. C is an arbitrary function of time. We will include the time dependence of C in the velocity potential and let C be a constant. It is assumed that the only external force field is gravity. Z=0 corresponds to the mean free-surface level. The constant C can be related to the atmospheric pressure or the ambient pressure.

We choose $C = \frac{p_0}{\rho}$. It can be shown that higher order terms ($|\nabla\phi|^2$) are much smaller: $g\xi + \frac{\partial\phi}{\partial t} = 0\Big|_{z=\xi(x,t)}$

A water particle will follow the wave elevation at surface:

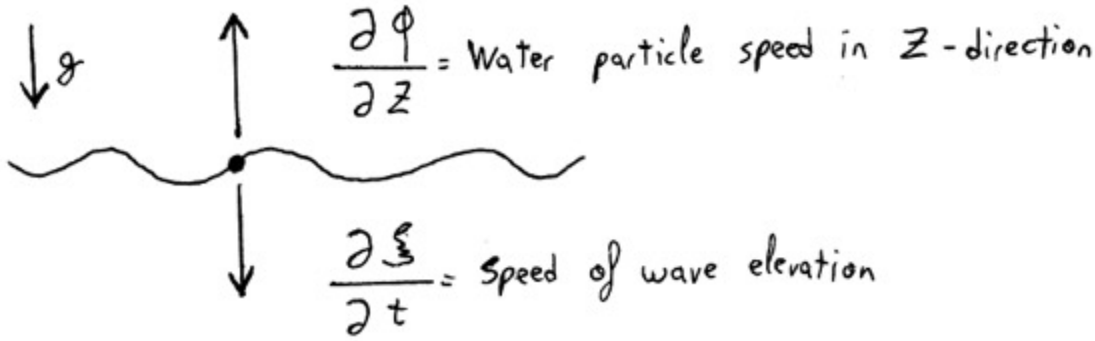


Figure 38: Water particle following wave elevation at sea surface. Source: Author.

We linearise all terms about the mean sea surface Z=0 because wave amplitude is small compared with wave length.

Then, we have all the necessary conditions of a Boundary value problem to be solved. $\nabla^2 * \varphi = 0$ must satisfy:

$$\frac{\partial\varphi}{\partial Z}\Big|_{Z=-h} = 0$$

$$g\xi + \frac{\partial\varphi}{\partial t} = 0\Big|_{Z=0}$$

$$\frac{\partial\varphi}{\partial Z} - \frac{\partial\xi}{\partial t} = 0\bigg|_{Z=0}$$

Motions can be divided into wave-frequency motion, high-frequency motion, slow-drift motion and mean drift. The oscillatory rigid-body translatory motions are referred to as Surge, Sway and Heave (with heave being the vertical motion). The oscillatory angular or rotation motions are referred to as Roll, Pitch and Yaw (with yaw being rotation about a vertical axis).

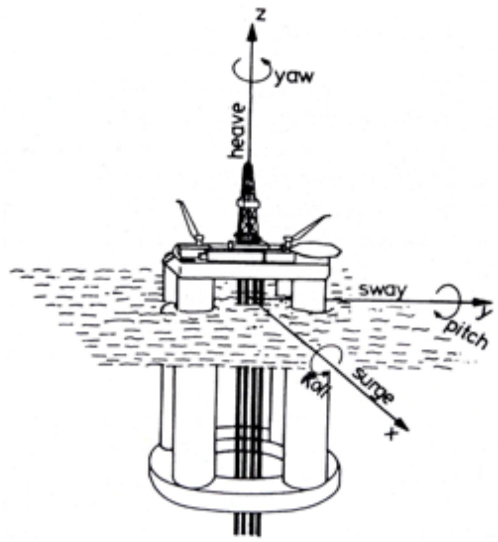


Figure 39: Rigid body motions. Source: Faltinsen, O. M. Sea Loads on Ships and Offshore Structures.

For a moored structure, surge, sway and yaw are the main motions produced by waves, current and wind. These effects cause slow drift and mean motions. Slow drift motion arises from resonance oscillations. The restoring forces are due to the mooring system and the mass forces due to the structure.

Concerning drilling operations, the professor of the Department of Marine Technology of the Norwegian Institute of Technology O.M. Faltinsen explains that heave motion is a limiting factor (p. 8, 1998). The reason is that the vertical motion of the risers has to be compensated. It is therefore important to design offshore structures with low heave motion so that it is possible to drill in when needed, at any moment, as long as possible. These loads are important design parameters for the mooring systems. One is the breaking strength of the mooring lines. The other is the flexibility of the riser system.

Regarding the hydrodynamic classification of structures, “both viscous and potential flow effects are important on determining the wave-induced motions and loads on marine structures” (O.M. Faltinsen, p.10, 1998). The wave diffraction and radiation around the offshore structure is included in the potential flow. To make mathematical calculations on structures, we use the Morison’s equation (Morison et al. 1950). This equation is used to calculate wave loads on circular cylindrical structural parts of fixed offshore structures when viscous forces matter. The equation states that the horizontal force dF on a strip of length dz of a vertical rigid circular cylinder can be written as:

$$dF = \rho \frac{\pi D^2}{4} dz C_M a_1 + \frac{\rho}{2} C_D D dz |u| u$$

Note that the application of this equation in the free-surface zone requires accurate estimates of the undisturbed velocity distribution under a wave crest.

Regarding vessels, with Dynamic Positioning, Yaw, Surge and Sway can be controlled automatically and heading exclusively by use of active thrusters. The main environmental forces are wind, current and waves. These forces are measured by different sensors: gyro compass, VRU and wind sensor. The measurements of these sensors are processed by DP-system in conjunction with the Position Reference System and the model control will give necessary propulsion. A fully operational dynamic positioning system shall reliably keep a vessel in position when working.

5.4 DP system functions.

The Dynamic Positioning system is famous for the Auto Position function, a mode that controls surge, sway and yaw, and therefore maintains the vessel in a fixed position and heading. But apart from this function, there are many other functions available. (David Bray FNI, 2008).

5.4.1 Joystick mode.

This facility enables automatic integration of propulsion units, letting the DPO use a single joystick to control position and/or heading manually. When selected the joystick mode, the DPO can select or deselect Auto-Surge, Auto-Sway and Auto-Heading. So is up to the operator to control by means of joystick one of this modes or control the vessel exclusively by the joystick.

Figure 40: Havila Aurora DP independent Joystick cJoy. Source: Author.

5.4.2 Follow-target mode.

This mode is often employed when a vessel needs to maintain position relative to a moving target rather than a geographical location, such as a ROV, a pipe laying vessel, divers or an anchor handling vessel in the case of this project.

The ROV is usually equipped with an acoustic beacon and designated as “mobile”. A geographical fixed circle (radius, defined by the DPO) is placed around the ROV and this becomes the ROV’s operational area. The ROV (with beacon) can move freely with the vessel on a fixed location. If the ROV breaks out of the circle, the DP system reacts by adjusting the vessel position by an amount equal to the radius in the appropriate direction and generating a new circle, and so on.

