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Design and Operation of Anchor Handling Tug Supply Vessels (AHTS)

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Beijing, April 2013

Wenming Chen

陈文明

Abstract

The deep water oilfield market is becoming more important as the conventional oilfield market in shallow water cannot meet the energy requirements from the consuming market. The Offshore Support Vessels (hereafter it is called OSVs) market is becoming booming and the demand for OSVs has never reached the extent like today in previous periods.

Anchor handling tug supply vessel, hereafter it is called AHTS, is one of the main type of OSVs and can carry out several major operations like towing, anchor handling, supply, standby and so on offshore. This thesis will describe the market demand for AHTS, the influence of AHTS design and fabrication on operation, the introduction of the anchor system of offshore installations and anchor handling operations conducted by AHTS in deepwater. The anchor handling procedures will be discussed in details which is limited to experience requirements in some sense.

Risk analysis is directly important to the success of AHTS' operations offshore and a risk analysis is carried out for company owned vessels and rented vessels and it will refer to the technology, the procedures and the management involvement during the operation of AHTS. Several methods of risk analysis will also be mentioned in the thesis. After that, a case study about Bourbon Dolphin is discussed and the causes of the accident are illustrated combined with risk analysis. Anchor handling operations and other operations of AHTS are influenced by many criteria and any negligence may cause the failure of AHTS' operation or delay normal operation procedures.

The main objective of this thesis is to improve people's understanding of AHTS, and initiate people's interest in exploring the future development of AHTS. When considering the development of OSV or AHTS, emphasis should be put on the cultivation of HSE culture which is widely employed in the global offshore market.

Abstract in Chinese

由于传统的浅水油田市场不能满足消费市场的需求，深水油田市场变得越来越重要。油田支持船（以下简称 OSV）市场正日益变得火爆，而且市场对 OSV 的需求达到了一个历史上的新高度。

三用工作船（以下简称 AHTS）是油田支持船中一个主要的船型，她能提供的多种大型海上作业，譬如拖带、起抛锚、供应、守护等等。本论文将描述市场对 AHTS 的需求，以及 AHTS 的设计、建造对她的运作的影响。本论文还将介绍海上装置的锚泊系统和深水起抛锚作业。起抛锚过程在某种程度上受限于员工的工作经验，其具体操作细节将在本文中介绍。

风险分析与 AHTS 在海上作业的成功进行有着直接的联系。风险分析将从公司自有船和租赁船的角度对技术、AHTS 作业时面临的程序、管理等方面进行。随后关于“Bourbon Dolphin”的案例分析将结合风险分析对事故的原因和后果进行讨论。三用工作船的起抛锚和其他海上作业受到很多因素的影响，任何一个疏忽可能会导致其作业的失败或延误其正常的作业。

本论文的主要目的是提高人们对三用工作船的理解，并激发人们对探索三用工作船未来发展方向的兴趣。当考虑海上支持船或三用工作船的发展的时候，当今全球海上油田市场普遍流行的 HSE 文化也应当受到足够的重视。

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Abbreviations

ABS	American Bureau of Shipping
AHTS	Anchor Handling Tug Supply Vessel
BHP	Brake Horse Power
CAPEX	Capital Expenditure
DP	Dynamic Positioning
GoM	Gulf of Mexico
IACS	International Association of Classification Societies Ltd.
IMO	International Maritime Organization
LMS	Lateral Mooring System
MOU	Mobile Offshore Unit
OIM	Offshore Installation Manager
PCP	Permanent Chaser Pendant
PD Semi	Production Drilling Semisubmersible platform
RL	Reference Load
SMS	Safety Management System
TLP	Tension Leg Platform

Chapter 1 Brief introduction to AHTS

As the oil and gas exploration and production activities becomes more sophisticated and more deep water drilling activities are conducted through the world, there is a strong demand for Anchor Handling Tug Supply vessel (AHTS). The latest generation AHTS can meet the demands from modern oilfield activities and adhere to local and international requirements in terms of HSE policies.

1.1 A brief introduction of oilfield market and the demand for new generation AHTS

1.1.1 A brief introduction of oilfield market

Nowadays hydrocarbon energy plays an important role in people’s life and the reliance on oil and gas has never achieve the extent like today before. In order to ensure the energy supply for people’s daily life and industry demands, people put more attention to deep-water market where huge market exists and keep the conventional oil and gas operation on shallow water at the meanwhile.

According to GBI research in 2010, the global oil and gas field services market has witnessed considerable growth in recent years due to an increase in the Exploration and Production (E&P) activity and growth in the activity in the offshore areas of the world (GBI Research, 2010). The growth of oil field market is driven by the high prices of crude oil and natural gas and high demand of crude oil and gas. The increasing demand of oil and gas is resulted from the high economic growth during the period from 2004 to 2008. The demand for oil and gas and prevalent high prices stimulate increasing activities in the offshore market. It was estimated that about $140 billion in 2008 will be created in the global oil field services market according to GBI research. However, the economy started to go down and the Financial Crisis happened in the middle of 2008. The offshore drilling expenditure is directly dependent on the exploration and production capital spending of the international oil companies and producers. The tight credit situation and uncertain outlook for the oil and gas market have affected the capital expenditure plan of the exploration and production companies. These factors have had a negative effect on the offshore drilling market in 2009.

However, with increased E&P activity and increased demand for oil and gas after 2009, the global oilfield market is expected to increase in the future growing to about $200 billion by the end of the forecast period in 2015, as Figure 1.1 (GBI Research, 2010).

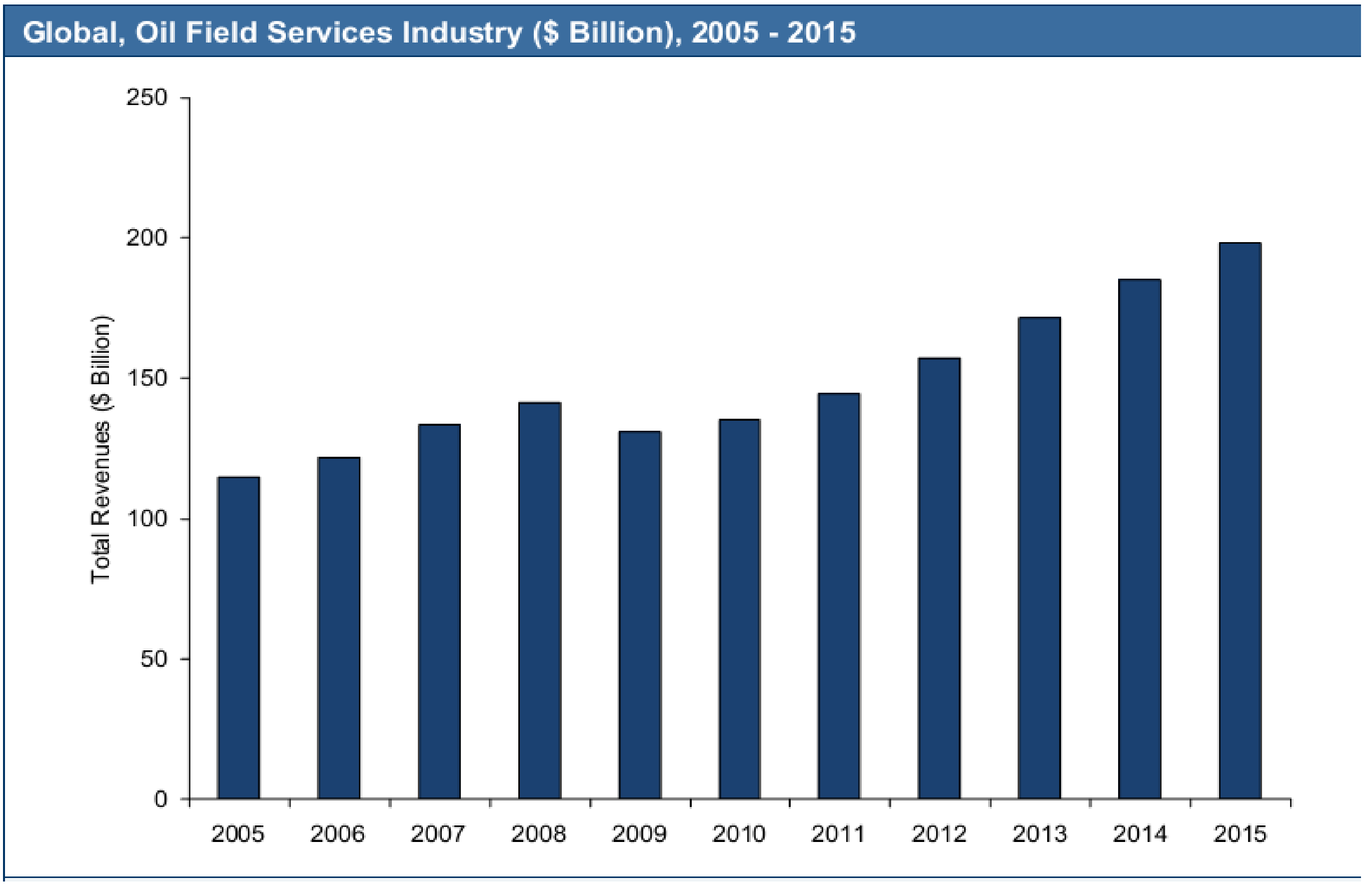

Figure 1.1 Global Oil Field Services Industry ($ Billion), 2005 – 2015 (Source: GBI Research, 2010)

Massive investment from oil companies will put into oilfield market due to strong demand of oil and gas and potential increasing space of the price of crude oil and natural gas. A number of international oilfield services companies like Schlumberger, Haliburton, and Weatherford seek the opportunities and enlarge their investment on global oilfield market.

According to research of Wikinvest (2011), many rig contractors build their own machines, oil rigs are far too complex for one company to develop every single part required for them to work effectively. Rig contractors spend more expenditure on upgrading their equipment than only building new ship. Oil and gas are extracted out of the ground quickly and efficiently. Once oil and natural gas have been extracted, they are transported from the rigs to refineries, and then from refineries to distribution centers. The transportation activities on offshore is conducted by supersized tankers operated by a number of maritime transportation companies or through pipes which are laid under sea ground.

1.1.2 A brief introduction of OSVs and AHTS

As the oil and gas exploring and production activities becomes more sophisticated and more deep water drilling activities are conducted through the world, there is a strong demand for different types of OSVs. Before coming to the importance and strong demand for OSVs, we will look into what are OSV and AHTS vessels.

1.1.2.1 What is an OSV?

In the oilfield of North Sea or many other areas in the world, a kind of special vessel is busy with various tasks which are relative to exploration and operation of oil and gas on offshore. This ship type has been given a variety of names but Offshore Support Vessel (OSV) is perhaps the more dominant one. According to Guidelines for design and construction of OSVs (2007), OSV is defined as a vessel

- "which is primarily engaged in the transport of stores, materials and equipment to offshore installations, and
- which is designed with accommodation and bridge erections in the forward part of the vessel and an exposed cargo deck in the aft part for the handling of cargo at sea".

Unlike conventional cargo ships, both the unique design features and service characteristics differ from those of conventional cargo ships and specific safety requirement are introduced to OSVs.

"One of more of the following design and operating capabilities can generally be expected of a vessel of this type:

- Large and open aft deck and equipment for cargo, anchor handling and towing operations
- Highly maneuverable, particularly at low speed or static operations
- Storage of consumables for offshore exploration and production activities: such as drilling fluids, bulk mud and cement, potable water, fuel, chemicals, etc". (Sarthy and Ham, 2005)

The origin of offshore support vessels may be traced to the Gulf of Mexico – where oil exploration first moved offshore in the 1950s (Sarthy and Ham, 2005). Those old vessels, fishing boats are used to supply offshore platforms with fresh water, fuel, food and materials for production. In following decades, purpose-built vessels to supply offshore rigs and platforms were designed and well developed.

With the strong desire for energy and the development of activities on deep water, OSVs are playing an increasing important role on the development of exploration and operation activities about oil and gas on offshore.

In the past, the sizes of OSVs are traditionally in the range of 40m to around 70m and the types of cargos carried on board were typically casings, pipes, machineries, equipment for offshore installations and so on. Within the main hull of OSVs, deep tanks are typically provided for OSVs for the carriage of drilling water, liquid mud and brine, etc. While new generation OSVs are required to provide more complicated support services to deepwater drilling operations. They are larger in size as compared to their predecessors for the purpose of providing larger deck areas and allow bigger under deck spaces for loading increasing number of bulk tanks for liquid mud, brine and cement, etc.

OSVs can be divided into several main types according to its functions: AHTS, PSV, Ice breakers, and so on. Figure 1.2 shows some types of OSVs. Different types of OSVs possess different functions and equipped with appropriate equipment on the base of applying to requirements and specifications of maritime organizations and specific working environment.

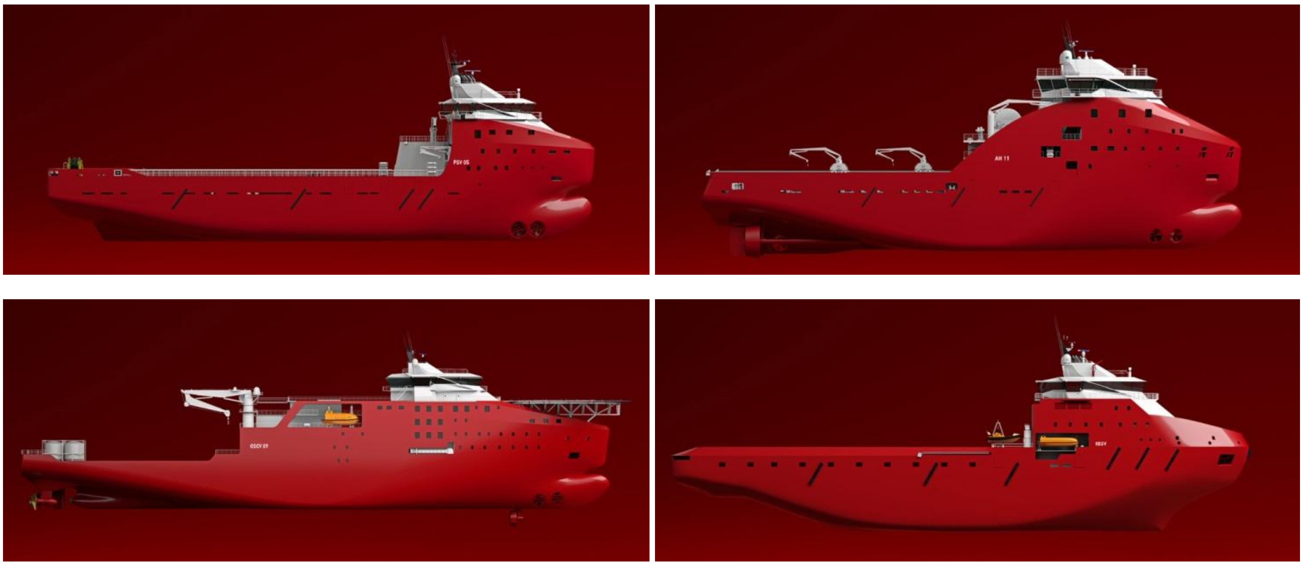

Figure 1.2 different OSV types (source: VARD)

1.1.2.2 What is an AHTS?

As the main type of OSVs, AHTS vessels have been putting concentration on offshore activities. AHTS is a kind of Multipurpose Offshore Service Vessels intended for towing of floating objects in open waters and objects on sea bed, subsurface deployment and lifting of anchoring equipment and supply services

According to the statement of Globalsecurity.org (2011), "An Anchor-Handling Tug [AHT] moves anchors and tows drilling vessels, lighters and similar vessels. An Anchor-handling Tug/Supply [AHTS] is a combined supply and anchor-handling ship. An Anchor is a heavy hooked instrument which, when lowered to the seabed, holds a vessel in place by its connecting cable. An Anchor Handling Tug is a tug equipped with a winch to lift a working barge's anchors. It is also often used as the working barge's tow tug. An Anchor Pendant is a wire which is attached to the crown of an anchor, enabling it to be pulled out of the seabed. The pendant wire is used by the anchor handling tug to set and retrieve anchors using the cable eye on the free end of the wire".

"An AHTS is an offshore supply vessel specially designed to provide anchor handling services and to tow offshore platforms, barges and production modules/vessels. The vessels are also often used as standby rescue vessels for oilfields in production". The description of AHTS is stated like this according to Global Security.org (2011). The AHTS is then often equipped for fire-fighting, rescue operations and oil recovery. The AHTS is also used in general supply service for all kinds of platforms, transporting both wet and dry cargo in addition to deck cargo. The focus has been on the vessels' winch and engine capacities as oil activity has moved into deeper and deeper water in order to offer the oil companies a safe and efficient operation in the challenging conditions of the deepwater area. (globalsecurity.org, 2011).Figure 1.3 is a kind of AHTS type made by Rolls-Royce.

Figure 1.3 AHTS- UT 790 WP (source: rolls-royce.com)

1.1.3 The demand for AHTS in oilfield market

As the main type of OSVs, AHTS can afford multi-functions for oil and gas activities in shallow, deep, ultra-deep water areas. The demand for AHTS has been growing in the oilfield market before the economic recession which happened in 2008. The years from 2006 to 2008 witnessed the most booming period for OSV industry. In particular, the new orders of AHTS in 2007 hit the record high of 362 vessels, while the figure in 2008 dropped to 201 units due to the oversupply. The new AHTS orders have seen sharp decline to roughly 56 units in 2011 since 2008. As the oilfield market regain the booming period these years due to the high oil price and the recovery of economy, the demand for AHTS reach a level higher than any period before. Especially those AHTS with high BHP (Brake Horse Power) and big deck space are in brisk demand.

AHTS vessel can meet specific demands required by rigs and other offshore installations which conduct more sophisticated and complicated activities through the world except some extreme environment. As the development of globalization and deep cooperation between different enterprises, most of oil and oilfield services companies have business in different areas and rigs or other installations are towed back and forth by AHTS. High BHP and high tension of towing line are advantages of AHTS which make AHTS become favorite assistant of rigs on offshore.

An obvious trend for oil and gas industry is that lots of activities are moved into deep water due to more requirements from market and higher technologies and more sophisticated equipment are employed. Oil rigs are designed to carry out activities on deep water, besides the high requirements for the rig itself, supporting activities from other vessels like AHTS are also important and influence the fluent operations of rigs. Fortunately, AHTS vessel with specific design and equipment can meet demands and requirements from rigs and other installations.

Nowadays lots of rigs are equipped with DP (Dynamic Positioning) systems which can make it possible that rigs can stay their position for a long time. While if there is any emergent situation happened for the DP systems, AHTS can act as an escort and conduct anchor handling operations which help rigs stay their position or move rigs away from hazardous environment.

Since an AHTS provide a multi-utility facility and oil drilling from the oceanic areas has increased, he increase in demand and usage of AHTS makes a lot of relevance and sense. Also as a point to ponder, it can be mentioned that AHTS involves anchor handling and is used for the purpose of rescue of other vehicles. An AHTS is one of those technological creations of the marine world that not only aid other technological developments' with smooth progress but also help in preventing oil rig capsizing and other types of mishaps at the sea. (SOLCOMCN, 2011)

1.2 The importance of design, fabrication and supervision

As the searching activities for oil and gas move into deep water, OSVs are required to carry out more tasks and perform better operations than before. Today's OSVs have increased cargo capacity, panoramic navigation bridge visibility, large accommodation spaces, enhanced crew amenities and state-of-art LNG dual-fuel propulsion and automation systems.

1.2.1 The importance of design

The design of AHTS is vital to its performance in later operation, inspection and maintenance. A good design will optimize the functions AHTS possess and make it possible that the AHTS can provide oilfield services in demanding environments. Like any other products, AHTS has to be competitively aimed to suit the market and as wide a market as possible.

AHTS can be modified and assigned to meet changing demands in later life, so the design of AHTS has to be flexible in design and plan stages. As the E&P activities becomes more diversified and the design of AHTS need to keep close pace with the offshore oil and gas industry. This is necessitated by the ever changing geographic theaters, environment, modes of operation, regulations, etc. Having a well designed vessel, optimized for its function and ease of construction, with a minimum of capital and maintenance cost and downtime.