Another way of using this mode is when the vessel has to be positioned relative to a slow-moving target. Variations on this facility may also be referred to as “follow rig” or “follow ship”.

5.4.3 Auto-track mode.

The auto-track mode allows a vessel to track slowly along a predefined line, itself defined by waypoints. The DPO specifies how the vessel will handle a waypoint passing and any track offset. Of course, the operator can keep a fixed heading in all the waypoints.

5.5 Risks associated to DP.

Up to this point we have seen the advantages of Dynamic Positioning system, but there are some important facts to take into account while operating in DP mode.

To begin with, we always need to have in mind that thrusters on DP mode always running, so as to keep the vessel in position. This means that if we deploy something to the sea (ROV, surface buoys…) we should be aware about the position of the thrusters in the vessel. A ROV’s umbilical is susceptible to be damaged by thrusters and propellers, particularly where the ROV is launched and the umbilical fed over the ship’s side or stern.

Moreover, two DP vessels operating near each other may also generate problems. Thruster wash from one vessel may disturb the positioning of the other, which could lead to thruster-thruster interference and positional loss by one or both vessels. A nearby vessel may cause line-of-sight loss on laser or microwave-based PRS. If one vessel is using underwater acoustics, the thruster noise or aeration of the other vessel may block acoustic returns.

It is also worthy to mention that while operating in follow-target mode, the vessel is mostly under control of the ROV operator or divers, rather than the Dynamic Positioning operator.

DPO’s need to comply with UKOOA regulations. These include individual operators regarding DP to:

- What type of DP certificate?

- How many operations performed at this specific job?
- Does the officer have position reference course training?
- How many DP exercises performed in the last 12 months?
- When was the last refresher course attended?

All of these problems should be considered in the risk assessment for the task.

CHAPTER 6: OPERATIONAL PART OF ANCHOR HANDLING.

The term Anchor-Handling can include many different work tasks, and this task has changed since the first operation until these days, but traditionally, anchor handling is thought of as a rig move. A number of anchor-handlers (usually 3 or 4) are set to move an oilrig from one location to another. The rig is disconnected from its mooring lines (from 8 to 12 lines), towed to a new location and moored at that location.

6.1 Mobilization and preparation for the operation.

The job starts onshore, where all the vessels involved in the operation receive a SOW (Scope Of Work) by the marine representative. This is a document describing the entire operation and relevant facts to take into account. Nautical charts of the area where the rig is deployed or where it is going to be deployed are important to be studied in advance (lights and signals and their frequency, dangerous, restricted or special areas, nature of the seabed and more).

All the equipment that will be used in the operation will be tested in advance (winches, gypsy, shark jaws, tow pins and cranes) and checked (work wire, J-hooks, Grapnels, chaser rings, buoys…)

A.160 (ES.IV) and A.209 (VII) IMO resolutions recommend to masters and officers to have at disposal at any moment all the steering parameters of the vessel, as well as stopping distance and draft. The recommended information, as stated by IMO A.601(15) appendix 3 is: (Colección Negocio Marítimo, 2015).

1. General Description.
    - 1.1 Vessel's particulars.
    - 1.2 Main engine's particulars.
2. Vessel's particulars in deep water.
    - 2.1 Vessel's demeanor when altering course.

2.2 Turning circles in deep water.

2.3 Turning circle in case of Man Over Board

3. Stopping particulars and speed control in deep water.

3.1 Stopping capacity.

3.2 Vessel’s demeanor decelerating.

3.3 Vessel’s demeanor accelerating.

4. Manoeuvring particulars in shallow water.

4.1Turning circle in shallow water.

4.2 Squat effect.

5. Manoeuvring particulars in wind conditions.

5.1 Force and moment in wind conditions.

5.2 Limitations for maintaining heading.

5.3 Excursion caused by wind.

6. Manoeuvring particulars dead slow ahead and dead slow astern.

7. Further information.

7.1 General description.

7.2 Ship’s particulars.

Along with the SOW, each vessel with receive a loading list. This list contains all the equipment that they will need for the operation. When loading wires, chain and fiber rope, the vessel is backing towards the quay with the stern in.

There will be a briefing with all the crew members of the vessels before the job starts. It is divided into two parts: one operational briefing and one safety briefing (it could be the client or an external company or agent holding this brief). At this meeting it will be appointed one HSE vessel, weather forecast and tidal predictions for at least the next 48 hours and recent safety issues are discussed, among others. The weather limit for starting any Anchor

Handling operation is 3,5 Significant Wave Height and 30 knots wind.

In addition, it is important to have full knowledge of the offshore structure involved in the operation. Being aware about the number of lines during the operation, as all communications with rig and other ships (HSE vessel included) will relate to this numbering (as will be explain later on).

Each vessel has to make a Safe Job Analysis (SJA) for the operation. They also need to calculate stability and ballast, and prepare a watch schedule with rest hours to ensure that all crew members are well rested for the operation, as it could take several hours or even go on for days.

6.1.1 Prelay Operation

Nowadays, most anchor spreads for a rig are laid out in advance. There is a previous operation for positioning and tensioning up of anchors and anchor chain before the rig is on position. The advantage of this is that the connection of the rig later on will go very fast. But we need to be sure that all anchors are holding the load that they are supposed to hold.

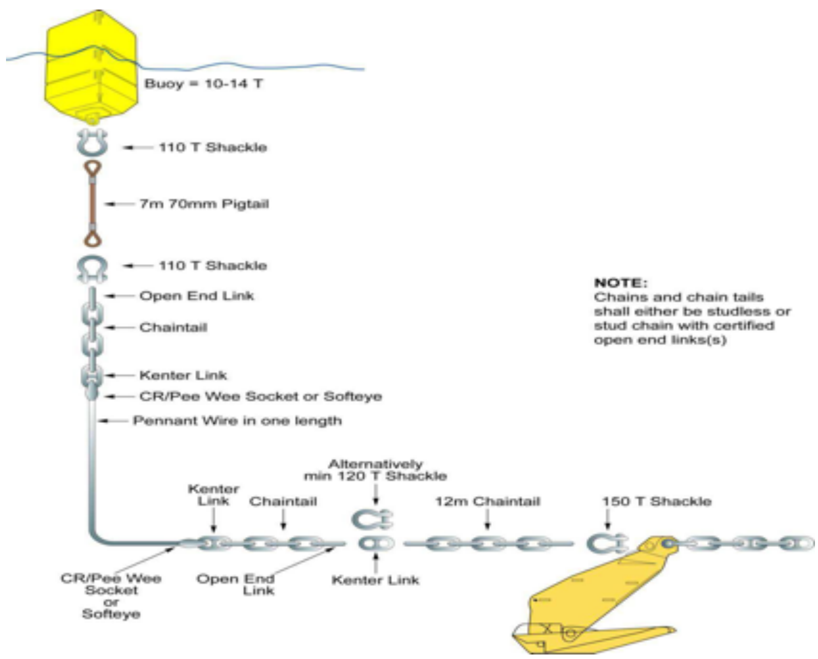


Figure 41: Pendant buoy system suitable for prelaid mooring lines. Source: NWEA Guidelines for the Safe Management of Offshore Supply and Rig Move Operations.