AHTS is designed with high horsepower to tow drilling units and perform anchor handling operations as well as the ability to carry supplies to platforms. The increase in deep water exploration has led to higher horsepower vessels to handle the heavier gear required to operate at such depths. In the offshore service vessel fleet, new deep-draft, very large, high-horsepower anchor handling/tug /supply vessels have evolved to move these large new sophisticated drilling rigs, handle their anchors, chain and mooring lines, and meet all kinds of service demands of the new generation of deepwater rigs and production platforms. It is possible that the industry might move in the direction it did back in the late 1970s and build some ships which are intended to do less than the whole job. In those days, the specialist ships were AHTS, and they were found to be more efficient than ships with longer decks which were trying to do the supply job as well. (globalsecurity.org, 2011)

1.2.2 The importance of fabrication and supervision

The fabrication of AHTS can optimize the construction of OSVs' fleet. AHTS possess its own advantages which other types of OSVs do not have and the demand for AHTS has been growing again after the economy recession. The quantity and quality of AHTS can meet the demand from oilfield market and the requirements from advanced offshore activities nowadays. Most of AHTS are near to be abandoned or cannot qualify for operations due to small special rooms and BHP. However, fabrication of AHTS can solve or at least relieve problems of lacking qualified AHTS.

The fabrication of AHTS is important to the quality and performance of AHTS which will have a significant influence on AHTS in its whole cost lifetime. The fabrication of AHTS needs to tightly follow up what was designed in the contract in the beginning phase. The specific requirements for the operability characteristics and construction style and other criteria are declared in the fabrication contract by which the obligation and relative business and statutory issues of both ship owners and builders are also specified.

1.2.3 The supervision and inspection of AHTS' fabrication

The fabrication of an AHTS is a huge complex project with characteristics like technology-intensive, heavy workload, wide operation, long period of design and fabrication and so forth. It will normally take one year from the order to the delivery of AHTS. Therefore, besides sea trials, the supervision and inspection of the fabrication of AHTS shall check the quality of fabrication and follow up the latest situation continuously which can help to find problems promptly and ensure the safety of sea trial and reliable operability. Supervision of the fabrication of AHTS will give appropriate adjustment on operational and economic issues, the convenience of operation and maintenance and comfortable habitation and other unreasonable issues.

Materials used to build AHTS need to meet the requirements of rules which are included for strength, formability and we1d abi1ity characteristics and toughness appropriate to the application involved. For most marine structures, application is generally assigned to three categories; special (most critical), primary (intermediate), and secondary (least critical). Steel toughness requirements increase with criticality of application. Nondestructive test standards are used to detect the defects of steel materials and other equipment during fabrication.

As NORSOK STANDARD (2004) states, materials selection shall be optimized and provide acceptable safety and reliability. As a minimum, the following shall be considered:

- corrosivity, taking into account specified operating conditions including start up and shut-down conditions;
- design life and system availability requirements;
- failure probabilities, failure modes and failure consequences for human health, environment, safety and material assets ;
- resistance to brittle fracture;

- inspection and corrosion monitoring;
- access for maintenance and repair .

Chapter 2 Overview the influence of AHTS design and fabrication

For Offshore Support Vessels （OSVs）, the requirements to the design shall be clear from the Engineering department. Specific emphasis will be put on requirements for operational purposes. The Shipping department will follow up the design development in order to ensure that new buildings meet the specifications and requirements of the company and that the vessel operations are ensured.

2.1 The classification of AHTS and their application

2.1.1 Classification Societies

Classification societies establish and maintain technical standards for the construction and in-service maintenance of ships and offshore units. Classification is a life cycle approach to the design, construction and operation of an OSV. After delivery, maintenance of classification requires periodic surveys to verify that the vessel remains in compliance with the applicable rules (Sano, et al., 2012). Classification Societies create notations to specifically address design requirements and recognize these specialized capabilities. The notations attest to the vessel's capabilities and identify the class Rules and requirements that will be applied throughout the class process.

Classification and statutory services comprise five parts: Class notations, design analysis & Approval, Surveys during Construction or Major Modification, Surveys after Construction, Statutory Inspections. Classification societies create notations to specifically address design requirements and recognize these specialized capabilites. The notations attest to the vessel's capabilities and identify the class Rules and requirements that will be applied through the class process (Sano, et al., 2012).

Classification Societies offer comprehensive range of classification and related services to designers, builders, owners and operators of offshore support vessels (OSVs) which includes AHTS, PSV, specialized multi-purpose vessels and so forth.

Dedicated to safe ships and clean seas, The International Association of Classification Societies LTD. (IACS) makes a unique contribution to maritime safety and regulation through technical support, compliance verification and research and development. More than 90% of the world's cargo carrying tonnage is covered by the classification design, construction and through-life compliance Rules and standards set by the thirteen Member Societies of IACS (IACS, 2011). Figure 2.1 shows the logos of thirteen member societies of IACS.

Figure 2.1 The logos of thirteen Member Societies of IACS (source: http://www.iacs.org.uk/)

The purpose of a Classification Society is to provide classification and statutory services and assistance to the maritime industry and regulatory bodies as regards maritime safety and pollution prevention, based on the accumulation of maritime knowledge and technology. The objective of ship classification is to verify the structural strength and integrity of essential parts of the ship's hull and its appendages, and the reliability and function of the propulsion and steering systems, power generation and those other features and auxiliary systems which have been built into the ship in order to maintain essential services on board. Classification Societies aim to achieve this objective through the development and application of their own Rules and by verifying compliance with international and/or national statutory regulations on behalf of flag Administrations (IACS, 2011).

An OSV is defined as a self-propelled vessel whose regular trade is to provide services in support of exploration or production of offshore energy or alternative energy resources. Such definition is broadened from traditionally supply function to cover emerging new service types such well intervention and wind turbine installation, maintenance and repair, etc. Enhanced classification criteria have evolved in concert with the latest developments and have anticipated the advancements in OSV designs which take into account the frequent change in roles, capabilities, propulsion and specialized systems.

Vessel need to be assigned with notations which are designed by Classification Societies and the service capacities of vessels are defined clearly. Every notation means the specific capabilities that the vessel possesses. At least one notation is assigned to reflect the specialized capabilities. It is common that a vessel is assigned with a combination of notations corresponding to its multi-functional and service capabilities. The requirements corresponding to notations need to be complied with and the equipment of vessels are prepared to engage in operations related to relevant functional services.

As a main type of vessels on offshore activities, AHTS are designed with a combination of notations unavoidably due to it possesses multi-function and provide a certain range of services to platforms or other offshore installations. "Anchor handling operations implies towing of floating objects in open waters and objects on seabed in addition to subsurface deployment and lifting of anchoring equipment". According to Design Issues and Trends for the New Generation of Offshore Support Vessels which is a paper prepared for presentation at the Offshore Technology Conference held in Houston, Texas, USA, 30 April-3 May 2012, different OSVs are assigned with different Class Notations which are shown below in

Table 2.1

Table 2.1 OSV Types - Class Notations (Source: Sano et al., OTC 23319, 2012)

Services	Additional Class Notations
Offshore Supply	**Supply, Supply-HNLS**
Anchor Handling/Towing	**AH, TOW**
Fire Fighting	**FFV 1, FFV 2, FFV 3**
Diving and ROV Support	**DSV AIR, DSV MIXED-GAS, DSV SAT, DSV Capable, ROV, ROV Capable**
Oil Spill Recovery	**OSR-S1, OSR-S2, OSR-C1, OSR-C2**
Safety Standby Rescue	**SSR**
Pipe Laying	**Pipe Lay**
Heavy Lift	**Heavy Lift**
Well Intervention	**WI, WI-READY, WI-TEMP**
Well Stimulation	**WS, WS-READY, WS-TEMP**
Well Test	**Well Test Service, WT-READY, WT-TEMP**
Escort	**ESCORT**
Wind Turbine Installation, Maintenance and Repair	**WIND-IMR**
Cable Laying	**Cable Lay**

Vessels with class notation Offshore Service Vessel intended for anchor handling operations built in compliance with the requirements in this section may be given the class notation Anchor Handling. Vessels with class notation Offshore Service Vessel intended for towing operations built in compliance with relevant requirements in this section may be given the class notation Towing.

In addition to compliance with applicable American Bureau of Shipping (ABS) Rule and statutory requirements, equipment and systems for anchor handling and towing services are to comply with the requirements in this Section. Alternatively, equipment complying with a recognized standard may be accepted provided the recognized standard used in the design of anchor handling and towing equipment is specified by designer and acceptable to ABS. Equipment and systems for anchor handling and towing services are to be approved and inspected by ABS.

Vessels with notation AH are to be fitted with the following items:

- One or more anchor handling w inches designed to deploy and recover the anchors
- Stern roller for anchor handling operations
- Towing pins in way of the stern roller
- Equipment for temporary securing of an anchor

Vessels with notation TOW are to be fitted with the following items:

- Towing winch or towing hook
- Heavy duty bollards (ABS, 2011)

2.1.2 Winterization

Winterization is defined as the preparation of a ship for safe operation in extreme cold weather conditions by adapting the design and operation procedures to the requirements imposed by the intended service (Legland, at el., 2006). Vast reserves of gas and oil are expected to be developed in the offshore areas of the Arctic. Figure 2.1shows the daily temperature of a few weather stations in the Arctic and table 2.2

gives the estimated temperatures based on figure 2.2. These temperatures are plausible in comparison with reference ships.

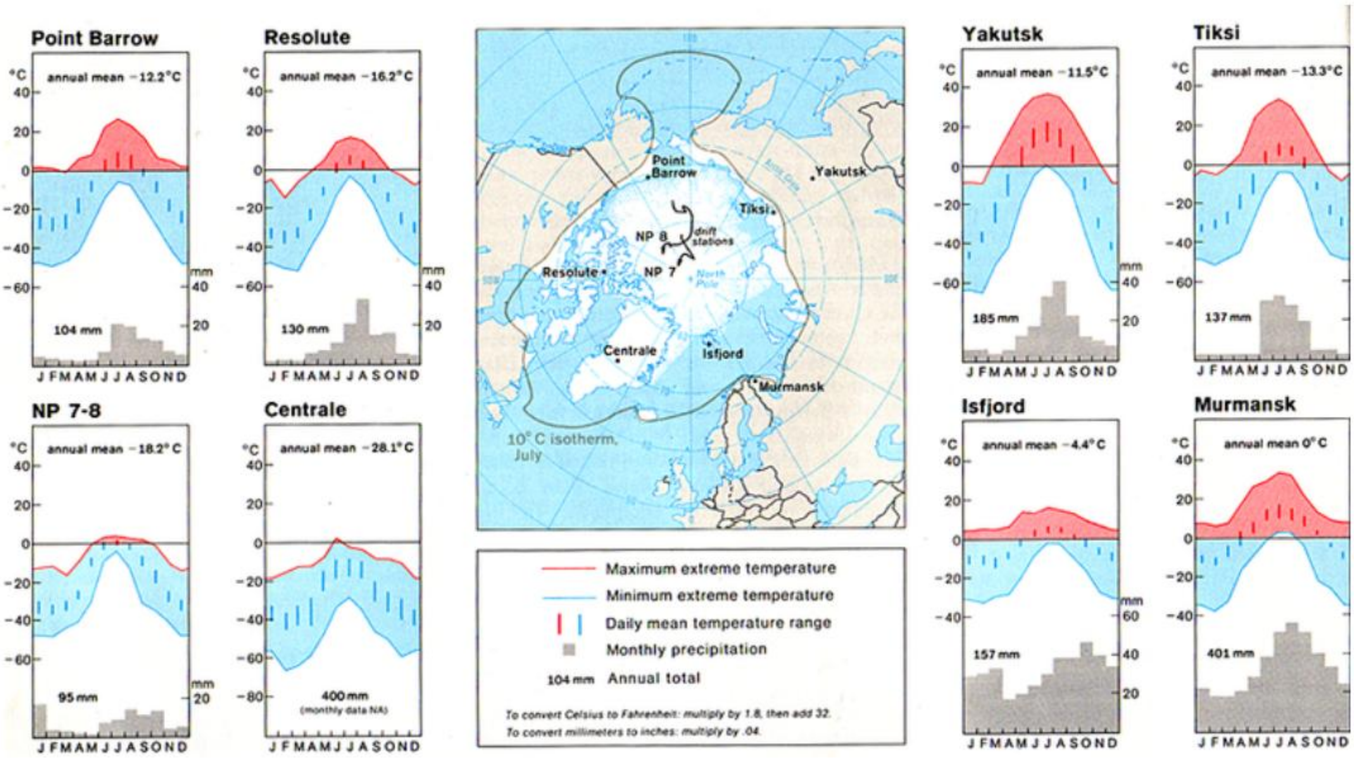

Figure 2.2: Annual daily temperature of a few weather stations in the arctic (source: Delft University of Technology 2013)

Table 2.2: Design temperatures for the three operational areas (Source: Delft Univ. of Technology, 2013)

	t_bT	t_eT	t1
Barents Sea	March -30℃	January -30℃	-10℃
Beaufort Sea	April -45℃	November -45℃	-25℃
Baffin Bay	May -40℃	December -40℃	-25℃

t_b=begin time window, t_e=end time window

T represents the minimum extreme temperature

The factors of winterization are indicated by figure2.3. They can be addressed by combining heating, covering, adaptation or automation of equipment and improvement of procedures. The main goals of winterization are to ensure safe and workable operations with respect to the ship stability, operations and crew conditions (Bos, et al., 2013).

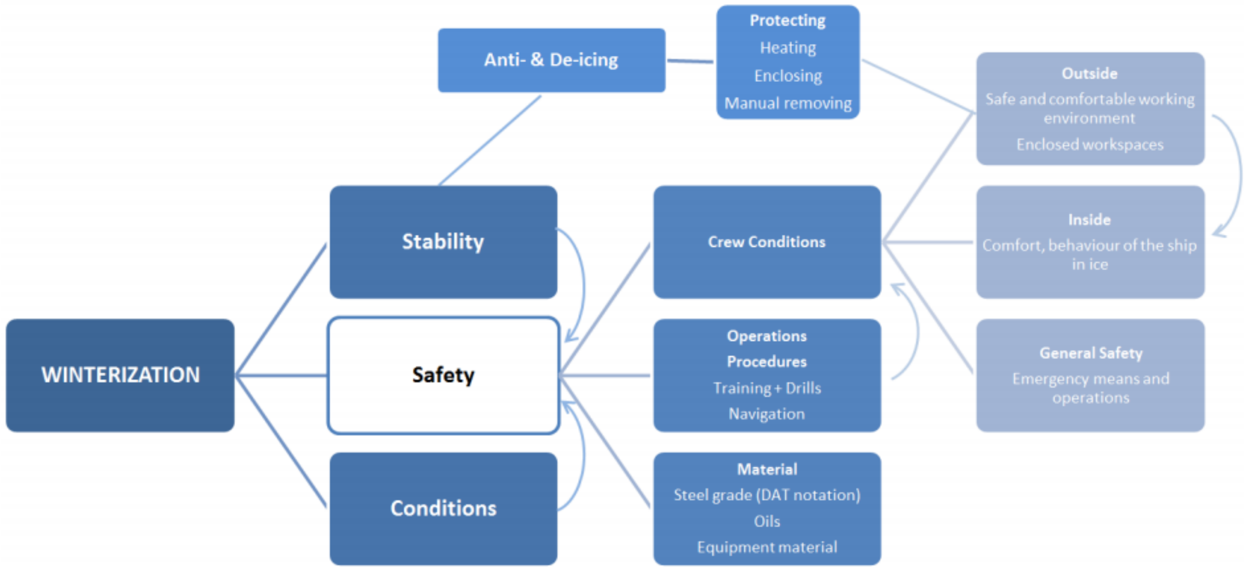

Figure 2.3 Components of winterization (Bos, et al., 2013)

Winterization of vessels operating in the arctic environment is a big challenge and the vessel design, winterization and operation have to meet the requirements and needs of the crew and be applicable to the extreme cold weather condition. The requirements of winterization for AHTS to conduct operations in cold weather area can include the followings:

- Materials and coatings;
- Hull construction/arrangement an equipment;
- Vessel systems and machinery;
- Safety systems for personnel;
- Specific vessel requirements for four vessel types;
- Crew considerations;
- Crew training

The vessel exposed to low air temperatures cold weather regions must be constructed with ductile materials suitable for operations in this environment. Structural steel and grades for weather exposed plating and for in board framing members attached to this plating may need to be upgraded if the design service temperature for the vessel is below the calculated design temperature of the material at the specific location (Legland, et al., 2006).

Due to a growing need for the support of oil and gas exploration in colder climates, there is an increasing demand for offshore supply vessels with ice class and ice-breaking capabilities. Anchor handling in ice can cause greater stress on involved structures and crew than in open water and the equipment should meet the requirements for working in cold environment. The vessel has to deal with ice accretion in adverse weather condition De-icing training is also necessary when the cold season comes or in case of work in extreme freezing regions.

2.2 The influence of design on operability

A well-designed ship is a result of collaboration, experience, innovation and state-of-the-art equipment. The vessel is created in harmony with the elements in which it will operate. To achieve this, the overall economy, reliability, safety, and environmentally sound designs need to be kept and each of this factors is vital to developing profitable ship design for the operator.

The design of OSVs has a great influence on operability when OSVs perform offshore activities. Safety, reliability and operability and environment protection are important issues that shipbuilders and ship owners will take into account. The requirements for OSVs from oilfield markets are dynamic and become more rigorous and the designer of OSVs has to consider the future demands and present technology if OSVs manufactured today wants to fit for future market. Now some of factors, which may influence the operability of vessels, are discussed in the following paragraphs.

2.2.1 Form

The form of vessels has a great influence on its operability. Generally, AHTS is design with forecastle in the bow and an open deck in the stern like other OSVs.

Vessels with design features new environmental friendly hull lines optimized for improved eco-drive in all weather conditions. These kinds of vessels are in particular designed for environmentally friendly operations with focus on low fuel consumption, and in accordance with Clean Design requirements. With its new highly optimized hull form and fore ship together with the specified propulsion configuration, the vessel will have particularly good sea-keeping abilities, a fuel efficient transit mode and a good station keeping performance.

The X-BOW is a backward-sloping bow that starts at the extreme front of the vessel. This allows for the sharpest possible bow shape. The result is that a continuous and sharp bow shape, which smoothly divides both waves and calm water. Increased volume above and up front allows the vessel to efficiently respond to large waves.

A conventional bow has a forward-sloping bow shape that starts at the extreme front of the vessel and drops down and back. The actual start of the bow at the waterline is moved back, and the bow shape at the start of the waterline is less sharp. Result is not hard to find that a bow that pushes the waves down and forward - this absorption of energy slows the vessel (Ulstein, 2011).

One of productions of Ulstein-X-BOW is famous in ship industry. “The unique and environmentally-friendly X-BOW hull line design offers significantly higher transit speed in adverse weather conditions, as well as enhanced fuel economics. The bow shape ensures soft entry into waves, thus reducing speed loss, pitch and heave accelerations, as well as eliminating slamming and vibration problems associated with conventional bow flare” (Ulstein, 2013).

Work deck, the plats which laying on aft deck of AHTS needs to be thick enough to carry out cargos and carry out anchor handling operations. The thickness of plat on aft deck is required not less than 25mm (1in.) according to ABS rules. The arrangement of course varies from case to case which is considered by Classification Societies and ship owners. The stresses in deck members are not to exceed the following values in Table 2.3 (ABS, 2011).

Table 2.3 the stress in deck members (source: ABS GUIDE FOR BUILDING AND CLASSING OFFSHORE SUPPORT VESSELS 2011)

	σ N/mm^2 (tf/cm^2, ltf/in^2)	τ N/mm^2 (tf/cm^2, ltf/in^2)
Longitudinal Beam/Girder:	124 (1.26,8.0)	69 (0.70,4.4)
Transverse Beam/Web:	140 (1.42,9.0)	85 (0.87,5.5)

2.2.2 Power Supply

The power supply for normal operation of the anchor handling or towing winch is taken from the same source for propulsion, such as shaft generator, shaft power take-off (PTO). An independent (redundant) power supply with sufficient capacity for the winch operation is to be available to ensure the vessel's maneuvering capability during anchor handling or towing operations is not degraded (ABS, 2011).