One prelaid mooring line consist of a ROV (for pick up), anchor bridle, an anchor, anchor or bottom chain, a marking buoy, buoy wire and a surface buoy.

To begin with, the ROV pick up system (this is a loop with a subsurface buoy connected at the end of a line that enables an ROV to hook the vessels work wire to the line on the bottom) and bridle are deployed. Special attention must be taken when deploying it overboard, as thrusters on DP are continuously operating. The bridle is connected to each of the flukes of the anchor, which is then positioned on the stern roller. The winch operator resets the counter on the gypsy and starts to lower the anchor to the bottom when the vessel is in the correct position. For positioning the vessel, Auto-Position mode in DP could be used.

When the anchor is almost on the seabed (say about 10-15m), the ROV moves in towards the anchor and monitors it while it is being set at the sea bottom. ROV operator should take special care on the vessel's heave, as the anchor can move upwards and backwards. It then verifies the position and alignment of the anchor on the bottom. The vessel is then maneuvered along the route for the mooring line while the winch operator pays out chain.

When all of the bottom chain is laid out, the work wire of the vessel is connected to the end of the chain and a certain length is paid out. The ship will then tension up the line to a certain tension according to the Scope of Work. The tension required on each line is usually different. Hopefully, the anchor will not drag; but if it does, it would probably need to be reset. After the tensioning is completed, the work wire is recovered and another wire is connected and lowered out. If the rig is in location, at the end of this wire a surface buoy is connected and deployed. The surveyor onboard will mark the position of the buoy dropping point. If the rig will not arrive at the location promptly, the vessel can lay the buoy wire down on the seabed instead of connecting a surface buoy.

After so, the vessel moves on to the next line and repeats the operation for all lines until completion of the job.

6.2 Receiving or Delivering PCP.

Before receiving or delivering the PCP, the vessels involved in the operation move in and receive the NAVPACK from the rig. A NAVPACK is a navigation system that enables surveyors on the rig to send and receive positioning data to and from each vessel. The vessels use it to view position on anchors, anchor lines, possible subsea buoys and pipe lines and own vessel position. Before using it, it has to be tested.

After receiving and testing the NAVPACK, the vessel moves in and receives the PCP (typically about 60m) from the rig. The PCP is used on semisubmersible rigs to prevent anchors from having to be buoyed off for recovery. It is secured on deck on the shark jaws and connected to the chaser ring (mentioned before) or directly in the rig chain end. The other end is lifted by the rig's crane onto the vessel. The deck crew will be standing ready with a long hook at the stern of the ship. Extreme caution must be taken, as sometimes these operations are done in bad weather and sea conditions and the vessel during this part of the operation is really close to one corner leg of the rig.

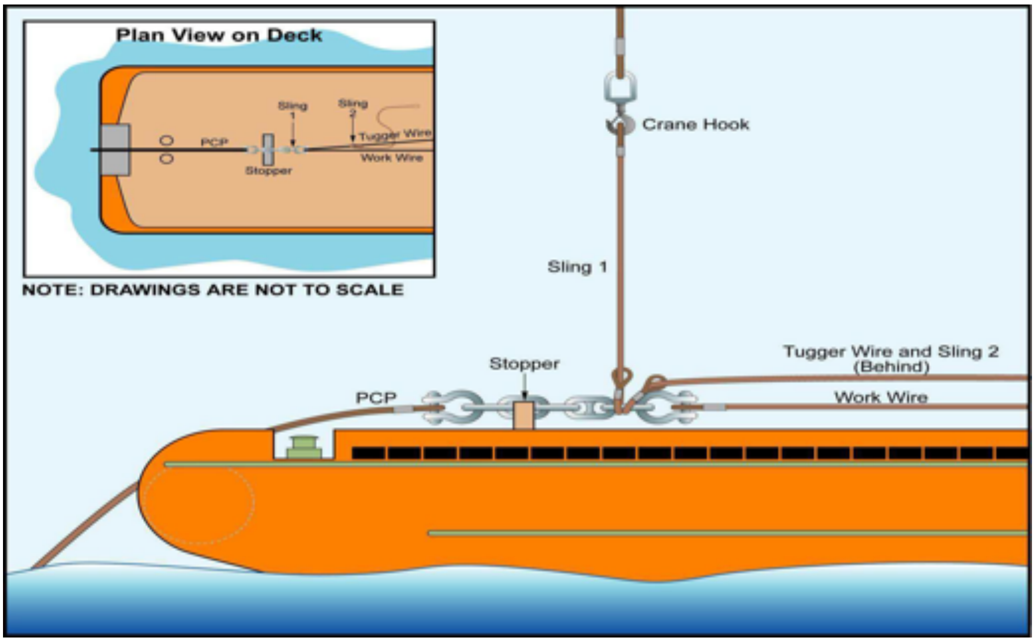


Figure 42: Connecting Chaser Pendant. Source: DNV GL.

The diagrams below apply to Permanent Chaser Pendant components. A swivel should not be used in the pendant system, only on the working wire.

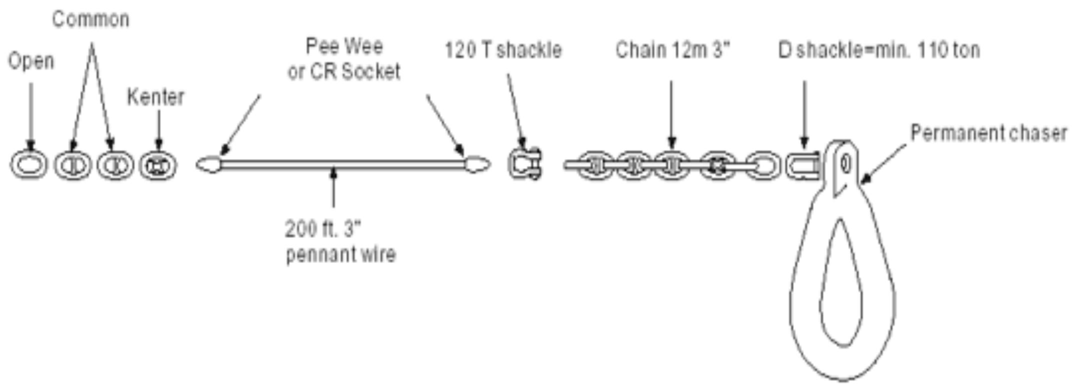


Figure 43: Permanent Chaser Pendant (I/II). Source: NWEA Guidelines for the Safe Management of Offshore Supply and Rig Move Operations.

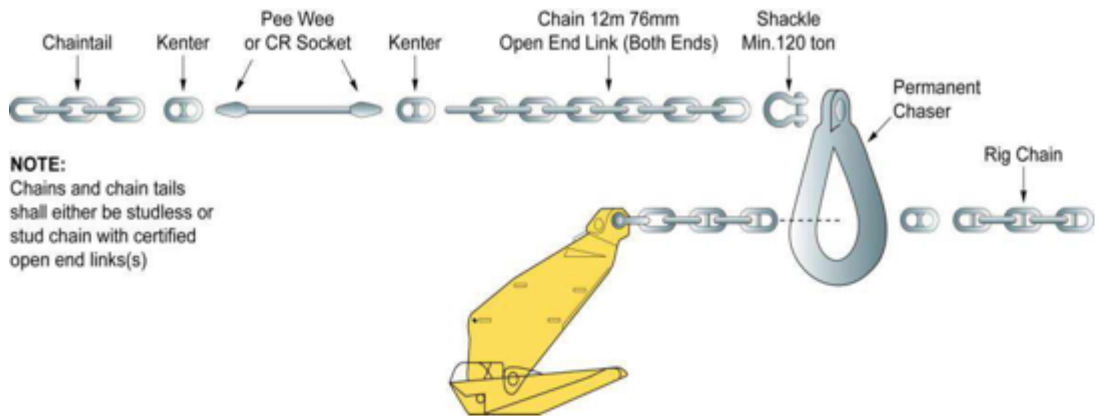


Figure 44: Permanent Chaser Pendant (II/II). Source: NWEA Guidelines for the Safe Management of Offshore Supply and Rig Move Operations.

They will then catch a small wire sling connected to the chain tail in the end of the PCP and connect it to the towing drum. After that they pull it on board and secure it in the shark jaws and towing pins.

6.3 Chasing the mooring line.

By “chasing” we understand the moment when the vessel receives the PCP from the rig, connects it to its work wire, anchor-winch driver on the rig lowers away the anchor and the vessel starts to move out the rig towards the anchor. The engineer on the ship will heave up on his winch until the anchor is very close to the stern of the ship. Once in position, the vessel's driver will align the vessel on the required heading. When the vessel has pulled the chaser ring onto the stock of the anchor they start to break the anchor off the seabed. In that moment, the rig starts to pay out chain thus reducing tension on the line.

As offshore structures can be placed in waters up to 1500 meters depth, it is normal to use fiber rope in the mooring lines. There will be some kind of stopper plate installed in the line so that the chaser ring is stopped before it is allowed to come onto the fiber. When the chaser ring is stopped in the chaser stopper, the vessel starts to heave in as it moves forward off the rig.

When the chaser ring and stopper comes on deck, one end will be pointing towards the rig and the other towards the anchor. Everything will then be secured in the tow pins and shark jaws (one end on each shark jaw) and disconnected.

When the ring is moving on the chain it can normally be felt as a rocking motion in the ship and seeing the wire leaping up and down on the deck. That is a welcomed and positive confirmation that everything is going the correct way. Suddenly the movement would cease. Then is the time to stop the vessel and to start lifting it to the surface, assuming that the ring is on the anchor.

6.4 The rig.

For offshore structures, the mooring is of vital importance for station-keeping, in order to operate. The mooring systems used can be classified into the following two main groups: spread moorings and single-point mooring.

Spread moorings consist of a combination of chain, wire or synthetic cable (rope) at strategic points on the offshore facility so it maintains station, usually on a fixed position and heading. An advantage of spread mooring system is that it is usually cheaper than turret moorings. The main spread mooring structures are semisubmersibles and spars.

6.4.1 Process of exploration, positioning and development of offshore oil fields.

Surveying is the very first stage of exploration. The first stage of exploration in areas likely to contain hydrocarbon deposits is usually a magnetic, gravimetric and seismic survey, with acquisition of data. Bottom cores are usually obtained as part of this survey. These operations are carried out by seismic ships towing a number seismic streamer cables and two acoustic sources. The in-sea hardware is spread out by a “diverter” on each side that is composed of one or more hydrofoils. Streamer cables are controlled by small hydrofoil units (typically spaced 300 m part along a streamer).

In the course of developing a field, numerous wells are drilled. Those which will not be required again are sealed with cement below the sea floor and abandoned. These are known as plugged and abandoned wells (P & A). Other wells which may be required at a later date are known as Suspended Wells. They have their wellheads capped and left with a pipe and other equipment usually projecting from 2 to 6m, but in some cases as much as 15m, above the sea floor. Wells which are in use for producing oil or gas are termed Production Wells. Their wellheads are surmounted by a complex of valves and pipes, similar to that on the suspended wells. Production wells may be protected by a 500m exclusion zone. Nowadays, several wells are drilled and tested before the rig comes to position and starts to operate. But in the past, the rig was deployed as soon as they found a suitable well. While the rig was drilling and producing, they were testing other wells near. This practice supposed a high risk.

If oil has been discovered, a supply vessel will be required to transport quantities of equipment to allow for the rate of flow of oil to be tested. This process consist in recovering well fluids (crude oil) by flowing the well for a couple of hours through the equipment, checking its volume and form. Once this is done, the well can be capped and the rig is ready to move on. (Victor Gibson, p. 14, 2008). If the hole turns out to be dry it is plugged with cement, as explained before (plugged and abandoned wells, P & A). After doing so, anchor-handlers are recalled and the anchors recovered, and the rig towed away to another location.

Then, an exploration rig is towed and positioned into the precise position defined by the geologists. It will then be sunk to the seabed in different ways, depending on the type of rig and water depth. It may be jacked up on its legs, or anchored by the use of anchor-handlers. Nowadays several rigs maintain station with the dynamic positioning system, as explained in the earlier chapter.

Once on the location, the rig will “spud in”. This is the time when the drill bit rotates and excavates the first few meters of the hole. This is the very first stage in the drilling programme. The speed with which drilling takes place depends on the water depth and the hardness of the strata being penetrated. That is why the exploration of a field may be measured in years in some cases. (Victor Gibson, p.11, 2008).

The initial phase of a drilling operation requires the rig to extend a 91,44cm (36”) drill bit on the end of the drill string to the seabed. This is the cutting tool on the end of the drill string.

The rig then goes through one of its more onerous processes: the installation of the blow-out preventer (BOP). This is a collection of rams and valves which can be closed to ensure that control is maintained over the well being drilled. Not less important is the riser: a large diameter pipe which connects the drilling rig with the well. It does also provides means of returning the mud to the surface. (Victor Gibson, p.11, 2008).

The main part on a drilling rig is the derrick. At this point in the operation the end is lowered through a hole in the center of the drill floor until it can be connected to the top of the BOP. Once it is connected to the first joint of riser, the whole lot is lowered away until the top of the joint can be held in place while the second joint is heaved into the derrick and connected to the top of the first joint. Finally, the BOP will be positioned above the wellhead connector and can be lowered into place. Once in position, the hydraulic connectors are activated and the rig is connected to the seabed. (Victor Gibson, p.11, 2008).