In view of its operation characteristics and tonnage, AHTS are propelled by two or more large diesel engines which are equally assigned on each side. Considering the energy saving and environmental protection, diesel-electric propulsion is equipped with vessels. The diesel-electric propulsion system reduces the total cost of operation and maintenance. Less energy is consumed by diesel-electric propulsion than diesel propulsion system. Environmentally toxic gas emissions are also reduced and the vessel gains stable maneuverability. Even the traditional propulsion system looks less expensive to purchase, a vessel equipped with diesel-electric propulsion system can save more fuels substantially in later operating periods. The wear to the engine will also be reduced when using diesel-electric propulsion system. Figure 2.4 shows a simple arrangement of propulsion system of MAN Diesel.

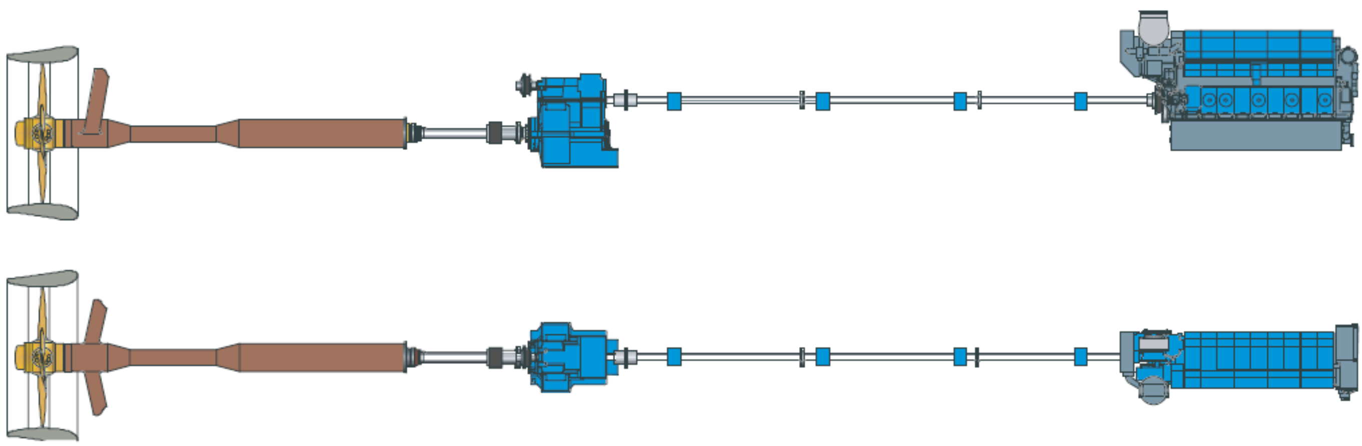

Figure 2.4 Side and top view of the port-side propulsion system arrangement (source: MAN Diesel, 2009)

2.2.3 Equipment

Equipment of AHTS shall meet the requirements of Classification Societies and all involved parties. It needs to comply with recognized standards and provided such standard gives a reasonable equivalence to the requirements of authorities and relevant organizations.

2.2.3.1 Anchor Handling Winch

Hoisting and Holding Capabilities
The design of winches is to provide for adequate dynamic and holding braking capacity to control normal combinations of loads from the anchor, anchor line and anchor handling vessel during deploying or retrieving of the anchors at the maximum operational speed of the winch. The mechanical components of the winch and associated accessories are to be capable of sustaining the maximum forces from the hoisting, rendering and braking including any dynamic effects as applicable without permanent deformation as follows:

- Operational braking capability is to be at least 1.5 times the maximum torque created by the anchor handling line calculated with the rated breaking strength. In addition, the brake is to be capable of stopping the rotation of the drum from its maximum rotating speed.
- Brake holding capacity of 80% of the maximum torque created by the anchor handling line calculated with the rated breaking strength and able to stop the rotation of the drum at its maximum speed (ABS, 2011).

Winch Brakes
Each winch is to be provided with a power control braking means such as regenerative, dynamic, counter torque breaking, controlled lowering or a mechanically controlled braking means capable of maintaining controlled lowering speeds (ABS, 2011). Brakes are to be applied automatically upon loss of power or when the winch lever is returned to neutral.

2.2.3.2 Gear

Anchor handling and towing winches, storage reels, towing hook, towing bitt and towing bollard are to be located as low as practicable and preferably be arranged in the way of the vessel's centerline in such a position that the working point of the line force is to be close to, but abaft of, the center of gravity of the vessel in the expected operational conditions (ABS, 2011).

The towline and anchor handling line may be either steel wire or fiber rope of the appropriate diameter. The breaking strength of the towline and anchor handling line needs to meet the requirements and not less than the reference load.

Towing pins, shark jaws are to be arranged in the aft deck of vessel and are located in or near the center line of the vessel and it is easy to keep the balance and stability of vessel when conduction anchor handling and towing operations.

Anchor handling and towing winches are designed to allow quick release of drums and lines in the operation conditions or in emergency situations.

2.3 Procedures and requirements for AHTS fabrication follow up

The fabrication of AHTS is vital important to the operation of AHTS in its later life. The fabrication of AHTS needs to follow classification society's requirements and include the practical operation requirements of the vessel owner. Clear and scientific procedures for the fabrication can reduce the risk of delaying delivery of the vessel which is expected by company to be put into operation as soon as possible.

2.3.1 The meaning of fabrication

The fabrication of new generation OSVs can replace the old fleet of vessels on one hand and meet the significant functional demand from offshore market on the other hand. Demand for OSVs is expected to surge due to at least three fundamental factors:

- The aging fleet
- The unsuitability of existing fleet to support deepwater activities
- The expected continued growth in offshore exploration and production activities fueled by high oil prices (Sarthy and Ham, 2005).

Presently, the average age of the world's fleet of OSVs is more than 20 years. In terms of the age structure of the existing fleet, 45% of the world fleet is aged 25 years and over and 29% is aged between 20 and 25 years old. Assuming the same level of demand and an average vessel life of 25 years, significant renewal of the existing fleet will be required in the years to come to satisfy the demand (Sarthy and Ham, 2005).

In earlier days, the offshore activities were mostly focused on shallow water and the requirements for OSVs were relatively simple. However, as the exploration and production activities move into deep water, the requirements for OSVs become stringent. OSVs have to take more materials such as drilling pipes, mud, fuels, water or even foods and so on due to longer trip than before. Considering the economic issues, vessels need to travel fast and take more tonnages. Larger power and sophisticated equipment are also need to be outfitted on vessel in order to conduct complex operations. The fabrication of new OSVs can take these issues into account and make adjustment when considering future development. A good fabrication and supervision can reduce a number of problems during later inspection, maintenance, repair and other periods.

2.3.2 The procedures of fabrication

Guidelines for the design and construction of offshore support vessels

The fabrication of vessels is an extremely complex business. The time between taking an order and delivery vessel is short, which means that lots of tasks need to be well scheduled and performed in parallel. Figure 2.5 illustrates the process of shipbuilding which comes from AVEVA, a world's leading engineering software provider.

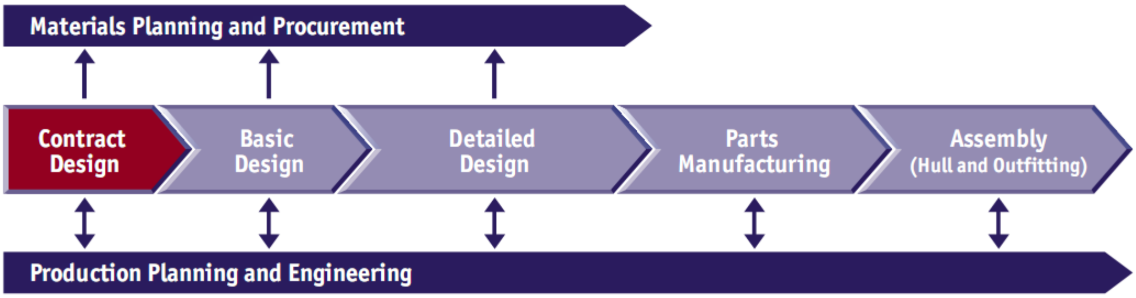

Figure 2.5 The process of shipbuilding (Source: AVEVA)

The contract of shipbuilding include contract design, basic design, detailed design, parts manufacturing, assembly (hull and outfitting) briefly, materials planning and procurement and production planning and engineering are also included in the process of shipbuilding.

The process of shipbuilding from concept to delivery needs to be scientific and efficient. A good shipbuilding process can not only reduce rework and improve efficiency but also shorten building period and ensure the delivery of vessel on time or in advance.

Contract design

An excellent contract design is of vital important because it can less searching and waiting time during fabrication. It should define initial design and building strategy well for the project.

The design of offshore supply vessel is a large and complex process that requires significant amounts of information and detail works which need to be conducted by collaborative departments like project management and various discipline design teams such as structural design and piping design.

The owner of OSVs sends invitation to tender to qualified manufacturers or broadcast its project to public and then pick up a few numbers of manufactures. After considering the whole qualification of these manufactures, the owner chooses the best one and signs a contract which includes lots of details about the fabrication of OSVs. The contract design includes but is not limited to following issues: the classification of the OSV, the configuration of the OSV, equipment outfitted on the OSV, materials to be used for the construction of OSV, the delivery time, finance issues, etc.

In real fabrication of OSVs, specific software or tools and typical technologies are used for the purpose of managing all kinds of information and coordinate the process of fabrication. For example, Tribon technology has been used in the shipbuilding industry for more than 40 years. Its number one objective has been to provide the world's shipbuilders with unique software solutions to increase their efficiency. Over 260 shipbuilders and design agents in 39 countries rely on Tribon applications from start to finish and they include 75% of the world's top 20 shipbuilders.

When an offer becomes an order, the design information can immediately be re-used and refined without being recreated as the project develops and progresses. The better the design is, the less risk there will be in the tender. The result is greater accuracy with the best possible price – and a reduced risk regarding what the profit will be at the end of the day.

The design of a modern ship is a large and complex process that requires strong collaboration across project management and various discipline design teams such as structural design and piping design. In addition, a project may have multiple design teams working at various sites collaborating together to design the ship. Ensuring efficient and integrated design tools as well as project management and collaboration tools is critical to ensure that ships are designed in the most efficient manner so that engineers can have the utmost confidence in their designs. The collaborative shipbuilding design solution provides shipbuilders with a suite of products to effectively address these needs.

Basic design-less rework leads to savings

Contract design is followed by basic design phase during which major equipment selection, general arrangements, systems design, spaces allocation and structural design are given final approval by classification societies and ship-owners.

Different alternatives for equipment from suppliers all over the world can be reviewed and compared during basic design phase. Technical data for each piece of equipment can be downloaded into the design and technical enquiries can be sent to suppliers for more information. For the purpose of saving cost and reducing downtime, parallel performance as shown in figure 2.6 is popular to be conducted in the building process.

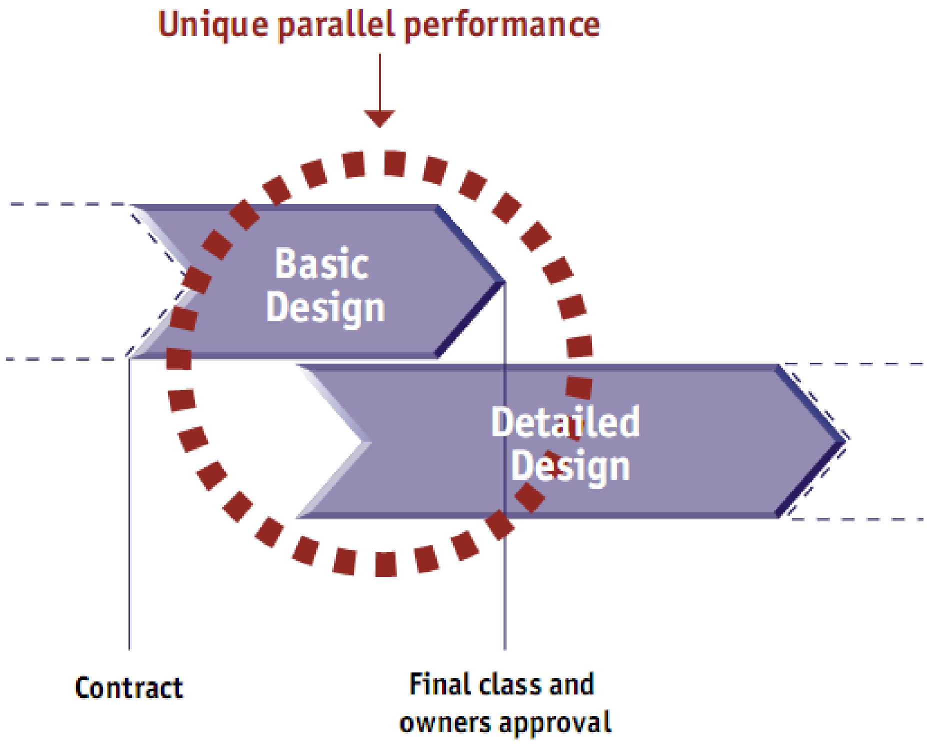

Figure 2.6 Unique parallel performance (Source: AVEVA)

Important decisions regarding the preliminary definition and arrangement of principal structural members are made and framework for associated design guidance is provided through basic design. The aspects in this phase include classification drawings, steel material estimates, equipment lists, weld lengths and weights and centers of gravity reports. Initial design structure can be transformed into production blocks which lead to more accurate calculations and better estimates of materials and work content.

Tribon M3 is useful for a variety of design scenarios, one of them being when subcontractors make the entire or parts of the design. Tribon M3 is used for preliminary definition and arrangement of the ship's structure and compartment. The system is an aid in making important decisions regarding the preliminary definition and arrangement of principal structural members, and it provides the framework for associated design guidance.

Classification drawings, steel material estimates, equipment lists, weld lengths and weights and centres of gravity reports needs to be generated through expert software like Tribon M3. The preliminary structural definition developed in the Basic Design phase can be used for detailed design and preparation of production information. This is possible thanks to an advanced block splitting function that transforms the initial design structure into production blocks. The use of the Tribon PIM in the Basic Design phase leads to more accurate calculations and better estimates of materials and work content (AVEVA, 2011).

Detailed Design

In the detailed design phase, many designers can work in parallel creating detailed layout of compartments, defining systems and making the details of the steel structure. Design time is often lost whist waiting for supplier information. Thus, it is vital important to find and manage supplier information assisted by scientific technology. Major equipment as well as fittings and minor components need to be selected in this phase of design.

As the complexity of process of shipbuilding, dealing different work in parallel will reduce rework and improve the efficiency of work. The whole configuration of the vessel should follow the drawings and documents which are agreed between owner and builder. What kind of materials to be used, the specific type and size of equipment which will be installed on bridge and engine room, the capacity and location of liquid and bulk material tank and other issues are stated in detailed design phase. In the Detailed Design phase, Tribon M3 provides an efficient system for concurrent design. Therefore many designers can work in parallel creating detailed layout of compartments, defining systems and making the details of the steel structure.

Design time is often lost whilst waiting for supplier information. During the Detailed Design phase, designers can find detailed supplier information on Tribon.com – for major equipment as well as fittings and minor components that need to be selected in this phase of design.

Parts Manufacturing -profit through accuracy

After documenting, all types of parts which are of a very high standard will be put into manufacture.
Features like allowance for shrinkage in manufacturing should be taken into account and all parts need fit first time.

In Parts Manufacturing, plate parts are cut from raw plates, stiffeners cut from raw bars, cables cut from cable drums, pipe spools fabricated and so on. Different types of production equipment require special information all of which can be extracted directly from specific software which can be configured to provide the information needed for flame cutters, profile cutting robots, pipe benders, automatic flange welders, etc. in each shipyard.

To keep rework in production down to a minimum, it is essential that the information for Parts Manufacturing "anticipates" the influence of the manufacture and assembly process in such a way that the assembled end product has the correct shape and dimensions according to the design requirements. To achieve this, the piece parts must be automatically adjusted in size from the nominal design size to compensate for issues such as shrinkage, stretch and edge preparation for fitting and welding (AVEVA, 2011).

Simulation and automation of production and manufacturing processes can be performed within the integrated collaborative platform. Supports the complete shipyard production processes right from Plate cutting, Panel Fabrication, Block Assembly, Pre Outfitting, Grand Assembly & Dry dock. The results of planning include manufacturing execution, construction planning & manufacturing drawings, schedule validation in 3D, sequencing, optimized material, resource and space utilization as well as logistics.

Assembly

All the different parts must be assembled into one product through many stages of assembly. The ambition is to manage both the planning and the physical assembly efficiently by carrying out assembly operations at as early assembly stage as possible. The planning of the assembly process requires extensive support to organize the design information to result in production assemblies.

Shipbuilders and owners can even define assemblies before the detailed design is complete to define a build strategy in the aid of specific software or technology, so that design activities can be coordinated in line with the production process. Each assembly can be a mix of hull and outfitting items. Due to the complexity of creating the required control information, machines in the workshops are often not fully used to their full capacity.

According to the research of Korea Advanced Institute of Science and Technology (2001), in the block assembly process, blocks are made in the bays by assembling the small parts made in the cutting process. Two types of bays in the particular shipyard are considered. One is called fixed-bay and the other is called moving-bay. Moving-bay is more efficient in its operations but it can only assemble small and flat blocks. On the other hand, a fixed-bay is mainly used to assemble curved blocks and large blocks. Space resource and man-power resource are the two most important resources in a bay.

Chapter 3 Operations of AHTS

3.1 Anchored offshore installation

According to NORSOK STANDARD (1997), anchoring systems on installation kept in position by anchors with or without thruster assistance while performing marine operations, shall:

- comply with the requirements of a recognized authority, and
- be verified to have the required capacity for the proposed location.

This chapter will introduce the anchor system of installation on offshore first before illustrating the anchor handling operation held by AHTS in following part.

3.1.1 New trends of offshore installation mooring system

Before Word-War II, offshore activities were limited to some shallow water areas. In the mid-1940s, significant changes in the oil industry were made due to the peace-time when strong public demand of oil and gas energy was required. Offshore installations such as drilling platforms performed its operations on shallow water in the beginning of offshore industry, and platforms were supported by construction of a piled jacket structure, in which a framed template has piles driven through it to pin the structure to the sea bed. Most of activities conducted by platforms were held in shallow water areas where these platforms could stay their positions by jacket structures itself and anchor systems were only needed during changing position.

As the development of high sophisticated intellectual technology and mature geography knowledge, people’s activities are stretching into ultra-deep water where significant quantities of hydrocarbons are located. In order to carry out oil and gas exploration activities on ultra-deep water, special offshore installations are required and installed in deep water where special mooring systems are necessary to used and keep stable stations for offshore installations.

The mooring systems were used and are still used on offshore installations and consisted of lines connected to the bow or stern of the installations which stayed moored for a short duration of time. When the exploration and production of oil and gas started offshore, a need for more permanent mooring systems became apparent. Numerous different mooring systems have been developed over the years. Drilling rigs, generally the semi-submersibles are moored using an eight point mooring. Two mooring lines come together at each of the columns of the semi-submersible as figure 3.1 shown.