When the riser is in place the drilling cycle proper starts. As the drill bit rotates, oil-based mud is pumped down the center of the drill string and allowed to flow back up to the outside (carrying with it the debris and providing a hydrostatic head). By the year 2000 pseudo oil-based mud was being used. Chemicals are added to water to raise the viscosity. Apart from providing good lubrication, this new compound does not react with any of the substrata (as water-based mud sometimes does). The only disadvantage of pseudo oil-based mud is that more expensive than traditional oil-based mud. (Victor Gibson, p.13, 2008).

Once the company has decided that the field will be productive, construction of a platform takes place. The base unit is known as the jacket. It is a steel structure or base of the platform which is floated out, and on which the production and accommodation units are situated. It is towed out to the location, and once there, it is set upright and pinned to the seabed. Thereafter the modules are shipped out on barges and lifted into place with a heavy lift crane. In the past, the different modules of the platform were towed by barges. But nowadays, the most challenging way of transport a platform is by Heavy Lift Vessels (HLV). This type of vessel can carry platforms up to 50 or 60 thousand tones. The main reasons for using HL instead of barges are:

- HL vessels have better stability than barges.
- Embarking and positioning of offshore structures on HL is easier than in barges.
- HL vessels are faster than barges, as these vessels are designed for those tasks and to work on the offshore space.
- The risks associated to HL vessels are less than the ones using barg-es and tugs together.
- Insurances are cheaper than barges, as risks are smaller.

From the moment when it has been decided that a field or well will be developed, a race against time begins. It becomes essential that the field will be brought on stream as soon as possible, as a great amount of money is invested in the platform structure. (Victor Gibson, p. 18, 2008).

During the drilling phase the rig must be supplied with the commodities needed for the job, which include casing, mud, chemicals, cement, fuel drill water, potable water and food for the crew. (Victor Gibson, p. 13, 2008). In the past times the operation was made more complex by the fact that the semi-submersibles had difficulty moving from operating to transit draft and back again without discharging most of the top weight, so the assigned offshore vessels would load up with the rig's riser and drill pipe and transport it all to the shore, then dash back again to carry out the move. Once the rig had arrived at its new location and had been anchored up safely, the ships would then bring all the equipment and necessary materials and goods out again. By the mid 1990's virtually all semi-submersibles had been upgraded in order to be enable to carry a greater load on deck (variable deck load) as it is known, and so this particular phase of the operation became unnecessary. Most importantly, the marine riser, the length of tube connecting the wellhead to the rig, could remain on board the rig.

From each wellhead, oil or gas is carried out in pipes, known as flowlines, to a production platform were primary processing, compression and pumping is carried out. The oil or gas is then transported through pipelines to a nearby storage tank, tanker loading buoy or floating terminal, or direct to a tank farm ashore in shallow waters. One production platform may collect the oil or gas from several drilling platforms, and may supply a number of tanker loading buoys or storage units. Such production platforms are sometimes termed field terminal platforms.

6.4.2 Semi-submersibles

When oil wells where discovered in deep water, new drill rigs and platforms were necessary. The development of Semi-submersible rigs came in 1960's. The first semi-submersible made its name in 1961. In the beginning, these structures were used for drilling purposes, but since the early 80's, these have also been used as production platforms. This offshore structure is a

Mobile Offshore Drilling Unit (MODU). It is a free-floating column-stabilized watercraft consisting of: main deck (Topside Deck Structure) on top of the columns connected to the underwater hull or footings by columns or caissons, in order to avoid much of the effects of sea and swell. Drilling equipment, mud systems, living quarters, helideck, crane flare boom and so on are placed on the main deck. Ballast tanks, thrusters, sea water pumps, among others are arranged in the underwater hulls. Semi-submersibles may also be equipped with oil and gas separation and treatment plants, pumpline stations and electricity generators. (Jan Babicz, p.29&30, 2016).

Figure 45: Semi-submersible offshore rig. Source: Maersk.

Station-keeping of semisubmersibles is usually achieved by chain -or wire-spread mooring. The advantage of using a mooring system is that it ceases to be totally dependent on the rig. The technique used is to lay a set of moorings (suing either a patent from a drag embedment anchor or else suction anchors) and then disconnect the rig from its current set of moorings and move it to the new position and connect it up to the new set of moorings. The advantage of suction anchors is that they are deployed really easy. But, on the other hand, it depends on the hardness of the strata being penetrated. In the Gulf of Mexico for instance would be correct, but not for the North Sea, as it presents a hard strata.

Modern Semi-submergible drilling units are equipped with Dynamic Positioning systems with several computer-controlled thrusters that respond to the unit displacement or accelerations; combining both mooring systems. These do not usually have oil or gas storage capacity. The weight of columns is high and without sufficient buoyancy in themselves. These type of structures have two submerged horizontal tubes called pontoons (lower hull or footings) provided at the bottom of the columns for additional buoyancy and also act as a type of catamaran hull when in transit to or from a site at low draft. The most common arrangement are either twin pontoons or a ring (continuous). In contrast, a rig pontoon may be used for such units meant solely for one fixed location. Semi-submersibles are designed in a special way, in order to minimize the risk of large heave motions by designing a low natural frequency in heave (that is, a small water plane area compared with the volume displacement). Concerning their distribution, platforms may stand singly or in groups connected by pipelines to each other.

Horizontal motions are another factor of importance. As a rule of thumb, the upper end of the drill string may not move more to one side of the center of the drill than approximately 5% of the water depth.

They may have a displacement up to 55000 tonnes when operating, and are used for drilling in depths to about 1700m in the anchored mode, or in the case of dynamically positioned rigs, in excess of 1700m.

The advantages of semisubmersibles are that can achieve good (small) motion response, with a restoring force due to sea, wind and currents loads bigger than 20 seconds. (O.M.Faltinsen 1998). This kind of drilling units can work in rough sea conditions. Generally, semi-submersible have the least vertical motions and hence the highest workability. In order to enhance further the workability, the vertical motions of the structure at the location of the drill string are compensated for by a so-called heave compensator. One normally wants to have the heave period above 20 seconds so that there is seldom any wave energy to excite resonant heave oscillations Therefore, can be easily positioned over a well template for drilling. Also the unit allows for a large number of flexible risers because there is not weather vanning system.

What is more, semi-submersibles are easy to transport from one location to another.

The disadvantages of semisubmersibles are that pipeline infrastructure or other means are required to export produced oil. Moreover, only a limited number of rigid risers can be supported (because of the bulk of the tensioning systems required). Most semisubmersible production units are converted from drilling rigs; this means that the topsides weight capacity is usually limited.

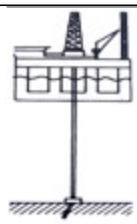
Semi-submersible	
Heave period	>20 s
Restoring force	Waterplane area
Dominating excitation mechanism around the heave period	Swell (long waves)
Important damping	Viscous effects

Table 7: Resonant heave oscillations on Semi-submersibles. Source: Faltinsen, O. M. (1990). Sea Loads on Ships and Offshore Structures.