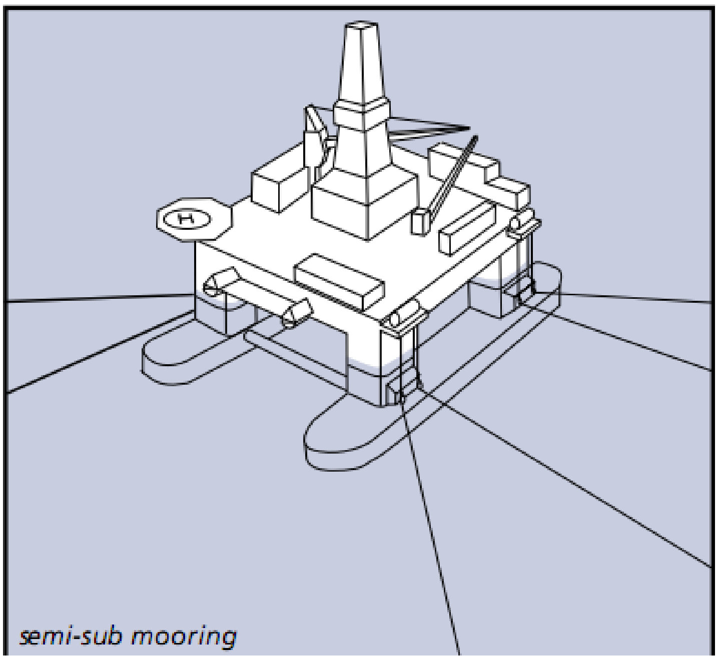

Figure 3.1 Semi-sub mooring lines (source: Vryhof anchors)

When oil and gas exploration and production was conducted in shallow to deep water, the most common mooring line configuration was the catenary mooring line consisting of chain or wire rope. For exploration and production in deep to ultra-deep water, the weight of the mooring line starts to become a limiting factor in the design of the floater. To over-come this problem new solutions were developed consisting of synthetic ropes in the mooring line (less weight) and/or a taut leg mooring system (figure 3.2)

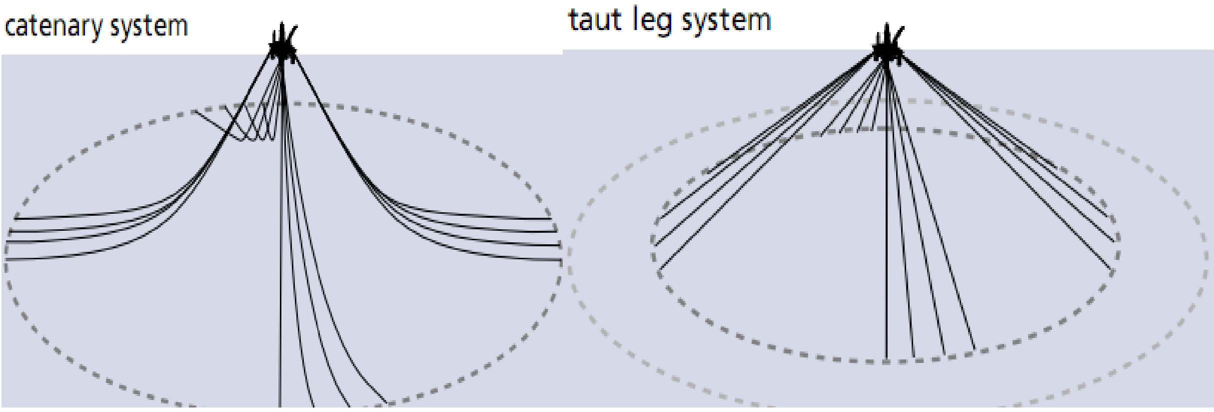

Figure 3.2 Semi-sub mooring systems (source: Vryhof anchors)

In recent years, the application and research into floating platforms are becoming more and more widespread with the extension of exploration of deepwater hydrocarbon resources to deep and ultra-deep waters (Qiao, Ou and Wu, 2012). New generation of floating platforms such as Semi-submersible platforms, Spar platforms and Floating Production Storage and Offloading (FPSO) units all need to be kept their original position by mooring systems when they are put into production (Qiao, Ou and Wu, 2012).

3.1.2 The introduction of mooring systems

There are three main type of mooring positioning systems as show in figure 3.3 are taken into account when choosing mooring positioning systems in most of oilfields, catenary mooring system, semi-taut mooring system and taut mooring system.

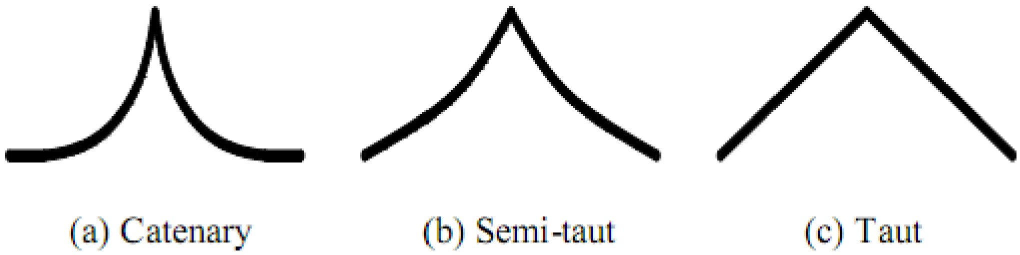

Figure 3.3 Configuration of mooring line (Qiao, Ou and Wu, 2012)

Due to the ultra-deep water, offshore installations like FPSO, semi-submersible, drill ship, lay barge etc. cannot stay its position by jacket structures but with the aid of Dynamic Positioning systems or mooring systems. Semi-submersible platforms usually possess Lateral Mooring System (LMS) which is a catenary mooring system comprised of linear winches, wire, chain, submerged buoys and anchors. It is used to position the offshore installation over specific well locations and to resist lateral environmental forces.

The accurate specification of environmental and mooring material characteristics is of critical importance to the design of any offshore structure. The main construction of semi-submersible platform includes two pontoons, four columns, deck and derrick, and the main characteristic parameters are listed in Table 3.1 (Qiao, Ou and Wu, 2012).

Table 3.1 Parameters of semi-submersible platform

Parameters	Value
Deck (m)	74.42×74.42×8.60
Column (m)	17.385×17.385×21.46
Pontoon (m)	114.07×20.12×8.54
Tonnage (t)	48206.8
Center of gravity from water surface (m)	8.9
Roll gyration radius (m)	32.4
Pitch gyration radius (m)	32.1
Yaw gyration radius (m)	34.4
Initial air gap (m)	14
Diameter of brace (m)	1.8
Water depth (m)	1500

There are four groups of mooring lines which installed in each corner of semi-submersible platforms. Each group possesses four mooring lines and each mooring line consists of three segments: upper chain, middle wire and bottom chain.

The introduction of Auger Project

The Auger Project, in a record breaking 2860 ft of water, represents a $1.28 investment and included Shell's first Tension Leg Platform (TLP) (Enze, et al., 1994). It was a high level project in the world at that time and represented a new chapter in the history of deepwater industry.

The Auger TLP is held on location by a combination of a lateral mooring system(LMS) and tendons. The LMS is an 8 point catenary mooring system comprised of 5-inch diameter wire, chain, linear winches, submerged buoys, and anchors. It is used to position the TLP over specific well locations and also resist lateral environmental forces. The tendons are supported on tendon porches attached externally on the hull near keel level. The 12 tendons are mechanically latched in groups of three each to four individual foundation templates. The templates are 60 ft by 60 ft in plan, 48 ft tall, and weigh 610 st in air. Each template is secured with four 72-inch diameter piles driven to a penetration of 364 ft below the sea floor and mechanically swaged into the template guide sleeves (Enze, et al., 1994).

The LMS was an expensive system in terms of hardware, complexity added to the hull, and problems encountered during installation, The LMS has proved to be a workable system; however, the need for an LMS and associated cost can be eliminated by utilizing a skidable drilling rig with a matrix well pattern, surface BOP, and high pressure drilling riser system. The following figure 3.4 is draft of steel catenary riser systems.

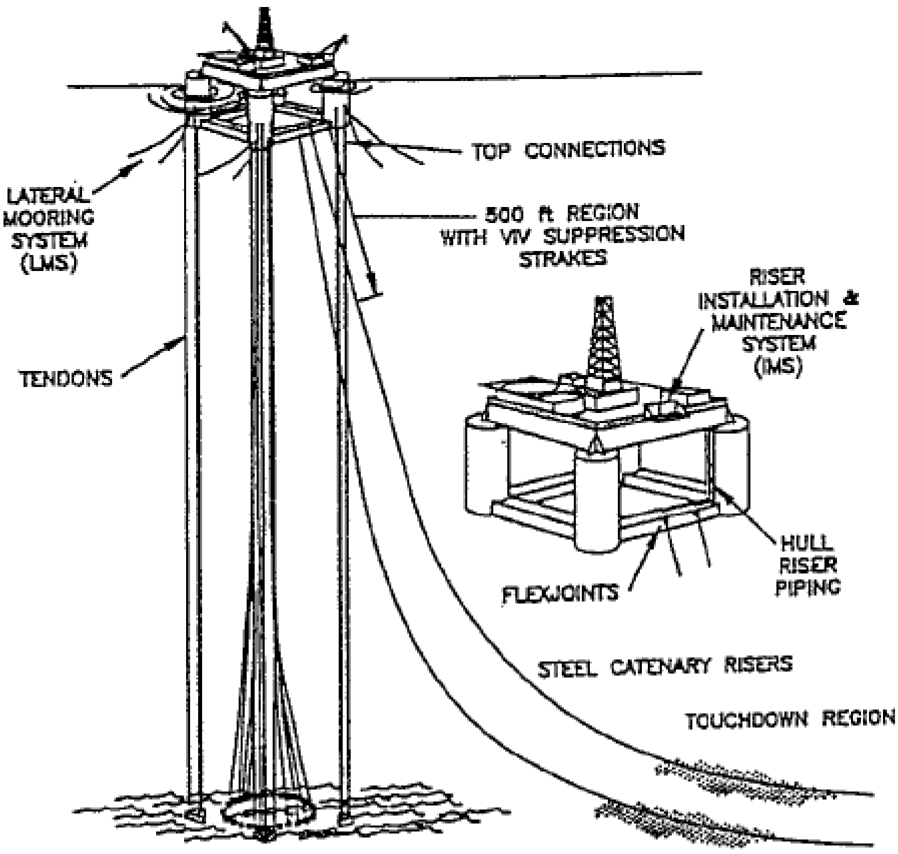

Figure 3.4 Steel Catenary Risers (source: Enze, et al., 1994)

3.1.3 Component Selection

Platform Winching System

Winching systems for platforms are considered for inhaul and payout of the platform section of each LMS line. There are different types of winching systems which includes linear winch/wire, chain jack/chain, rotary winch/wire and windlass/chain, etc. Linear winches with wire for the platform section were chosen due to the lower cost, lighter weight, better fatigue performance, and better catenary characteristics of the wire (compared to chain) plus the proven experience of the linear winch for 5-inch wire.

The winching system of platform needs to payout and inhaul the line fluently and quickly for considering the high tension from the AHTS. It would be frequently to operate the winching system during anchor handling operation. The winching equipment is located inside the TLP columns to provide a cleaner operating environment, to protect the equipment from corrosion, and to provide better access for maintenance. There was also some cost savings in the manufacture of the equipment since it could be designed for an enclosed environment. However, this arrangement did complicate construction of the TLP columns and will make replacement of large parts more difficult.

Mooring System

Multi-leg wire-chain spread moorings with drag or suction pile anchors have long been the work-horse for permanently moored production platforms (D'Souza, Barton and Hatton 2002). These systems have been developed well and are widely used in most areas like Gulf of Mexico (GoM) in 1500m. The cost of installing the mooring system is of the order of 10% of total capex and will command a larger percentage of the capex pie in ultra deepwater (D'Souza, Barton and Hatton 2002). As a development of offshore industry, a new material of synthetic fiber rope was introduced for wire rope with significant cost-reductions and performance improvements. Polyester rope mooring represents a significant step in mooring system. The main benefit of polyester rope moorings is the potential for significant reduction in installed cost for a deepwater PD Semi in the GoM versus wire rope mooring (D'Souza, Barton and Hatton 2002). New installation techniques are employed in the mooring systems and lower installation costs are obtained than with use of suction piles.

Anchor System

Most semi-submersible drilling rigs today use Stevpris anchors. These have the advantages that they have very high holding power for their weight, will dig into most bottoms, are cheap, and are safe and stable on deck. The disadvantage is that, if they land on the bottom with flukes upwards, they will never dig in. Both drag anchors and piles were considered during the LMS design. Drag anchors were selected as a result of increased confidence in their holding power, the ability to accurately position the anchors at set down, and the ability to monitor the anchor drag during proof loading through the use of a specially designed program. A significant cost savings was realized by selecting anchors over piles.

3.1.4 Anchor holding capacity

The holding capacity of an anchor is governed by the following parameters:

• The fluke area, which is limited by the strength of the anchor design.
•The penetration of the anchor. The penetration of the anchor is governed by the soil type, the anchor type, the type of mooring line that is used and the applied load.

An increase in fluke area or an increase in the penetration depth of the anchor results in a higher holding capacity. (Vryhof Anchors, 2010)

An anchor connected to a wire rope mooring line will penetrate deeper than the same anchor connected to a chain mooring line. This is caused by the higher lateral resistance (penetration resistance) along the chain mooring line. This effect is noticeable in all soil conditions, but especially in very soft clay where very deep penetration can be obtained. The holding capacity of a chain mooring line, due to friction in and on the seabed, is larger than the holding capacity of a wire rope mooring line.

When an anchor reaches its ultimate holding capacity, i.e. it will not resist any higher loads, at shallow penetration a wedge shaped piece of soil (in front and above the anchor) will fail. The holding capacity of the anchor can then be described as a combination of the following parameters (figure 3.5):

- The weight of the anchor (A).
- The weight of the soil in the failure wedge (B).
- The friction of the soil in the failure wedge along fracture lines (C).
- Friction between fluke surface and soil (fluke area) (D).
- The bearing capacity of shank and mooring line (E).
- The friction of the mooring line in and on the soil (E).

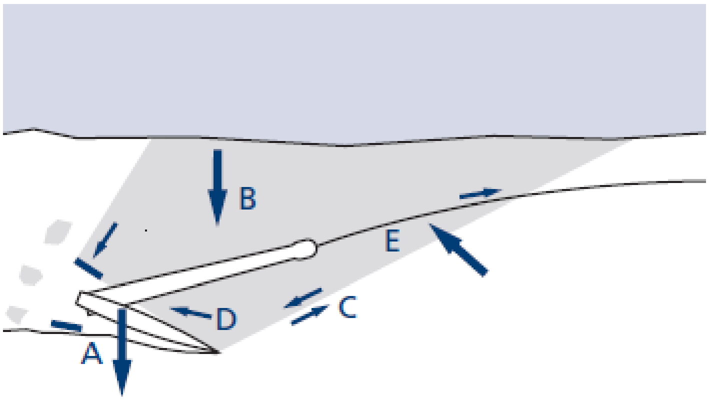

Figure 3.5 Parameters influence the holding capacity of anchor (Source: Vryhof Anchors)

3.2 Anchor Handling by AHTS

3.2.1 The requirements of AHTS before Anchor Handling operation

An anchor handling operation is a potentially hazardous operation due to its complexity and potential unexpected changes during operation. Crew members involved in the anchor handling operation need to appreciate the limitations of semi-submersible platforms and AHTS and the equipment installed on it. According to NWEA’s Guidelines For The Safe Management of Offshore Supply And Rig Moving Operations, a rig move plan should be made and a work specification shall be prepared that provides the necessary background information on the rig move operation and describes the operation at the required level of detail. The purpose of the work specification is to ensure a safe operation for personnel and the environment and provide common guidelines for standardizing the relocation of the MOU and anchor handling, etc. A management of change process should be agreed with all parties involved. Any deviation from the work specification shall only be permitted in accordance with this agreed management of change.

The responsibilities of the operating company, the Mobile Offshore Unit (MOU) Owner, the Offshore Installation Manager (OIM), the ship-owner and the Master of the AHTS should be clarified for the consideration of averting interest conflict. For instance, the OIM has overall responsibility for the safety of the installation and personnel at all times as per statutory requirements and the MOU owners' policy. However he may delegate some of the rig move operational tasks to a suitably qualified person such as the Tow master who should also consult with vessel Masters in the process.

3.2.2 Stability

Stability needs to be taken into account before starting anchor handling operation. Besides weather conditions like wind force and wave height, worst scenarios which may cause the end of the prolonged operation should be considered when considering stability calculation.

The vessel stability depends primarily on the magnitude of mooring load, angle between vertical axis and mooring load, angle of attack, and weather conditions (Gunnu and Moan, 2012). A wide range of research has been conducted on stability for many years and most of studies focus on static stability during sailing or loading and loading cargos in offshore. Limited researches are deployed to study stability during anchor handling operation. There are few of statutory and regulation referring to stability during anchor handling operation and most of regulations and guidelines treated anchor handling vessels as supply vessels. The weather condition is not mandatory to be considered during anchor handling operation. However, on the other hand the mooring load can result in additional overturning moment during anchor handling operation and the stability of vessel at this moment is really critical. The dynamic transverse stability of anchor handling vessels has been reduced due to the mooring loads and the vessel cannot go back to its original position during the operation which is easier to result in hazardous effects than normal supply operations. The effects of wind and wave are also needs to be taken into account during anchor handling operation as it may cause capsize situation. The accidents like famous capsize case of Bourbon Dolphin and Stevns Power may be treated as rare events but the consequents of such events are fatal and the loss of ship and crew members or the reputation of company.

Anchor handling vessels can be subjected to high mooring loads during operation phase and the average ranges of bollard pull capacity of this vessel are in the range of 70 to 160 tones which can meet the requirements of mooring loads in normal situation. With the movement to deep water, the capacity of bollard pull capacity is designed in the order of 150 to 200 tones. So the vessel can be exposed to higher moment during operation. Anchor handling vessels are normally designed with adequate bollard pull capacity and stability and it is rare that the sole influence of wind or wave can lead to capsize during operation. Usually, the combination of wind, waves, and mooring load can bring the vessel into more dangerous situations (Gunnu and Moan, 2012).

3.2.3 The procedures of anchor handling operation

A series of operations to deploy and retrieve anchors for oil rigs or floating platform at a distance is called anchor handling operations. The assisting vessel should be equipped with high bollard pull, stern roller and high handling capacity winches on board (Gunnu and Moan, 2012).

The anchor handling operation should be executed in accordance with work specifications and statutory documents for the purpose of safety. The procedures of anchor handling operation will be discussed by rig, AHTS and their relative parties. In practice, there is not an invariable method which is applied to all of anchor handling operation. The method of anchor handling operation could be alternative according to the weather condition, water depth and equipment installed on rig and vessel. However, basic procedures of anchor handling operation will be discussed in the following parts.

3.2.3.1 Operation Planning

When the requirements of anchor handling operations are mentioned and it is necessary to carry out anchor handling operations according to the situation of oilfield. All of the participating parties are informed and prepare relative information and materials which is required by anchor handling operation. Situation assessments of anchor handling operation are conducted by the rig owner, the operation team of rig, and other relative parties. Situation assessments includes the situation of rig, weather conditions, feasibility of equipment located on rig and risks which can be forecasted and hidden. The next step is to carry out rig move meeting.

3.2.3.2 Rig move meeting

Before performing anchor handling operation, rig move meetings are necessary to be organized by operating company. Participants of anchor handling operation are informed to take part in and sufficient time is arranged for them to review the rig move plan. These participants include:

- OIM/Tow master (preferably the ones on board during the operation) and Representative from MOU owner operations department (and MOU Safety Delegate in the country of the operation)
- Onshore and/or Offshore drilling supervisor for operating company
- Onshore logistics representative from operating company
- Person responsible for navigation company/contractor
- Marine Representative for operating company
- Representative from owner/operator of pipeline/other installation if relevant.
- Additional specialist personnel as required.

The rig move plan needs to take part in criteria relevant to aspects of anchor handling operation. The plan shall include work specification that provides necessary background information on the anchor handling operation and describes the operation at required level of detail. Weather conditions during operation needs to be considered and the coming three days' weather before anchor handling operation needs to be considered. Wave height and the strength of wind should not exceed statutory requirements. The participating parties involved in anchor handling operations will verify and confirm the results of rig move meeting.

3.2.3.3 Preparation of AHTS

When it is available to conduct anchor handling operation after the situation assessment carried out by participating parties, anchor handling vessels are hired and contract between rig owner and vessel owner will be signed which specified the responsibilities and obligations of each parties.

The hire of appropriate AHTS is really important to the safe operation of anchor handling. Competent candidates, abundant experience, equipment on vessel and situation of vessel and other conditions need to be taken into account when rig owner starts to hire AHTS. The selection of support vessels for offshore operations is often based on the experience from similar operations in regions with similar environmental and geographical conditions（Hovland and Gudmestad, 2008）.