A typical rig is anchored up with 8 mooring lines. It is then numbered from 1 to 8, being the number 1 the starboard side of the rig's bow and counting clockwise. Number 8 will be located on the port bow. Of those eight lines, four of them are main mooring lines and four are named breast anchors.

In a rig move operation, the four main anchors are the last to be disconnected and the first ones to be connected up at the new location. The main anchors will be numbered 1 and 8 at the bow, and 4 and 5 at the stern.

The rig chain comes over the gypsy or winch on the rig, follows the leg down and into a fairlead. The fairlead is a guide wheel located on the rig's leg. After the fairlead the chain goes out toward the anchor. Below the fairlead there are bolsters for each anchor line.

6.5 Catching and deploying the buoy.

A lasso is used for catching the buoy. The lasso is basically a wire connected at both ends to the end of the work wire. The ship backs up against the floating surface buoy and the deck crew throws a lasso over it. After this, the buoy is heaved in on deck over the stern roller using the towing winch. After so, the deck crew members pull the pelican hook across under the buoy pennant and close it up. With the pelican hook latched over the first pennant, the winch operator slacked back on the work-drum and allow the pelican hook on the end of its wire to take the weight. Finally, the deck crew members step forward with wrenches, hammers and marlin spikes to disconnect the buoy. Sometimes they need to use very large wrenches and even oxy-acetylene cutting gear (gas axe) as the threads on the shackles can be damaged. (Victor Gibson, p.96, 2008).

Figure 46: Deck crew member with a wrench disconnecting the thread in a shackle.

For releasing surface buoys, they can be either lowered into the water using a towing winch as well or they can be dropped using the quick release function on the shark jaw. This second option is faster, but increases the risk of damaging the buoys and equipment on deck, and even more the security of deck crew. So lowering them down is the preferred way to do it if possible.

6.6 Decking the anchor.

It is important that the anchor comes up with the flukes pointing upwards. Otherwise, it could damage the wooden deck of the vessel. All the deck crew to be in a safe location when the anchor comes over the stern roller. If the anchor is covered in clay, mud or else it might be necessary to clean it before it is decked.

6.7 Breaking loose an anchor.

When an anchor has penetrated the seabed there are a few things to take into consideration. The length of the line must be adjusted according to the water depth. A wire and chain length of 1.2 to 1.5 times the water depth is normal. The anchor is never to be pulled off the seabed by brute force, but it needs to be worked with for a period of time (or as we state in Spanish "más vale maña que fuerza"). We should never use more than 150 tons when breaking loose and anchor. This operations can take hours to break loose an anchor that has penetrated deep into soil, but sometimes it breaks loose immediately as well. The vessel can choose to vary the wire length out to change the angle of attack on the anchor.

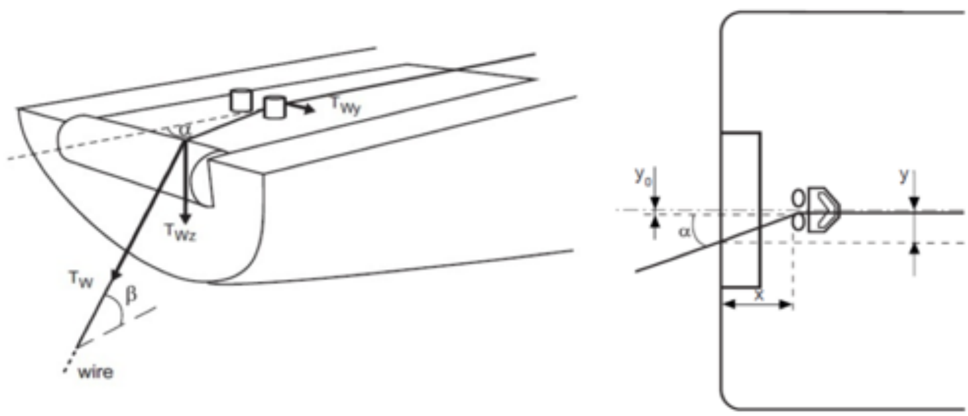


Figure 47: Wire tension and position of wire. Source: Bureau Veritas.

If the vessel is operating close to the rig and connected to it with a short length of wire between them, the wire could suddenly become tight. A strong force will be inducted and high torque will be necessary. The temperature of the towing winch engine will increase and the fuel consumption as well. It would be important that the winch payed out wire automatically to avoid the wire from snapping.

6.8 Winch operator in Anchor Handling operations.

The bridge is managed by at least two people during Anchor Handling: one winch operator and one person maneuvering the vessel. It is usually the second officer that is the winch operator during the operation. The captain or chief officer is responsible for the operation and maneuvers the vessel.

In the past, winches were operated on the front of the aft deck, near the Anchor Handling and towing winches. This was dangerous, as the line could break if too much strength was paid. On modern vessels the winches are controlled by joysticks installed in the winch chair in the bridge. Pumps and controls for the winches are operated via touch panels. The second officer also controls the shark jaws, towing pins and centering devices. There are screens monitoring the aft deck and winches as well.

The winch operator has a main focus on the work on deck and communicates via UHF (or VHF in low range) to the deck crew. Modern vessels are equipped with speakers in deck connected to the bridge. This means that he or she has to be updated to the situation, thinks ahead and is prepared for the next step of the operation.

If the operation takes place in deep waters and large and heavy lines are deployed, there are very high forces on equipment. Thus, it is important to keep extra focus on the tension controller on the winches. The operator can adjust how “strong” the winches are.

Another winch operator task is to take notes of times for different parts of the operation. He or she might also have to write down identification numbers of all equipment being installed or removed in or from the mooring lines. However, it is common to use dedicated personnel for writing down id’s on equipment. These dedicated people are external people from the equipment supplier companies and not part of the normal marine crew. This task may also be taken by deck crew members.

6.9 Disconnection of a mooring line during a rig move operation.

As mentioned before, after receiving the NAVPACK from the rig, the vessel moves in and receives the PCP from the rig. The PCP is secured on deck with the tow pins and shark jaws and connected to the ships work wire. The vessel then pulls the chaser ring out of the rig, chasing out towards the chaser stopper. Length of work wire is adjusted according to water depth and mooring line length.

When the chaser ring is stopped on the chaser stopper (before it gets to the stock of the anchor), the rig starts to pay out chain thus reducing tension on the line. The vessel starts to recover the work wire and PCP until the chaser ring and stopper are secured on deck. Then, the ring and stopper are disconnected and removed.

At this moment, the vessel has two ends on deck: one end towards the rig and one end towards the anchor.

The work wire is now connected to the end going out the anchor and paying out wire while the vessel moves back in towards the rig. The rig operators connect the 60m PCP to the rig chain. When the vessel has moved all the way back to the rig the crane comes down and picks up the PCP. The vessel is now only connected to the line going out to the anchor. The work wire is recovered first and then the fiber rope that is in the line. The work wire may be stored in a separate compartment and fiber rope will most likely be stored on the secondary winch.