Brief meeting needs to be organized by vessel owner and the condition of vessels and the crew manned on vessels should be assessed due to the additional hazardous and hidden risks companied with anchor handling operation. The load equipment and communication apparatus are prepared and checked and it is ensured to be on standing by condition. Vessels and equipment installed on it are checked carefully and ensured to stay on applicative level. The vessel owner needs to inform the preparing condition to the rig owner for the sake of efficient communication and good cooperation between two parties.

3.2.3.4 Preparation

When the anchor handling activities are assessed by rig owner and vessel owner and it is confirmed to be available, the notification of anchor handling activities will be given to the oilfield and preparation work is started to be done. On one hand, after receiving the notification from the rig owner, the rig which will be towed and handled anchors starts to prepare the previous work before activities. The rig is prepared and be appropriate to carry out anchor handling activities. For example, the competent crew members, the balance condition of rig, foods reserved for the following days, equipment condition under load, and other aspects needs to be taken into account. Risk assessment on rig is necessary to be taken due to the high risk when carrying out anchor handling operations. On the other hand, the vessel which is called AHTS exactly starts to conduct job safety analysis (JSA). The procedures of anchor handling activities are disassembled and the risks are analyzed when conducting JSA. Preventive measures are scheduled and prepared after realizing the risk or hazardous.

The vessels start to prepare and conduct anchor handling activities after risk assessment. Safety meeting is required to organized and competent crew members are assembled and understand the situation of anchor handling operation. Equipment like winch, towing lines, sharks are checked and verified and are ensured to be in appropriate situation. The JSA and work schedule of AHTS is completed and delivered to rig which will conduct the anchor handling activities under the cooperation of AHTS. The agreement between these two parties will be made and operational conditions are verified. The preparation work of AHTS and rig will ensure a high safety level and reduce risk due to their careful effort.

3.2.3.5 Receiving PCP from rig

The master of the AHTS maneuvers the vessel carefully and get close to the rig. During the approaching process, AHTS always has a MOB boat ready to be launched when crew are in the aft deck of vessel. For considering the complexity and high risk of anchor handling operation in deep water, there are three or more AHTS have been put into operation. The main AHTS which possess strong power and high performance goes into position where the length is appropriate for towing operation when there are any emergency or it is necessary to tow the rig.

When the vessel get close to the rig and get ready to receive PCP from rig, the vessel and the crane on rig must agree on work process through risk assessment and simultaneous operations are avoided due to its high potential risk which will result injuries to crew members who work on the deck of AHTS.

The crane hangs out the PCP and lowers to the deck of AHTS slowly under the command of chief officer or bosun (in North Sea). The crew in the deck must pay attention to the head of pennant and avoid to be hit by the pennant or the crane block. The master keep vessel in position until deck crew connects the pennant and work wire. After landing on deck, the pennant was secured on shark jaw (figure 3.6) and connects to the work wire. There are 5 or more links at the end of pennant and it is used to avoid lifting the socket when securing the pennant on shark jaw. Deck crew should try to shorten the time when standing nearby pennant line which is in tension.

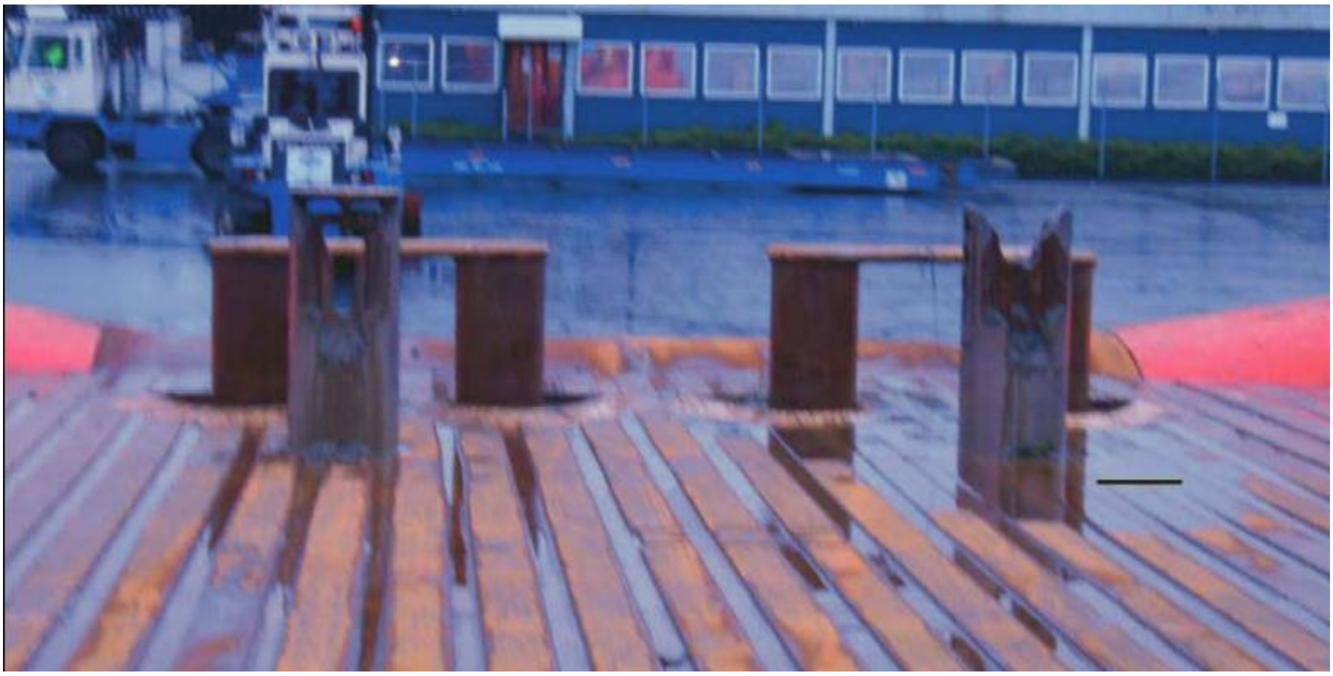

Figure 3.6 Photograph of shark-jaws and towing- pins

The crew members in the main AHTS throw a line into the rig through hand or equipment. The line which connects with the pennant line (PCP) on rig is pulled into the deck of AHTS and pennant line is connects to the towing line on AHTS.

3.2.3.6 Position for picking up buoy

Before the use of chasers, all anchors were buoyed off. With the increasing number of mid line buoys and inserts, this practice is reappearing. Normally, a pennant wire is 120 or 150m long, 77mm diameter wire with hard eyes on each end.

The master of AHTS maneuvers the vessel and close to the buoy which connects to the anchor of rig in order to get the anchor efficiently. The chief officer of vessel organizes crew members who carry out activities on deck. As the AHTS get close to the buoy, sailors get ready to pick up the buoy. They use nylon line to pick up the buoy. Two man stands on the aft of deck and with both end of the same line on hand, when the aft of vessel get close to the buoy, they throw the line and get the buoy and drag the buoy into the deck through winch. When the buoy crosses over tow pins on aft of the vessel, the shark jaw which locates before pins lifts up, and locks the head of line which connects to the buoy. The towing line on vessel winch connects to the pennant line of buoy and tows the buoy up on deck.

3.2.3.7 Grappling

Grappling is a common method used to grapple the chain which is connected to anchor. A grapnel is carried on deck with a notch cut in the flukes to take wires of about 85mm diameter. Grapnel is used for recovering chain or wire form the seabed where the anchors of rig are positioned. A length of chain is inserted between the grapnel and the work wire and the grapnel flukes in to the sea bottom, thus the grapnel lies under the wires which connects to anchor and lies on sea bottom.

Usually, the chain between the grapnel and the work wire is put out twice the water depth and try to steam across the wire to be caught. Normally the wire laid down on sea bottom can be caught. While the problem is that, the wires lay down is dropped short and its weight is small so the weight of wires cannot be observed on winch display until the wire comes tight heaving in.

If recovering a broken chain the grapnel immediately locks on, and tension rapidly rises. AHTS steams slowly away from the rig while recovering, to prevent the chain twisting up which the work wire tends to cause as load comes on.

3.2.3.8 Chasers and their application

In traditionally, anchors of rig are equipped with a buoy for picking up and it is retrieved by pendant wires which are connected to pendant eye situated on the anchor for the purpose of facilitating handling. However, in deeper water higher anchor break-out forces are encountered and it results in longer and heavier pendant wires and consequently larger buoys. The continuous movement of the buoy by the waves will cause wear to the pendant wires, especially for the pendant wires close to the buoy. If the pendant wires are broken and the buoys float free, the anchors are much more difficult to find and recover.

To overcome these disadvantages, chasers were introduced. Chaser is a kind of rings which chased along the cable towards the anchor and back again to a rig. With the aid of chasers, pendant lines or buoys are not compulsory to be employed. The use of chaser system eliminates buoys and it will reduce wear on the system. Figure 3.7 and figure 3.8 are common chasers widely used in anchor handling operation.

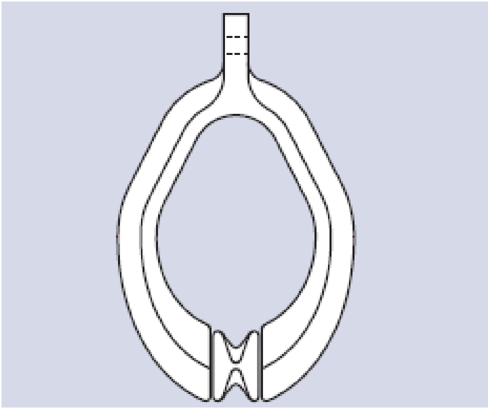

Figure 3.7 The permanent wire chaser (source: Vryh of Anchors)

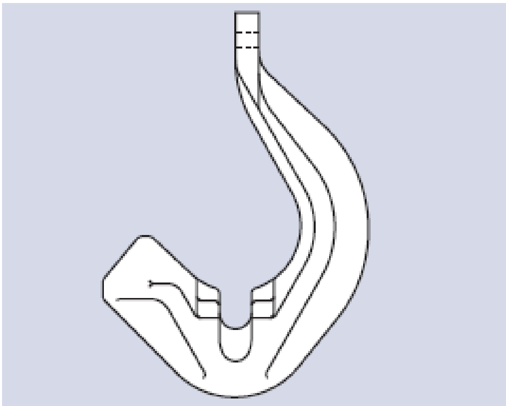

Figure 3.8 The J-lock chaser (source: Vryh of Anchors)

3.2.3.9 Heaving up anchor

Before heaving anchors up, chasers are widely used in deep water during anchor handling activities. The deck crews receive the chaser from rig and connect it with the work wires. The vessel should be kept in position and avoid strong movement during this operation phase. In order to reduce the wear resulted high interface pressures between chaser and mooring lines, tension on mooring lines should be ensured before chasing. During the chasing process, tension should be kept on the chaser all the way out to anchor. A kind of materials that is softer than the steel used for the mooring line is employed, so the wear is taken by the chaser and not the mooring line. The high interface pressure arise from pulling the chaser along a slack mooring line and maintaining high tension in the chaser work wire when chasing a tensioned mooring line. It would be best that mooring lines are fully tensioned during the chasing operation. The permanent chaser is captive on the mooring line and will not become disengaged due to slack work wire.

The length of the chaser pendant line should be at least 1.5 times the water depth for the purpose of optimum chasing operations.

During the process of chasing, the vessel must be aligned with the anchor line which can reduce the wear between the chaser and anchor line. The master of the AHTS controls the speed of vessel and tries the best to avoid sudden tension which can breaks out the pennant wire of chaser when anchor is stuck in sea bottom. If the anchor is stuck in the seabed, there is a risk of the pennant breaking. When the chaser get close to the anchor which deployed on sea bottom, the tension of pennant wire starts to strengthen and sufficient tension on wire should be kept until the weight of the anchor line is greater than the weight of anchor. Then the anchor is heaved up and pulled over stern roller. During this process, large force is involved and wire may break. Therefore, the aft deck is empty when heaving up anchor for the purpose of avoiding injuries. Clay, up to two-thirds of the total anchor weight, may be brought up and render the deck slippery and inaccessible.

In deep water, the weight of the anchor line becomes of predominant importance (Vryh of Anchors BV, 2010). If the weight of anchor lines is larger than 8 times the anchor weight, the anchor could be pulled against the chaser as illustrated and it could even position itself upside down. During this situation, damage might occur and it is difficult to boarding the anchor (figure 3.9).

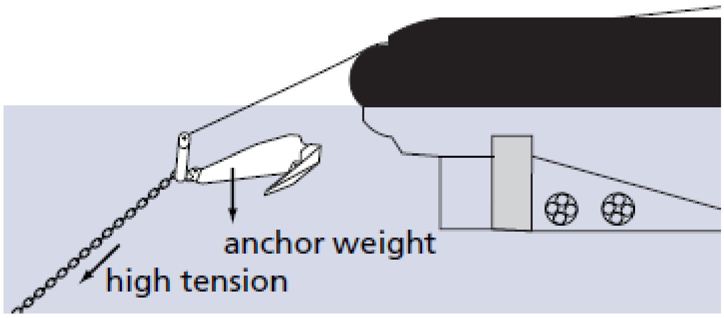

Figure 3.9 damage might occur (source: Vryhof Anchors)

If the weight of anchor line is reduced, the situation illustrated above could be avoided. A preferred solution is to pull the anchor from the bottom and have the rig haul the anchor line which will allow the boarding of anchor near the rig where loads are smaller. An alternative method is to hang the anchor line up and reduces the load of anchor line. This can be done by lifting the anchor line using a lock chaser or grapnel handled by a second vessel.

It is recommended to board the anchor with the chain between the fluke. While there may be another problem that the anchor may be pulled over the roller on the wrong side. Damage to shank and fluke might occur when the chain is hanging over the anchor due to the large forces. To overcome this, a common method is used and the anchor is hung up under the stern roller for a moment before heaving up on deck. The anchor will rotate itself under the twist moment. The vessel is turned to free the anchor line from the anchor and haul gently. The anchor can be heaved up on deck when is come up with right side. However, this situation should be avoided as damage may occur.

3.2.3.10 Racking the anchors

After heaving up the anchors of rig, anchors of rig are then sent to rig and racked on the bolster of rig. Rig heaves in anchor line and the AHTS keeps sufficient tension in pendant with chaser remains in tight contact with anchor. Thus anchor remains correctly oriented.

The rig hauls the anchor line and the AHTS keep sufficient tension on the chaser and move towards the rig according to the hauling speed of rig and the load situation of anchor line. At some distance from the rig, AHTS pays out winch wire while keeping sufficient bollard pull (at least 1.5 times anchor weight) to keep chaser on anchor head. Under the tension and effect of gravity, the anchor flukes point towards the rig and it is effective to rack the anchor on the bolster. Rig hauls the anchor line and the AHTS adjust the course according to the situation. When the anchor arrives at bolster, AHTS reduces tension to 15 tons and rig haul anchor line in tension. As soon as the anchor is resting on bolsters, AHTS slack pendant wire completely and send the pendant line which connects the chaser to rig.

3.2.3.11 Deployment of anchor

Deployment of anchors is an important activity during anchor handling operation and it is completed under the assistance of one or more AHTS. It is common to use chasers for handling anchors of rig and the use of permanent pendant line is similar to the use of chasers.

Laying anchors

The anchor is preferred to be decked on the AHTS before running out as the requirement of operators. AHTS takes the anchor and chaser on deck, pulls out the work wire from the rig. The work line should be kept between the flukes of anchor during the process of running out anchor line. The AHTS increase power until anchor line tension rises on rig winch tension meter. The anchor line is run out the full distance with anchor on deck or on roller sometimes.

Once the primary anchors moves, the assisting vessels could be used to take the weight of the chain at the rig end (figure 3.10). And once the wire is deployed they could move to a position astern of the main vessel and take some of the weight, once more to reduce the possibility of damage.

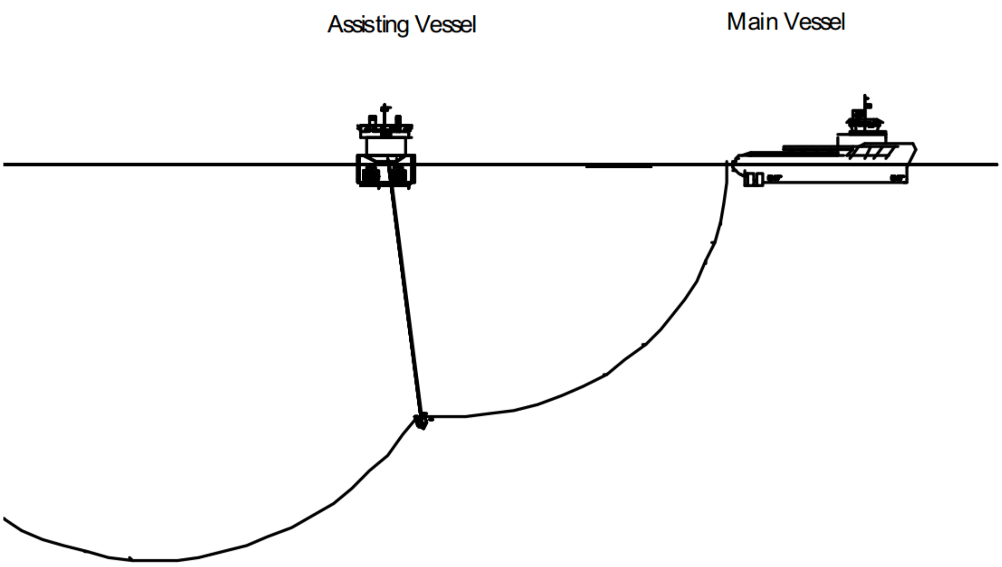

Figure 3.10 Cooperation between assisting vessel and main vessel

As the tension reach the expected requirement, rig gives order to lower the anchor and the AHTS pull out towing line till anchor arrives at roller. If anchor is kept on roller, keep triangular plates below the main shackle on the drum for stability of the anchor. The chaser can be kept on deck or roller. Under this situation, the propeller thrust passes underneath the anchor and will not influence the fluke.

AHTS reduce the propulsion when lowering anchor across the roller after receiving the order from the rig and keeping chaser on anchor head for control of anchor orientation and lowering anchor. Once below the propeller wash zone, constant tension is kept in order to ensure that anchor does not fall through chaser if the weight of anchor is lower than the load of working line which is connected with anchor and oriented to the rig. Constant tension could keep the anchor in the chaser and oriented correctly. In some circumstances AHTS prefer to run the anchor hanging from the pendant line below the propeller wash approximately 60 to 80 meter above the seabed due to this method requires less power on the winch during the actual laying of the anchor (Vryhof Anchors, 2010).

It is real important to communicate between the AHTS and rig especially when the anchor hangs 10 to 15 meter above the bottom. The AHTS stop lowering anchor and then inform rig which then instruct AHTS to pay out pendant line until it is about 1.5 times the water depth. AHTS increases power till tension is again seen to rise at the rig. The rig commences to pull in slowly and the AHTS further increase power until tension rises further at rig winch. At this moment rig gives order to AHTS to lay the anchor. AHTS immediately stops the propulsion and is consequently pulled back-wards. AHTS pays out pendant line and maintains paying out pendant line after anchor has landed on the bottom till a wire length of 1.5 to 2 times the water depth is out. Enough wire must be paid out not to disturb the anchor during buoying off or waiting.

Rig continues heaving the work wire to a sufficient load and embeds the anchor fully and creates confidence in good setting for the load can examine the holding capacity of anchor. This can also strengthen the stability to the anchor when stripping the chaser back. The AHTS cannot pull the pendant again when the anchor is loaded in seabed because it may land upside down. The rig keeps the work wire in tension and AHTS can retrieve the chaser and return to the rig. The wear between the chaser and work wire can be reduced when the work wire is in tension and the chaser can be retrieve easily without too much friction.

Piggy-back methods
If the first anchor is not supposed to possess enough holding capacity, the second anchor is connected at 3 to 4 shank lengths distance from the first anchor which is not influenced by the pull from the second anchor. This method is called piggy-back methods. The holding capacity of the piggy-back method may be up to 2.5 times the holding capacity of the individual anchors, due to the extra penetration of second anchor. For optimal performance of the combination, the pendant line between the two anchors should be wire rope, to promote penetration and obtain better holding capacity (figure 3.11, Piggy-back method).

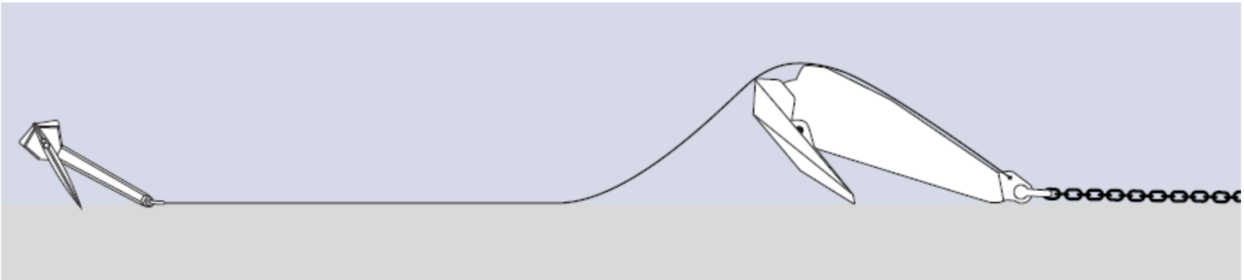

Figure 3.11 Piggy-back method

According to OLF/NSA Guidelines for Safe Anchor Handling and Towing, the wire between the piggyback anchor and primary anchor shall have a breaking load of a minimum of 70% of the holding tension of the primary anchor. The wire between the piggyback and primary anchor shall be fastened to pad eye or bridle. The piggyback anchor shall be adapted to the sea bottom conditions based on the site survey (OLF/NSA, 2003).

In piggy-backing method, several alternatives are employed to positioning the semisubmersible. One method is using a Stevpris anchor (non-hinging) in combination with a Stevin anchor (hinging). The Stevpris anchor is main anchor and the Stevin is back-up. This is the best solution when using a fixed shank anchor as the fluke of the Stevpris anchor cannot be pulled closed. The pad eye near the anchor shackle is connected with a pendant line and the performance of anchor is not influenced.

Another popular method is using two Stevpris anchors. The holding capacity of the combination of two Stevpris anchors may be equal or higher than the sum of the individual holding capacities of the anchors. The installation procedure of two Stevpris anchors in piggy-back is as follows:

- Pay out the main Stevpris anchor, with the mooring line connected to the anchor shackle and the pendant line (wire rope for optimal performance and approximately three times the shank length of the first Stevpris anchor) connected to the padeye behind the anchor shackle.
- Connect the other end of the pendant line to the anchor shackle of the second Stevpris anchor.
- To lower the second Stevpris anchor to the seabed, a second pendant line is connected to the padeye behind the anchor shackle.
- Using the second pendant line, the Stevpris anchors are lowered to the seabed and positioned and buoyed off.

- The Stevpris anchors are then tensioned by pulling on the mooring line (figure 3.12) (Vryhof Anchors, 2010).

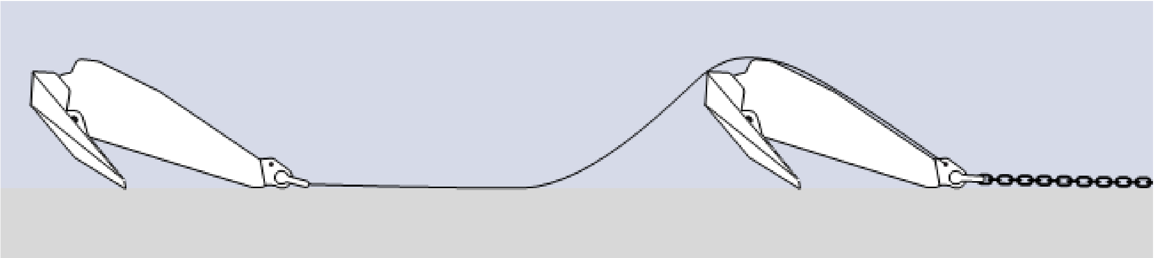

Figure 3.12 Tensioned Stevpris anchors

The piggy-back anchor should be laid in line with the mooring load, otherwise the piggy-back anchor makes the main anchor unstable. Wire rope is prefered to be employed as pendant line between the two anchors for the purpose of optimising performance of the combination. The holding capacity of the combination will be promoted the penetration will be strenthened.

3.2.3.12 Towing operation

Towing operations are common to be carried out in oilfield activities. In recent years, study of response of an offshore towing system to random sea becomes more important than before because of the increased "water depths for which platforms are now being designed" (Pajouhi, 1981).

Semisubmersible will be towed towards another position after its anchors are heaved up. Since uncertainties are unavoidable in determination of forcing functions, structural behavior and tolerances within fabrication and installation methods, therefore the tool of engineering analysis should include concepts and methods for evaluating the significance of uncertainties and its implication on the design and performance of the towing system (Pajouhi,1981).

Before conducting the towing operation, operation planning is completed under the work of involved parties and it includes the responsibilities of involved parties and the passage plan must be carefully developed with regard to water depth, other offshore and subsea installations, and emergency position. According to NORSOK STANDARD (1997), towing systems shall comply with the requirements of a recognized authority /recognized classification society and flag state requirements.

Towing pins and towing eyes

According to the ABS rules, towing pins and towing eyes (figure 3.13), if provided, are to be integrated into deck structure. Towing pins and towing eyes are to be capable of sustaining the breaking strength of the towline considering the most extreme line arrangement without exceeding the stress limits (ABS, 2011).

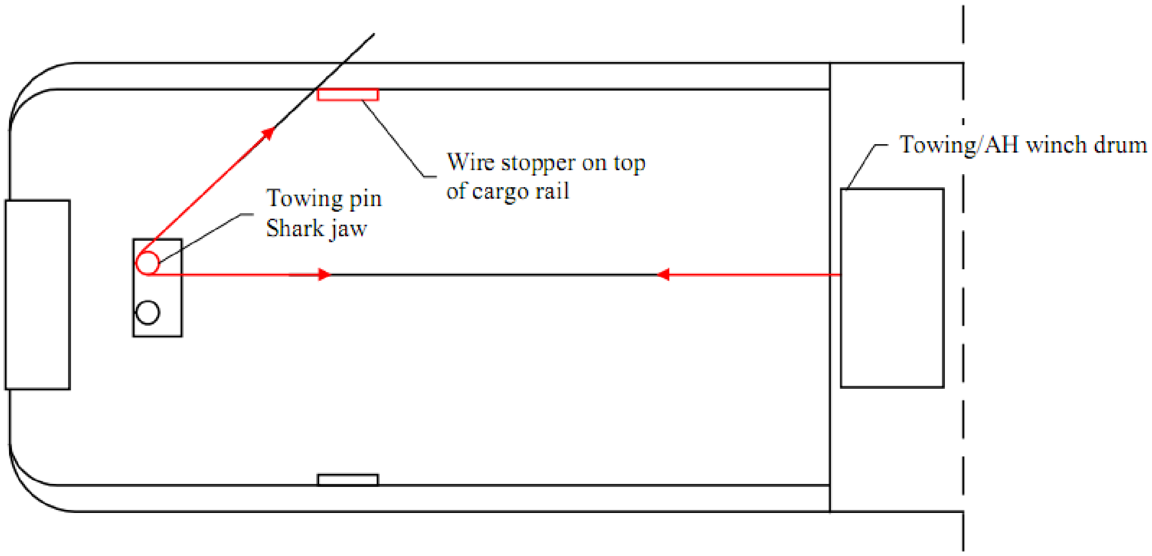

Figure 3.13 towing pins and towing eyes

The procedures of towing

After all of the anchors have been secured on the stern deck of vessel or have been racked on the bolster of rig, the rig starts to prepare for towing operation. The towline may be either steel wire or fiber rope of the appropriate diameter. The breaking strength of towline is to be not less than the Reference Load (RL) (ABS, 2011).

The master of AHTS gets ready to receive the permanent chaser pendant (PCP) from rig when receive the order for towing the rig. The vessel should be kept in position where keep a certain distance from the rig and detect whether the vessel can be kept in the position or not for the sake of safety consideration. The vessel and crane on the rig must agree on work process through risk assessment and avoid simultaneous operations. The crane low down the PCP and send it into the deck of vessel slowly. The master of AHTS should kept the vessel in position and avoid strong movement which might cause the collision between the vessel and rig or human injuries. The PCP is secured on shark jaw and connects to the towing line of AHTS. Two pins located in the stern deck of vessel are lifted up and the top surface of pins are touched with each other which can ensure the PCP or the towing line will not move towards the both sides and it will avoid the injuries cause by the sudden tension of towing line or PCP.

The shark jaw will not open until the PCP is confirmed to be connected with towing line. The towing line is then slacked and vessel starts to move forward. The distance between AHTS and rig cannot be too short to take action in case of emergency and avoid collision. Close attention should be paid to the length and catenary of the tow wire and its relation to the water depth and weather conditions.

During the towing operation, the route must keep safe distance from any other installations in case of break-out or towline failure. The officer of AHTS should pay close attention to the towing speed and heading. Changes should be made very slowly and in a controlled way if there is a necessary. Regular navigational warnings should be issued by towing vessels and other vessels can avoid break into operational areas. A second AHTS should be arranged and it navigates in the ahead of the main towing vessel for the purpose of safety and it can take emergency action if there are any emergencies. Figure 3.14

shows the righting arm and heeling arm curves.

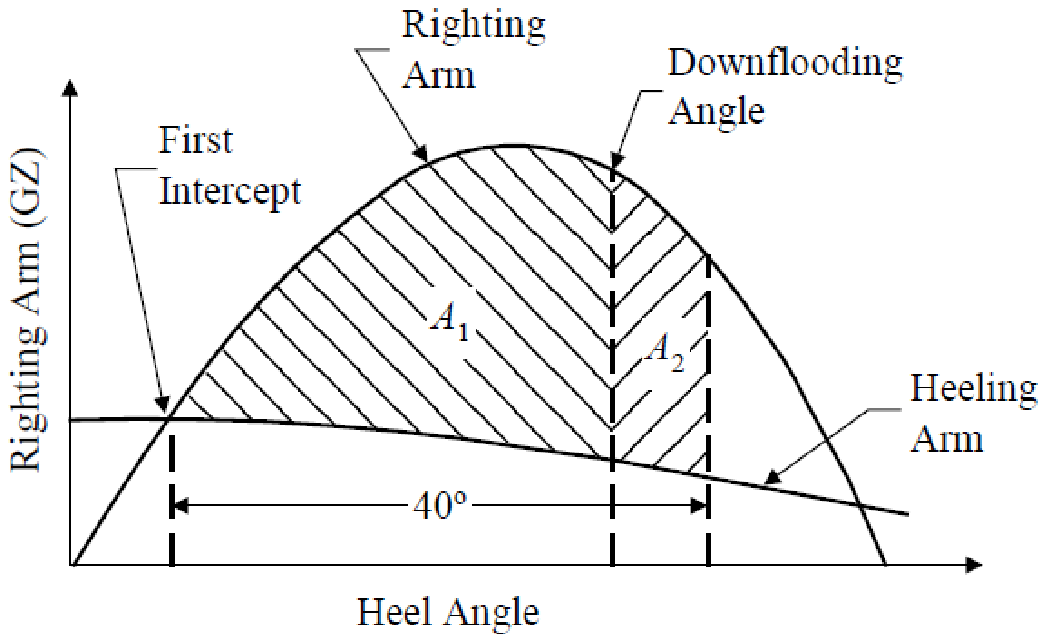

Figure 3.14 Righting Arm and Heeling Arm Curves

3.3 Experience requirements

All personnel shall be qualified for their assigned work. Qualification requirements shall be specified for job categories of significance to safety (NORSOK STANDARD, 1997). Anchor handling operations are complicated offshore activities which require competent personnel for the safety consideration. Due to the nature of anchor handling operation, participating personnel must additionally be familiar with all aspects of such operations (NWEA Guidelines for the Safe Management of Offshore Supply and Rig Moving Operations).

3.3.1 Master

The master of AHTS vessel need to possess relevant experience on the vessel class or design he is aboard. Before commanding anchor handling assignment, the master of vessel should perform at least 5 rig moves accompanied by an anchor handling experienced Master, or a suitable combination of rig moves and simulator training (NWEA Guidelines for the Safe Management of Offshore Supply and Rig Moving Operations). The master of vessel having previous anchor handling experience as master or chief officer is acceptable to command anchor handling assignment if he has an overlap period of at least 14 days with an anchor handling experienced master and at least one anchor handling operation must be performed during this period. The experience of commanding anchor handling assignment can be gained by chief officer who then is competent for master of AHTS.

A competent master who is familiar with the anchor handling operations can control the process of anchor handling operation and foresee the risks existed in the operation. Appropriate distance between AHTS and the rig and the tension of work wire should be controlled in a short time and adjusted to the offshore situation. Competent experience of a master is significant for the safety and success of anchor handling operation.

3.3.2 Officer

Besides master of AHTS is required for suitable experience, officers who are important team members in anchor handling team also needs to possess relevant experience. They shall be familiar with anchor handling operational guidelines on safety, and with safe use and limitations of equipment (NWEA Guidelines for the Safe Management of Offshore Supply and Rig Moving Operations). Chief Officers or officers in charge of the watch should have previous anchor handling operations experience of at least 5 rig moves or a suitable combination of rig moves and simulator training. Ship Owner shall document the officer’s compliance with this requirement. If supervising anchor handling work on deck, the officer must have anchor handling experience and be competent in anchor handling procedures and guidelines, anchor handling equipment set-up and function, and be familiar with associated hazards and risks. Officers working on the bridge during anchor handling and have tasks that may affect the safety of those working on deck shall be familiar with anchor handling deck work operations and the associated hazards and risks (NWEA Guidelines for the Safe Management of Offshore Supply and Rig Moving Operations)..

3.3.3 Winch operators

Winch operators also should be competent in the winch operation and safety system. Winch operating is a key factor which controls the tension of work wire or winch wire and the winch operator must be familiar with the functions and limitations of the winch he operates. A competent winch operator should accept relevant training and be issued certificate. The winch operator needs to pay careful attention to the order of the commander on deck and take correct actions promptly. Negligence may cause unexpected damages or human injuries.

3.3.4 Vessel Deck crew

Deck crew is the group who carries out the anchor handling operation directly and be exposed to risky situation for a long time. Personnel assigned anchor handling work on deck during anchor handling operations shall be familiar with guidelines and procedures for anchor handling activities. They use UHF/VHF radio and communicate with officer on bridge or under the command of chief officer or bosun according to the real situation and working area.

3.3.5 Safety training

All personnel on board vessels participating in marine operations shall have valid safety training. Appropriate simulator training is a valuable tool which is employed to train personnel who is going to take part in anchor handling operations. Simulator training can qualify personnel with relative experience and knowledge of anchor handling operation and maintain relevant competencies without exposed to risky operating site.

The anchor handling operations in deep water are new and it is essential to have experienced personnel on board rig and vessels. Experienced personnel can reduce risks which exist in the anchor handling operation and can help others avoid injuries during operation. Generally the training of experienced personnel who can be competent for anchor handling operation will take a long time and costs a lot due. So experienced personnel are always treated as the treasure of a company if it realizes how important experienced personnel are.

Chapter 4 Risk for AHTSs with respect to operations

4.1 The background of risks for AHTS

Considering the soaring market for oilfield services, companies with strong insights start to explore the global offshore support vessel (OSV) market. The size of the vessel fleet and employees are expanding quickly and are put into operations after short training periods. Risk is also an important criterion that companies have to take into account when considering market expansion as the oilfield services market is a high investment, high technology and high risk industry. Among those operations conducted by offshore support vessels (OSV), anchor handling operations and towing operations are listed as the most risky operations compared with the other operations.

For a fast development of fleet size and employee number, oilfield services companies have to rent vessels from outside and recruit new employees in order to meet the requirements for quick development. Risk analysis should be conducted and be used to detect risks existing in the operation of AHTS.

Risk analyses are often performed to satisfy regulatory requirements. It is, of course, important to satisfy these requirements, but the driving force for carrying out a risk analysis should not be this alone, if one wishes to fully utilize the potential of the analysis. The main reason for conducting a risk analysis is to support decision-making. The analysis can provide an important basis for finding the right balance between different concerns, such as safety and costs (Aven, 2008).

Aven (2008) states that by carrying out a risk analysis one can establish a risk picture and compare different alternatives and solutions in terms of risk, identify factors, conditions, activities, systems, components, etc. that are important with respect to risk. One also can demonstrate the effect of various measures on risk through risk analysis.

4.2 For company owned vessel

For company owned vessels, the risk or uncertainties can be classified into delays in fabrication, long time in dock, long maintenance periods, lack of maintenance and incompetent experience, etc. These risks are summarized in Table 4.1.

4.2.1 Delays in fabrication

The offshore support vessel (OSV) market witnesses a booming period after the recession period and OSV companies try to give orders for shipbuilding to OSV manufacturers. Obviously one who takes the market first will benefit from it firstly. So the schedule of OSV manufacturers is tight. The experience and reputation of OSV manufacturers are also to be evaluated as the quality of their products will determine the later operation and maintenance. At the meanwhile, the process of fabrication of a vessel is a long and complex process which starts from contract and ends with sea trial to the delivery. Any delay in any stage will cause delay of vessel's delivery which might cause unforeseen loss to the vessel owner.

4.2.2 Long time in dock

An anchor handling tug supply vessel (AHTS) or other OSV vessels require going dock for maintenance and repair after a regular operating period or when there is a necessity to go to dock. In most shipbuilding companies, docks are considered as the most important resources. So the schedule for the building process in the docks is made first so that the docks are fully utilized. Schedules for the other processes (like ship maintenance) are made considering the dock schedule, other restrictions and resources pertinent to each process (Kim, Kang and Park, 2001).

The cost of operation of AHTS is high and it includes the fuel, human cost, management cost, and the depreciation and so on. After putting the vessel into operation, the day rate of AHTS is high and the longer time the vessel staying in dock, the greater loss the vessel owner will encounter. And along time in dock will delay the offshore assignment which is important to the operation of oilfields and will cause a bad impact on the reputation of the vessel owner.

4.2.3 Lack of maintenance and human factors

Proper maintenance is beneficial to the fluent operation of AHTS vessel and lack of maintenance will increase the probability of occurrence of failure.

Risk is defined here as the sum product of the unreliability functions and the expected monetary loss for every event in the event trees. The risk functions are specified by plant information and inspection information. Monetary loss is calculated for all expected items related to unscheduled outage and recovery action. Two ways of optimizing maintenance planning are presented below, that is, the optimization of maintenance intervals and the optimization of life cycle maintenance scenarios (Fujiyama et al., 2004).

A great number of important equipment and systems is outfitting an AHTS for its complicated operation. Any wear or weakness of relevant equipment may result in risks or accidents during operation or cause delays.

For the towing wire, it should be maintained carefully and coated with oil for preventing corrosion. And the towing line needs to have changed the heads and the ends at certain period intervals due to constant tension on certain length of wire which may decrease its strength. And the towing winch needs to be checked and maintained during ordinary work, as the failure of the towing winch may result in the breakage of the towing wire or other emergency situations. Anchor handling and towing winches are to be capable of being operated from control stations located on the bridge and at least one additional position on deck with a clear view to the drums (ABS, 2011).

A control station is an important system for AHTS and each control station is to be equipped with suitable control elements, such as operating levers, with their functions clearly marked (ABS, 2011). Wherever practical, control levers are to be moved in the direction of the intended towline movement. The operating lever, when released, is to return into the stop position automatically and is to be capable of being secured in the stop position. The lack of maintaining a control station could cause unexpected consequences which could happen during anchor handling and towing operations.

The quick release device for either the anchor handling or towing rope or wire is to be operable from the control station on the bridge or other normally manned location in direct communication with the bridge. The quick release device is to be capable of disengaging the line at any combination of expected trim and heel (ABS, 2011). The failure of the quick release device will create an embarrassing situation when the anchor handling wire cannot be released and both the vessel and the rig are under an emergency situation.