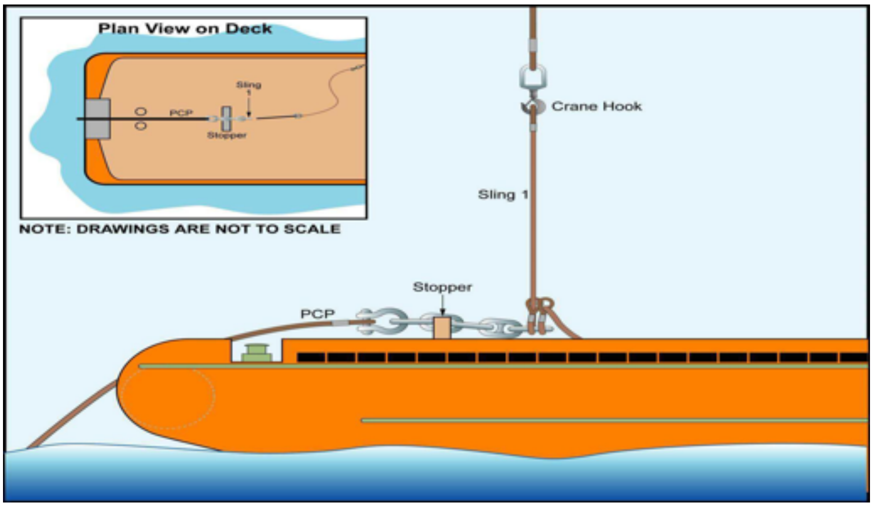


Figure 48: Releasing Chaser Pendant. Source: DNV GL.

When all fiber rope is recovered on boards and the bottom chain is secured on deck, a buoy wire is connected to the chain and paid out. At the end of the buoy wire a surface buoy is connected and deployed.

That completes the disconnection of one line and the vessel moves on to take the next line, beginning with receiving the next PCP and repeats the operation for the rest of the lines until the job is completed.

CHAPTER 7: RISKS INVOLVED DURING ANCHOR HANDLING OPERATIONS.

As said in the very beginning, anchor handling means dealing with heavy equipment in rough seas, a hostile environment. What is more, these operations can be carried out at night, making the job more dangerous. But as Victor Gibson says “sometimes there is no choice”. (2007, p.86).

Wire used in the operations can have twist and it tends to spring back, causing the wire to rotate at high speeds and with great force when on deck in tension. In addition to the dangers of rotating wire sockets on deck, tools have been known to come flying about and hitting crew members. In modern anchor-handlers there are wire clamps and other aids to reduce these risks.

When recovering chain through the gypsy, vibrations and rush smoke are generated. If crew members are working near the gypsy, they not only can breathe this smoke, but the rush can also enter in the eyes. It is of vital importance to wear the Individual Protection Equipments (IPE) such as glases, masks and son on.

Hands and fingers are especially exposed during operations and there are countless blue nails out there. In the worst cases, severed limbs.

Figure 49: A crew member being slapped by a loading hose in tension. Source: https://youtu.be/nw0gwqSBSKU

Another important factor is to focus on correct operation of winches, towing pins and shark jaws. Pushing the wrong button in the wrong moment can cause the shark jaw to lower instead of a towing pin resulting in unintended release of a mooring line.

High forces on deck are present, tuggers in operation, snapping tuggerwires, always stand on the “correct side of the loop”. It is totally forbidden to jump over a wire in tension.

During operations (especially in bad weather conditions) the deck is wet and mixed with clay. In addition, the masters of anchor-handlers often kept them heavily ballasted by the stern to make it easier to get the anchors on board. This practice makes the deck and equipment even more slippery and hard to work with.

Figure 50: Anchor Handling operation held in bad weather conditions. Source: https://youtu.be/nw0gwqSBSKU

In the picture above, an Anchor-Handling operation is being carried out in severe sea state conditions. The crew member at the very aft on deck is about to be hit by the effect of breaking waves. Luckily, no further injuries were occasioned on him.

When connecting kenterlinks, a piece of lead is used to secure the bolt. This piece of lead is pounded into the kenterlink with the use of a sledge hammer. Pieces of this lead will come flying many meters at high speeds and with great force. It is important to turn the other way to avoid hitting yourself.

When an anchor is buoyed off, the next job is to get the floating surface buoy onto the deck. To do so, the work wire (or even better the tow wire) is pulled down the deck and a long pennant shackled by its ends to it. This it is called the lasso. Two crew members stand, one either side of the roller holding the sides of the lasso, waiting, while the officer at the controls or the Dynamic Positioning operator backs up to the buoy. The risk on this operation is that if too much back up power is used, the vessel will overrun the buoy (with a possibility of damaging the buoy or the vessel thrusters). Luckily, if the buoy has not sink, the vessel has to move forward again. As it moves forward, the wash from the screws can drive the buoy away and the whole process has to be started again.

It is of vital importance to deck the anchor with the flukes pointing upwards. If luck is out and flukes are pointing downwards, as the winch operator heaves in the anchor on deck, the anchor's flukes will damage the wooden deck of the vessel, making it close to impossible to keep on further operations if the deck is not repaired.

Disasters, Losses and Incidents in the Offshore Environment.	
December 28th 1965	Sea Gem sinks.
1966	Two jack-ups sunk in the gulf of Mexico.
March 1968	Ocean Prince submersible lost when drilling on Dover Bank.
November 15th 1968	Gas blow-out on Hewett A and loss of offshore support vessel Hector Gannet.
April 15th 1976	Sinking of the Ocean Express jack-up.
1980	Alexander Keilland disaster.
1982	Loss of the Ocean Ranger.
July 6th1988	Piper Alpha disaster.
December 24th 1990	Loss of the Vulcan Service.
1995	Brent Spar incident.
October 19th 2003	Loss of anchor handling tug Stevns Power.
April 12th 2007	Loss of Bourbon Dolphin.

Table 8: Remarkable Disasters, Losses and Incidents in the Offshore Environment. Source: Gibson, V. Ships and Oil. The History of the Supply Ship.

CHAPTER 8: SAFETY IMPROVEMENT PROPOSALS FOR ANCHOR HANDLING OPERATIONS.

One would think that nowadays the offshore industry might have identified most of the threats to the safe operation of vessels servicing it, but as victor Gibson says, this proved not to be the case. (Victor Gibson 2008).

8.1 Planning up the operations

The operations carried out on board an AHTS vessel still involve many dangerous work situations. Luckily less than it used to be, but there are still some dangerous situations while in operations. These tasks demand strong focus on safety before and during operations. The success of any operation is entirely dependent upon the quality of the planning and contingency. At each stage of the operation there should be at least one escape route available to the vessel. Along the SOW (Scope Of Work) and the SJA (Safe Job Analysis), a Risk Assessment Document (RAD) is prepared by the operator and the oil company. The planning is based on experiences of what could occur or previously in other operations have occurred. This is a generic document, which is in continuous updating during the preparation period and during operations, in accordance with the incidents occurring. (David Bray FNI, 2008).

Proposals:

- Appropriate trim before starting the operation, in accordance with the loading list. If the operation requires unloading any goods for the rig, preparing an estimated trim for trim and stability conditions after un-loading. Also, if the operation is going to take a long time, master and chief officer should be aware that a great fuel consumption will alter trim.
- Hatches and watertight doors to be closed during operations.
- Pay special attention to checklists: pre DP operational checklist, rud-ders, navigation equipment and winches. Also, pay special attention

on visual checks of deck equipment for the operation (anchors, buoys, fiber and chain lines…).

- In the Safety Management System should appear all tasks that are being to be carried out and of course pay special attention to them.
- Any questions or doubts should be cleared before the job starts. It is better to find deficiencies or possible Proposals for the security of the operation onshore before the operation starts rather than while in operations.

8.2 Crew training

By 1991 five drafts had already been produced of a new code: “Code for the Assessment of Suitability of Standby Vessels for Attending Offshore Installations”. This new code required to all standby vessels to have at least two sources of motive power. This also meant crews to be more highly trained as well. (Victor Gibson 2008).

A basic principle of anchor-handling operations (and generally offshore operations) is that the master or DPO never takes a vessel into a situation from which she cannot be extricated under degraded status (that is, the situation after worst-case failure, often the loss of half the power and thruster capability). The vessel should never be taken into locations until they have planned their escape route. Indeed, the escape route must be kept clear at all times. (David Bray FNI, 2008).

Proposal:

- Well-training of the crew for operations. This also englobes regular exercises.

8.3 Decking anchors safely

When it comes to decking the anchor, as said before, the winch operator has to pay special focus on the anchor’s flukes. If the flukes are pointing upwards it is correct, but it flukes are pointing downwards, the flukes might tear up the wooden deck. A possible solution for avoiding damages on deck is to use an alternative material instead of wood. It can be replaced and carried out a modification in the form of a steel plate welded over the wood apron the width of the stern roller extending about a third of the length of the deck. All things considered, containers, anchors and even crew members would slide about dangerously on the steel, slippery when wet. Then, it is up to the shipyards to choose the lesser of two evils for the configuration of the deck.

It is essential to have clear visibility of the deck from the bridge at any moment, with a view to alert of any dangerous situation happening or bound to happen, and to lower risk for personnel injury. As said before, even though triplex MDH very often reduce the view from the bridge and down on deck, it removes the most dangerous working tasks on board. So whenever using it, I strongly recommend to active the CCTV system, so any risk can be spotted on time.

Proposals:

- Extra security measures to be taken when operating at night (illuminate the whole deck).
- Deck crew to use safety harnesses attached to lifelines while working on deck, especially when operations are carried out in harsh weather.

8.4 Comply with regulations

Regarding regulations, it is important to design offshore vessel with double skinned hulls, in order to prevent further disaster when a vessel hits accidentally an offshore structure or another vessel operating in the vicinity.

For the past 15 years offshore vessel owners have been obliged to man the vessels following some minimum criteria given by surveyors.

- How many years' experience onboard offshore vessels?
- How many years' experience on this type of offshore vessel?
- How many years as officer?
- How many years in current position?

- How many years in the company?

8.5 Preventive maintenance

Down in the engine room, it is of vital importance making a Preventive Maintenance plan, based on ours maintenance predictions. By doing so, cracked sleeves and damaged cables for instance, can be detected in time.

Proposal:

- Keep the deck clean, especially the engine room and bilges, so if there is any leak it can be spotted on time.

8.6 Avoiding contact with structures

As these vessel carry out their tasks in the vicinity of offshore structures, the risk of making contact with any leg or part of the rig and thereby damaging both the structure and the vessel is high. Of course, as Victor Gibson says: “modern designs of supply vessel having no part of their hull which is not double skinned”. (p.125, 2008). All things considered, I strongly recommend DP Class 2 for these operations. With this Class notation, the system has redundancy, so in the case of a failure the vessel can stop the operation and move to a safe location.

Proposal:

- Double skinned hulls vessels.

8.7 Officers specialization

All deck officers have to have to attend ship handling simulator courses, including DP training, reviewing incidents and learning from reported unwanted events. As a supplement, some companies have implemented onboard training systems. The officers are required to do DP exercises at regular intervals. Training is done by using the vessels equipment as it is during normal operation. In addition current weather forces are applied, so

DP is very realistic. Those exercises can be performed in open waters. However, some of the exercises require the vessel to be on the location offshore. (Odd R. Grinde – Arve H. Kvilhaug 2016).

It is not only to talk about safety of Anchor-Handlers, but also of the structures which they work with. Although the safety measure on these vessels has increased with time, it is proved not to be the case for Jack-ups and Semi-submersibles. In order to reach the standards of safety, both the vessel and the offshore structure have to ensure that they comply with safety standards.

8.8 Recovery speed

Based on my experience in the DP Induction course and anchor handling operation simulator, the recovery speed of the moorings is never to be high. If the vessel is recovering line and moving forward towards the anchor, little speed forward should be applied. If the speed is high, towing winch engine will overheat and could turn into problems. In the case of recovering line in auto position mode with DP system (that is, in a fixed position) in an old AHTS vessel or with little pull and break load, the vessel could travel astern.

Proposal:

- Speed of recovery of the mooring to be moderate: neither too slow, nor too fast. If the operation is not in a hurry, it is much better to avoid doing the tasks quickly. It is much better doing things safely than rapidly.

CHAPTER 9: CONCLUSIONS.

1.- Anchor Handling operations have improved quite a lot in terms of safety since the first operation took place, but there is still work to do in order to reach full safety standards.

2.- Being prepared for those operations and familiarization takes a long time. The best training is gathered while serving in the offshore space during operations. The knowledge of the operations can be almost achieved in training and induction courses, but the true experience comes only with onboard experience.

3.- For almost each accident there is loss of life, due to the fact that the human factor (that is, the crew) is exposed to potential risks during operations. That is why I strongly recommend to follow step by step the safety measures and checklists before and during the operations. As I said before, a good measure to avoid man overboard and therefore injuries is that deck crew has to use safety harnesses attached to lifelines.

4.- In order to improve safety in offshore operations, urgency is to be avoided while the tasks are being carried out. What is more, a great consideration on weather conditions has to be applied as well before and during the operations and finally, constant training and exercises are required for safety of the team involved in the operation. This involves not only the crew in the vessel, but also the ones in the offshore structure or ashore at the office.

5.- Taking into consideration the safety Proposals detailed in the earlier chapter and these conclusions, anchor handling operations (and generally offshore operations) will become safer, with less incidents and accidents, so therefore there will not be neither injuries nor loss of life.

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ANEXO II: Aviso responsabilidad UC

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