4.2.4 Experience to handle anchoring operation

An anchor handling operation is one of the most demanding and inherently dangerous tasks performed in the oilfield service industry. It is performed under lots of risk factors like long hours, bad weather, hand and finger pinch hazards and proximity to heavy buoys and wires under strain, etc.

4.2.4.1 Manning levels

Anchor handling operations normally have a high risk potential and it is important that personnel participating in such operations have good knowledge of all aspects of this type of operation (OLF/NSA, 2003).

The crew levels that are to carry out anchor handling assignments on board vessels should be determined and certain circumstances shall be taken into account. The neglecting of the minimum rest hours the crew on board should have, will easily make the crew members fatigue, especially when the anchor handling operation may go on continuously for several days.

4.2.4.2 Risk of collision between vessel and rig

When the vessel steers nearby a rig, the collision between vessel and rig is possible due to human factors and natural factors. The vessel master or officers sometimes are pressured to carry out operations where safety of vessel, installation or personnel is prejudiced and their original thought is that it is unsafe to undertake the operation under the current situation. The vessel master may lack the experience of facing complicated working situations and take wrong decisions which may result in collision between vessel and rig.

Under unfavorable weather situations like high wave height, unfavorable wind direction, poor visibilities, etc., the master may not be able to control the vessel and the vessel could move towards the rig and collide with the rig.

4.2.4.3 Risk during the anchor handling operation

Anchor handling involves a number of special marine operations. Risk exists in the anchor handling operation and should be treated carefully. Realizing the probability of risk is beneficial to conduct the operation safely and fluently.

The high tensions experienced in chains and wires may cause high heeling moments and may cause high transverse and/or astern movements of the anchor handling vessel. The vessel's motion through the water may also be affected by high hauling speed on the anchor handling winch or as result of any loss of bollard pull (Anchor Handling Manual).

The success of heaving an anchor from the seabed can be determined by the pulling tension which exist in the towing line and the weight of anchor cannot exceed the pulling tension or the vessel may be pulled astern at speed. Continuous thruster power should be kept when the anchor handling operation is carried out under high tension. If any simultaneous loss of thrust happens during pulling the anchor, considerable extra transverse force will be produced and a significant disaster may happen.

When people secure anchors on deck, high tension exists and personnel need to keep an eye on the situation and the movement of the pendant wire. Crews should try to shorten the time staying near the strained towing wire as long time exposure on the operating deck can increase the risk of getting hurt.

4.2.4.4 Lack of communication

The crew member in charge of anchor handling operations on aft deck should communicate with crane operator and vessel master effectively and clearly. He needs to report to the vessel master the movements of the vessel and the distance between the stern roller and rig column as the vessel master cannot see this due to the blind zone. The communication with the crane operator should be agreed and simultaneous operations are avoided for the sake of safety. Crews working on deck may be hit by the heavy hook or goods hung on it when performing works on aft deck. Table 4.1 gives relevant risks for company owned AHTS.

Table 4.1 Risks for OSV operation for anchor handling activities

Delays in fabrication	Uncertainties of OSV market Reputation of OSV builder Unexpected delay at any stage
Long time in dock	Delay offshore assignment Cause bad impact on reputation
Lack of maintenance and human factors	Wear or weakness of relevant equipment Corrosion of towing wire Failure of control station Failure of quick release
Lack of experience to handle anchoring operation	Low Manning levels Unexpected Risk during the anchor handling operation

	Lack of communication Risk of collision

4.3 For rented vessels:

4.3.1 The background of risk for rented vessel

The oilfield services market follows the global economic environment. It will go to booming when the oil and gas price is high and go to recession as the price of oil and gas becomes low. When the oilfield service market starts to recover from a recession, the offshore support vessel fleet may be maintained at low level for reducing cost. Some oilfield services companies cannot support enough and qualified vessel to meet the requirement from oil companies. To overcome this, generally oilfield services companies start to build new OSVs on one hand and on the other hand, they seek suitable OSVs from the free market and rent these under its management.

Renting vessels from outside can improve companies' operating capability and optimize the fleet configuration and maintain or enlarge business size; however, due to the enlargement of the fleet size and increasing complication of fleet management, the risk of operating the rented vessels starts to increase. These risks come from uncertainties on many sides and many uncertainty criteria connect with each other. Fully understanding the characteristics of these risks is beneficial to analyzing the OSV renting decisions scientifically.

4.3.2 Risks of rented vessel

Market risk
The oilfield services market is a fluctuant and flexible market with characteristics of high risk, long recession periods and short booming periods, and it is fast changeable, etc. Carrying out rented vessel operations means that the enterprise enters into the Asset element international market. The building costs of a vessel, second hand market information, requirement from clients, information about market development and other information increase the operating risk of rented vessel.

Management risk
Compared with operating a self-owned vessel, the risk of managing rented vessel becomes higher with the increasing changeability and diversity of the operating market. The OSV Company needs to strengthen its risk consciousness when optimize the proportion of rented vessels and self-owned vessels。According to ISM rules, shipping companies need to operate their safety management system (SMS) effectively. The company should establish procedures for the preparation of plans and instructions, including checklists as appropriate, for key shipboard operations concerning the safety of the ship and the prevention of pollution (ISM Code). The various tasks involved should be defined and assigned to qualified personnel.

System risk

Most of rented vessels operate its owner's safety management system which is different from the self-owned vessel. The problem is that the safety management system varies from company to company and the management of vessels certainly is different in different safety management systems. Operating vessels from different safety management systems will face conflicts or problems inevitably which is about safety management and the prevention of pollution. If the obligation of self-owned vessels and rented vessels cannot be defined clearly, the management risk will become an obstacle for the operation and development of the company.

4.4 Risk analysis

4.4.1 The risk analysis process

In the offshore industry, the probabilities of hazards is not low when compared with other industries, especially for an anchor handling operation which is acknowledged as a high risk operation due to its complexity. This chapter will talk about risk analysis and the appropriate risk analysis methods which are common to be employed in offshore installation and activities.

"The objective of a risk analysis is to describe the risk", i.e. to present an informative risk picture (Aven, 2008). According to Aven (2008), the risk analysis method can be classified in three categories: simplified risk analysis, standard risk analysis and model-based risk analysis. The purpose of these risk analysis methods is the same: to illustrate risk. In the planning phase and operational phase, different risk analysis methods are employed to describe risk. During the planning phase, coarse methods maybe be adopted as there is limited access to detailed information. As the information and data becomes easier to be accessed and the knowledge about the final solution is more abundant, more detailed analysis methods maybe carried out. More detailed risk analysis can be chosen to study the system specifically. One of the main purposes of risk analysis is to provide support for decision-making.

4.4.2 Identification of initiating events

"The risk analysis shall identify the relevant initiating events and develop the causal and consequence picture" (Aven, 2008).Identifying the hazard from the input, output and the process aspect will give the analyst and the decision maker a full perspective which is beneficial to understand the hazard deeply and take action promptly. Several methods exist for carrying out such an identification process, and in Figure 4.1 various techniques/methods that can be used are listed. "A common feature of all the methods is that they are based on a type of structured brainstorming in which one uses check lists, guide words etc., adapted to the problem being studied" (Aven, 2008).

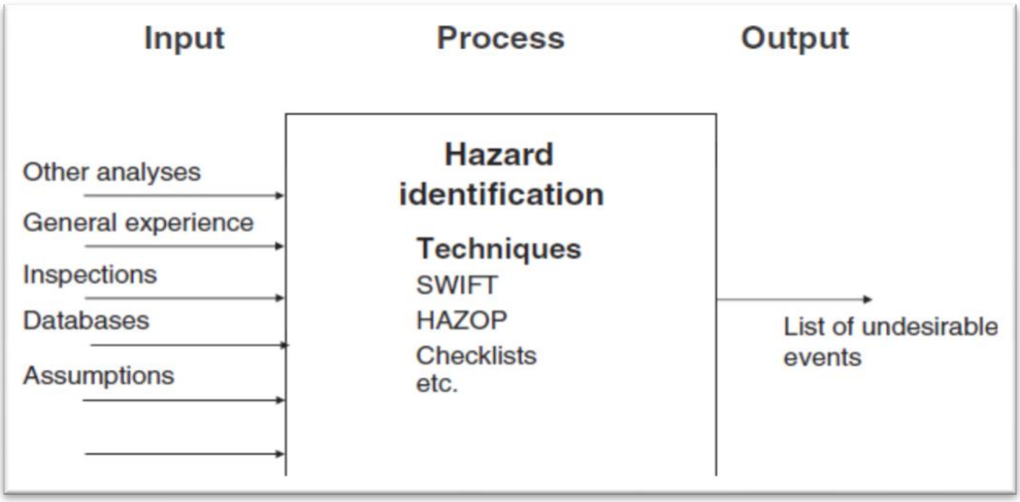

Figure 4.1 Hazard identification. (Aven, 2008)

4.4.3 Cause analysis

In the cause analysis, we study what is needed for the initiating events to occur (Aven, 2008). In the anchor handling operation, the reliability of quick release systems is vitally important to the safety of operation due to unexpected disturbing factors which could break in during the operation. Now we will here simply analyze the cause of a failure of the winch emergency stop system. The fault tree method is an important and widely-used method to help experts understanding risk analysis system. Figure 4.2 is a fault tree which is employed to analysis risk widely in industry. Take Emergency stop system for example, the cause maybe exist due to many facts. Before test, all pumps are not started and if the main winch drum work is not attached to the storage reel, this can be the cause of the failure of the emergency stop system. The wear of the break and uncoupled main winch drum from the gearbox and/or dog clutch can also be the cause. The failure of the break maybe the result from the wear of the break or the break is not put in the right position. Besides the break, the winch pumps and the winch coupling are also critical contributors to the failure of the emergency stop system.

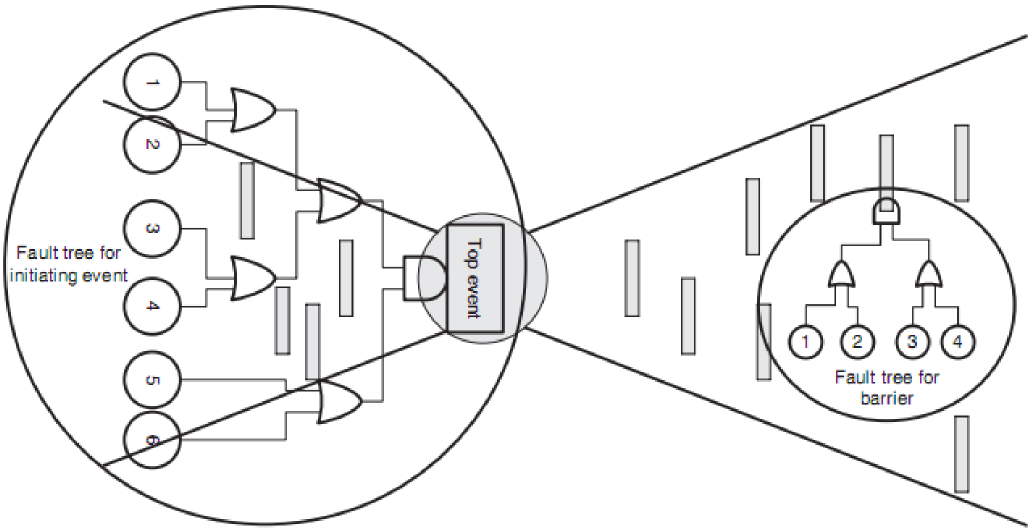

Figure4.2 Use of fault trees (Aven, 2008)

4.4.4 Consequence analysis

For each initiating event, an analysis is carried out addressing the possible consequences the event can lead to (Aven, 2008). An initiating event can result in different consequences of varying characteristics or extent. For example, the failure of the break may result in various consequences according to the effectiveness of the consequence reducing barriers. When releasing the towing wire from the winch, the break can be put in full position or half position according to the operation situation. In the meanwhile, the winch coupling has to be engaged when the brake is on. If the break fails to work, the releasing speed can be controlled by the winch gear and the winch coupling. If the tension of the towing wire is large, the master can adjust the vessel's speed and lighten the tension.

The consequence analysis deals with understanding and realizing the physical phenomena and the expected or unexpected outcomes related to the initiating event. After conducting the consequence analysis, the expert or decision makers can have an image about the activities in full aspects.

4.4.5 Job Safety Analysis (JSA)

A job safety analysis is a simple qualitative risk analysis methodology used to identify hazards that are associated with a work assignment that is to be executed (Aven, 2008).In order to identify and evaluate operational risk on the work-site, a job safety analysis (JSA) is carried out before conducting a task. The use of JSA can improve the safety awareness of the crews and reduce the occurring of risks. JSA is widely adopted in offshore oilfield activities and is even required in most companies' safety management systems or operational manuals. The JSA is based on checklist and each list is directly relative to the job. Firstly the work assignment is identified as a standard operation or normal practice according to industries' experience or companies' requirements. The job is divided into a number of sub-jobs according to its operating characteristics and each sub-job is analyzed by the personals that are going to carry out the job or are involved in the job deeply.

For example, the job of heaving anchors can simply be divided into sub-jobs like followings:

- Preparation before work (check relative equipment)
- Ship goes into position
- Grapple
- Picking up the buoys
- Secure and correct pennant wire
- Receive PCP from rig
- Secure and correct PCP
- Chasing out
- Pull out anchor from seabed
- Heaving anchor
- Pull anchor from stern roller
- Secure anchor line in shark jaw

- Disconnect and secure anchor on deck
- Run anchor line into chain lockers on rig
- Connect anchor line to towing line
- Connect pennant wire to anchor line
- Bolster anchor on rig
- Deliver pennant wire to rig

Often the sheets include a list of actions that are to be considered. The actions may for example be related to improved equipment and tools, better work instructions, improved education and training, and so on (Aven, 2008).

4.4.6 ALARP

In risk analysis, a kind of methods is employed to illustrate the risk when carrying out offshore operations. In this method, risk acceptance criteria are treated as inputs and to evaluate risk. Another method is to adopt the ALARP principle, which means that risk should be reduced to a level that is as low as reasonably practicable. According to the ALARP principle, a risk-reducing measure should be implemented provided it cannot be demonstrated that the costs are grossly disproportionate relative to the gains obtained (the burden of proof is reversed) (Aven, 2011).

The cost of risk-reducing measures is evaluated and the risk reducing measures may be implemented if the cost of implementing the measures is not judged to be large and less than the benefits. If the cost of risk-reducing is considered to be large, more specified evaluations and economic analysis like NPV are conducted. If the benefit is larger than the cost, the risk-reducing measure can be adopted.

Chapter 5 CASE STUDY

AHTS have been playing a dominant role in the offshore oilfield services industry and experts and enterprises that are relative to its operation have focused on these vessels. For their specialty and complexity, statutory rules or guidelines have not emerged until recent years. Especially, the accident of the Bourbon Dolphin vessel let people put more concentration on the management of AHTS vessels and their operations. Many aspects like the following influence the anchor handling operations: the construction in the first phase, competent personnel assigned to the vessel, the risk management during the whole phase, human aspects when conducting anchor handling operations etc. A failure of one aspect or more may result in unexpected consequences or disastrous accidents.

5.1 The introduction of Bourbon Dolphin

The Bourbon Dolphin capsized with the loss of the lives of eight of those on board, while carrying out anchor handling operations at the Transocean Rather on 12th April 2007.

Bourbon Dolphin was a new ship type developed by Ulstein Design, which is a part of the Ulstein Group (NOU 2008). According to the report, the vessel was designated DP2 Anchor Handling Tug Supply Vessel, built and equipped to perform anchor handling, towing and supply operations in deep water. She had a gross tonnage of 2,974 tonnes, was 75.2meters long and 17 meters wide. The vessel had a continuous bollard pull of 180 tonnes and a tension on the main winch of 400 tonnes. The vessel was put into operation immediately; up to the accident, she had completed 16 assignments.

The construction of Bourbon Dolphin satisfied requirements made by the flag state, Norway, and the classification society. For example, it was agreed that the vessel should satisfy the following IMO requirements:
– Resolution A.469 (XII) –"Guidelines for the design and construction of offshore supply vessels"
– Resolution A.534 (13) –"Code for safety for Special Purpose Ships"(NOU 2008).

According to the NOU report (2008), the vessel Bourbon Dolphin, shown in Figure 5.1, was built as a multifunctional vessel that could perform anchor-handling and towing plus supply and services. The vessel was to be capable of operating worldwide with the exception of certain areas such as the Arctic and Antarctic, "US inland waters" and other areas with special restrictions and requirements. The vessel was designed to have a continuous bollard pull of 180 tonnes and was certified for this by DNV on 3 October 2006.

Figure 5.1 Bourbon Dolphin

Some minor changes were made for the arrangement of Bourbon Dolphin and the changes were admitted to be minimal. The delivery of the vessel was delayed due to delays by the subcontractors.

5.2 The vessel’s arrangement

Many tanks were arranged in the vessel to be used for both ballast and cargo (as shown in table 5.1). These tanks needed to be cleaned before changing to another cargo and it would cost time and energy to clean them. Crews on a vessel are reluctant to fill such tanks with seawater when it is unnecessary to carry cargos like brine, barite, bentonite, mud etc. Thus the stability of the vessel is reduced. Before the case of capsizing, the company had not prepared instructions for use of the roll reduction tanks as required by the building regulations. Available training for anchor handling operation was also not meeting the operation requirements. The crews were not familiar with the maneuvering characteristics and stability etc. of the vessel.

Table 5.1 Tank capacities (NOU 2008)

Type	Capacity (m^3)
Fuel Oil	1205
Fresh Water	433
Water Ballast	1765
Brine	583
Liquid Mud	627
Slop	306
Base Oil	173
Dry Bulk	162
Rig Chain Lockers	522

5.3 The introduction of the case

On 12thApril 2007 the Anchor Handling Tug Supply (AHTS) vessel Bourbon Dolphin was engaged in anchor handling operations for the semi-submersible drilling rig Transocean Rather in the Rosebank oilfield (figure 5.2) to the west of the Shetland Islands (steamship mutual).

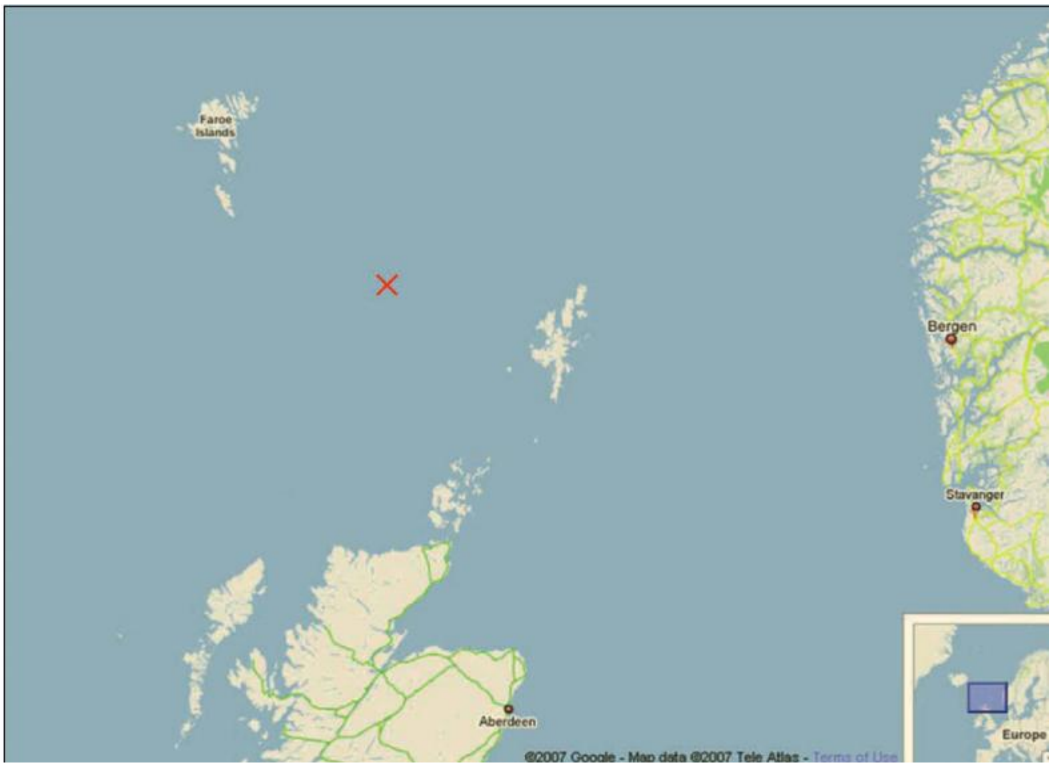

Figure 5.2 The Rosebank Field (source: NOU, 2008)

The semi-submersible drilling rig Transocean Rather was planned to be positioned on an ocean area with water depth of about 1100 meters. Four primary anchors were deployed and the rig was safely moored. Deployment of the secondary anchors, which the vessels had onboard, was then done diagonally and in pairs. Thus one-sided stress on the rig's mooring was averted, as shown in the mooring pattern, see Figure 5.3.

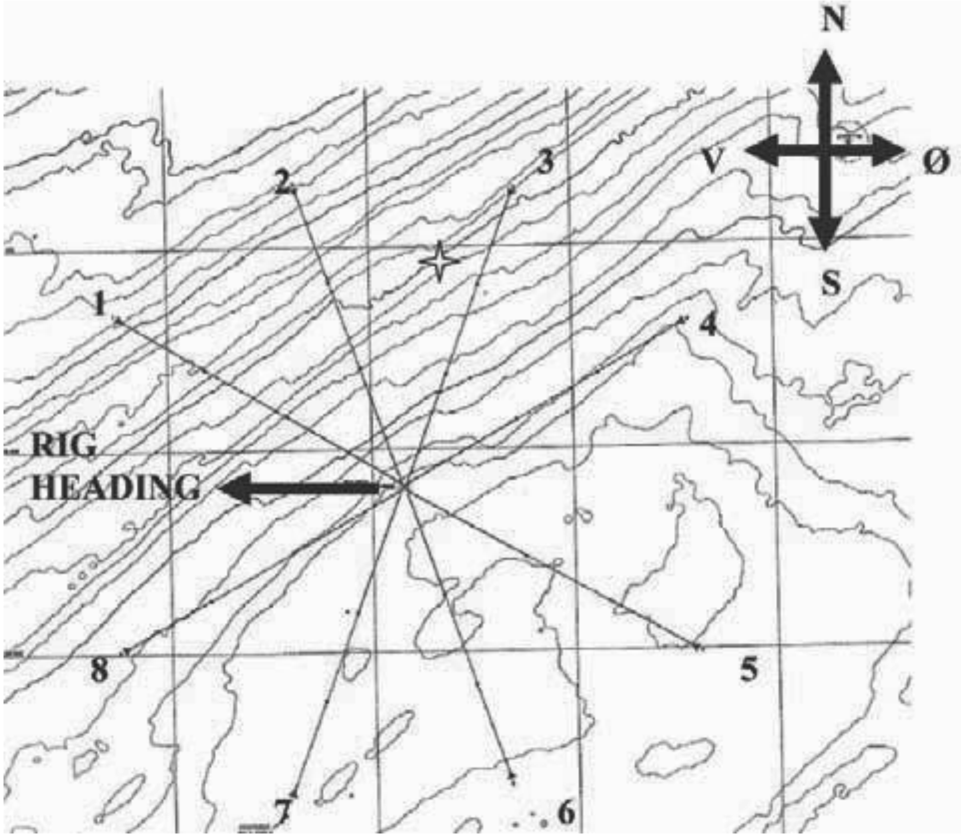

Figure5.3 The mooring pattern of the “Transocean Rather”

The AHTS Olympic Hercules was engaged in deploying anchor no.6 of Transocean Rather. The weather condition and the complexity of the operation showed that it was hard to put the anchor in correct position and high risks existed during the whole operation. Although Olympic Hercules completed the deployment of anchor no. 6, the difficulties of deploying the last anchor no.2 which was operated by Bourbon Dolphin on the opposite side of the rig was not reduced. The weather and sea conditions were really adverse. An increasing wind from the south-west was with 28-knot mean speed and gusting up to 35 knots (measured at 10m height). Wave height was given as 3.4m significant, max 5.9m, according to the forecast. The Bourbon Dolphin felt difficult to keep her position on the planned anchor track and her lateral thruster and engine were used near full capacity. The adverse weather condition and the weight of the mooring chain hanging from her stern put Bourbon Dolphin in a dangerous situation and Bourbon Dolphin had to ask for assistant from the rig. The Highland Valour was sent to assist Bourbon Dolphin and started to grapple the chain so as to lighten the load of Bourbon Dolphin. However, the Highland Valour failed to grapple the chain and a near-miss between Highland Valour and Bourbon Dolphin occurred. The grappling operation was not successful even if the Highland Valour finally got the chain. Both of the two vessels were too near to the anchor no. 3 and the Highland Valour had to release the chain. Unfortunately, the Bourbon Dolphin felt a persistent list to port.

In order to try and enable the vessel to turn to port so that she could be maneuvered back on location the vessel was turned so that the chain on the stern was moved clear of the inner starboard bow pin against which it was resting, which was then retracted into the deck (steamship mutual). The chain was located between the tow pins on the starboard of the vessel like shown in Figure 5.4. The chain then moved sideways rapidly until it was hard up against the port outer tow pin; the inner port tow pin had been retracted into the deck previously. The vessel subsequently listed to port and then righted itself. At the time the starboard engines stopped. The vessel then listed over to port a second time and rapidly capsized. Of the crew of 14, only 7 were saved, the other 7 crew and the Master's 14 years old son were lost or missing.

Figure 5.4 The Bourbon Dolphin with chain located between tow pins (Photo: Sean Dickson)

5.4 Contributory Factors to the Capsize

An accident is often a result of several contributory causes. The direct or proximate and indirect or underlying causes of an accident are many and various, that is to say, some factors directly cause the incident to take place and other factors have not directly caused the occurrence of incident but have contributed to the incident or the failure to avert it. The contributory factors to the accident of Bourbon Dolphin were many and varied.

5.4.1 The design and stability

The principle problem with the vessel appears to be the stability or the lack of it. After the accident, researches and evaluations were conducted and a number of issues with the stability were founded. It was originally designed to have a displacement of 2810t while it was found to have a displacement of 3202t which influenced the stability of the vessel and the maneuverability when carrying out anchor handling operations. According to the design document, tanks should be kept empty when conducting the anchor handling operation while the Bourbon Dolphin found that the vessel had to operate with large quantities of bunker fuel onboard so as to maintain adequate stability according to operational experience. The calculation of stability was not conducted scientifically and proved by classification society. Even if a load computer was equipped in the vessel, it was not put into use in practice. The stability of the vessel was an area of concern.

5.4.2 The rig move plan

The preparation before the anchor handling operation was not carried out well. Any Hazard identification and risk analysis prior to the operation was lacking prior to commencing the operation which naturally meant that the involved parties did not implement their responsibilities well. The weather limitations for the operation were not specified in line with the requirements of interested parties while the weather condition in previous days and during the operation should have been evaluated generally. The Master of the vessel pointed out that Bourbon Dolphin was not suitable for the operation due to the insufficient bollard pull and could only be used as an assisting vessel.

5.4.3The implementation of the operation

Before the occurrence of the accident, Olympic Hercules was fraught with difficulties. However, the tow master and OIM did not evaluate the situation and did not analyze the cause and consequences. Even if the Bourbon Dolphin drifted away from the track line and could not control the vessel back to the location, effective communication was lacking among the tow master, the OIM and the master of the vessel. The tow master took it for granted that the vessel took actions by itself according to the situation while the master of Bourbon Dolphin misunderstood the meaning of words of tow master and lowered the inner starboard tow pin which caused the fatal consequences. The operator’s representative on the rig did not take moral and human responsibility of assuring himself that also the crew of the Bourbon Dolphin were comfortable and safe during the last phase of the operation. He did not understand the scope of the instructions given to the Bourbon Dolphin and the measures proposed. The weather conditions were marginal and the maneuverability of the Bourbon Dolphin was limited. The operation of handling anchor no. 2 ought not to be initiated after considering these combined factors.

5.4.4 Other factors

Emergency release
Back-up systems or tools are always prepared in order to cope with emergency and avoid further damage or lost. In anchor handling operations, emergency release had been activated during the incident but the speed of paying out chain was noted to be only about 12m/min, when it should have been up to 40m/min. The paying out speed of 12m/min was not enough to stop the vessel capsizing by the mooring line.

Experience
Experienced staff is the most valuable treasure of an enterprise. The importance of experienced staff was testified in the Bourbon Dolphin accident. Due to the lack of experience, crew did not understand the

limitation of Bourbon Dolphin clearly and realized the latent hazard of the anchor handling operation. More experience on the part of crew might have helped to prevent the escalation of the event that led to the capsizing. Especially a new Master, who had not been on the Bourbon Dolphin before, was assigned to conduct the anchor handling operation lonely without the accompany of an experienced Master.

SMS for key operation

The ISM system required that the safety management system (SMS) should include key operations while the procedure of anchor handling operation was not included in the SMS. A job safety analysis (JSA) was not performed before the anchor handling operation even if a JSA is acknowledged to be a useful risk analysis method in offshore oilfield services industry.

Chapter 6 Summary and Conclusions

After illustrating most aspects of the AHTSs, this chapter will summarize the main contents of this thesis. Nowadays, the demand for oil and gas energy is high while the explored energy on land cannot meet the energy-consuming requirements of the global market. People's attention shift to the ocean from where they can obtain more energy and business opportunities. People's consciousness of using clean energy is unprecedented high even they consume more energy than previous periods. Therefore, the AHTSs are important vessels putting into offshore oilfield services industry.

AHTSs' activities extend to deep water as the development of offshore oil and gas industry and requirements for AHTSs are increased. An AHTS is a kind of Multipurpose Offshore Service Vessels intended for towing of floating objects in open waters and objects on seabed, subsurface deployment and lifting of anchoring equipment and supply services. Due to their multiple functions, the AHTSs play a key role in the oilfield services industry. In order to ensure the competent performance of AHTSs during their operation, it is necessary to supervise the building of an AHTS strictly as good fabrication can improve the operation of the AHTS in later periods and reduce risks that may cause serious damage and loss. The fabrication of an AHTS needs to follow the rules of classification societies and flag government. Equipment installed on an AHTS and the materials chosen to build an AHTS need to be selected after combined considerations.

The fabrication includes the contract design, basic design, detailed design, parts manufacturing, assembly etc. During the fabrication of an AHTS, good management is required and it is of vital importance to the success of the fabrication of the AHTS.

Before an introduction of the operation of AHTSs is given, the mooring system of semi-submersible rigs is simply explained and those main equipment or systems of a rig are discussed. This thesis illustrates the main operations of AHTSs – anchor handling and towing operations. Before the operation of anchor handling, a rig move plan and the responsibilities of all parties need to be clarified in detail.

The stability of an AHTS is necessary to be checked before putting the AHTS into operation. The stability is directly related to the safety of the vessel. If the stability of the vessel is not ensured, risks may not be averted especially when performing high tension operations like anchor handling and towing.

The procedures of anchor handling operations are concisely described and it varies from vessels to vessels. The anchor handling operations generally include but are not limited to following aspects:

- Rig move meeting
- Preparation of AHTS operation plan
- Safety job analysis
- Receiving PCP from rig
- Position for picking up buoy
- Grappling

- Chasing
- Heaving up anchor
- Racking anchor or securing anchor on deck
- Towing operation
- Deployment of anchor

During the anchor handling operation, experience and technology need to be taken into account. Safety training and risk analysis is necessary to be conducted because any negligence may result in a disaster accident like Bourbon Dolphin.

The risks for AHTSs from the aspects of management and operations are analyzed for company owned vessels and rented vessels respectively. For company owned vessels, the risks include:

- Delays in fabrication
- Long time in dock
- Lack of maintenance and human factors
- Lack of experience to handle anchoring operations

For rented vessels, the risks include:

- Market risk
- Management risk
- System risk

Different risk analysis methods are introduced for anchor handling operations. In a risk analysis one needs to explain the initiating events, causes and consequences clearly and one should provide advice to decision makers especially when facing alternative choices.

The management and operation of AHTSs is not an easy work and a lot of work is required before understanding the offshore oilfield services industry and the increasing function of AHTS. As the development of technology and fabrication improvement, the future of AHTSs is bright even if there are still some challenges one has to cope with in current days.

Chapter 7 Recommendations

With the development of the offshore oil and gas industry, services provided for supporting operations, accommodations, etc. which are required by the offshore installations become complicated and stronger than before. Therefore optimization of the OSV fleet is required from the oilfield services companies. As the main OSV type, AHTSs have been playing an important role in offshore oilfield activities.

The company should pay attention to the fabrication of AHTSs as good quality can strengthen the safety and maneuverability of the vessels. Then, the time staying in dock for maintenance and repair can be reduced, that is to say, the downtime can be shortened and more economic benefits can be obtained. Good form and matched equipment assigned to the vessel can strengthen the reliability of the vessel which is always used for challenging operations. Materials used to build the vessel needs to be of good quality. It seems to be easy to reduce the cost initially using cheap materials, but in the later operation phase it can be shown that using good quality materials is a wise choice and it can sustain the value of vessel in longer period.

The company should strengthen the training of crews on the vessel before high risk operations offshore are being conducted. Anchor handling and towing operations are becoming more challenging than before and current crew number and quality cannot meet the demand for growing deepwater activities.

Risk assessment needs to be carried out before performing offshore activities. Preventive and predictive measures should be taken or prepared in order to overcome expected or unexpected risks during operations.

The habitability of vessel and the working environment on the vessel need to be kept in a comfortable stage and then the crew staying on the vessel can stay on the vessel comfortably and keep good emotions which promote safe operations on the vessel. Staff is the most valuable treasure of the company especially in the high risky industry like offshore oilfield services.

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Appendices

Appendix1 Anchoring Operations and Towing Operations

(Source: NORSOK Standard, J-003, Rev. 2, August 1997)

Anchoring Operations
Anchoring systems on vessels kept in position by anchors (with or without thruster assistance) while performing marine operations, shall:

- comply with the requirements of a recognized authority, and
- be verified to have the required capacity for the proposed location.

A mooring analysis shall be performed by qualified personnel, using a computer programme approved by a recognized authority, to verify compliance with safety factors under the applicable weather conditions.

Less severe than all year weather criteria for a given return period may be accepted as a basis, taking into consideration e.g. time of the year, duration of the operation, distance to nearby installations, possibility to leave the site in an emergency situation.

Duration may be considered as follows:
- Until 3 days: The work may be commenced when the weather forecast provides adequate certainty that the presupposed wave height or wind speed will not be exceeded.
- Duration in excess of 3 days, but where it is possible within 24 hrs to bring the vessel into a condition which will resist greater loads, may be designed for a lower dimensioning environmental load. The operation shall be discontinued if the weather forecast for the next 3 days indicates values in excess of what has been presupposed.
- Duration in excess of 3 days, but where there is no danger of injury or damage to people or to the environment, or of major financial consequences, may be designed with a return period of one year for the time of the year in question. The time of the year should not be calculated less than two months.

Towing Operations
Towing systems shall comply with the requirements of a recognized authority /recognized classification society and flag state requirements.

When required, towing permit shall be applied for.

Appendix 2 The Members of IACS

(source: IACS)
The criteria for membership of IACS are given in the IACS Charter which can be found on the IACS website at 'IACS explained' www.iacs.org.uk/explained/default.aspx .
The Members are:

ABS:	American Bureau of Shipping
BV	Bureau Veritas
CCS	China Classification Society
CRS	Croatian Register of Shipping
DNV	Det Norske Veritas
GL	Germanischer Lloyd
IRS	Indian Register of Shipping
KR	Korean Register of Shipping
LR	Lloyd's Register
NK	Nippon Kaiji Kyokai (ClassNK)
PRS	Polish Register of Shipping
RINA	RINA
RS	Russian Maritime Register of Shipping

The current membership of IACS, together with website links, can be found on the IACS website at 'IACS explained > Members' www.iacs.org.uk/Explained/members.aspx .

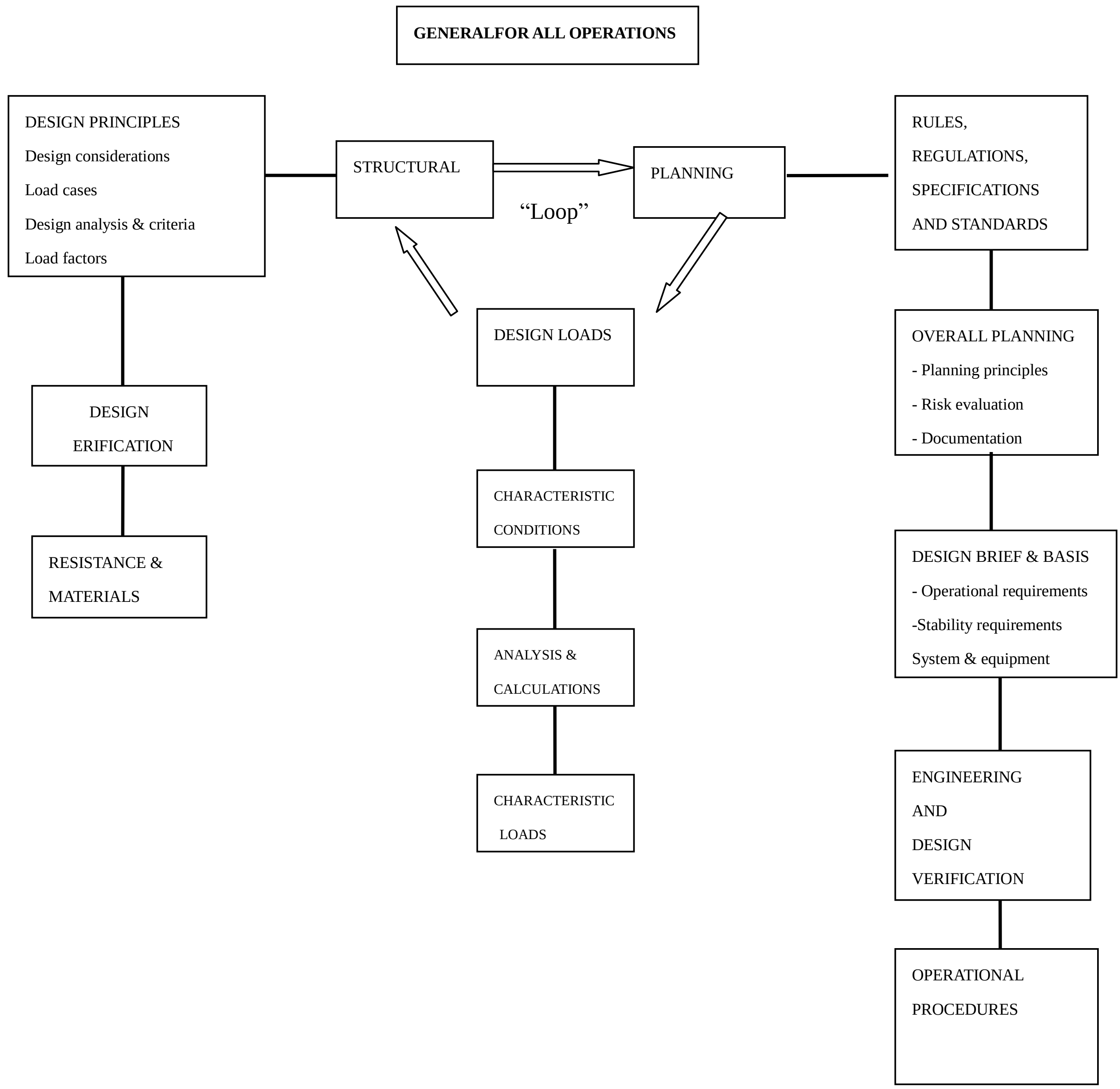
Appendix 3 Checklist for Towing

(Source: NORSOK STANDARD, J-003, Rev. 2, August 1997)

MAIN ASPECTS	KEY ITEMS	DNV Rule Ref.
Planning	Description of intended towing operation	Pt.2 Ch.2
- What	Objects to be transported, number, size, shape and weight	Pt.1 Ch.2 &
	Check that objects are built for the type of loads to be experienced during transportation. Wave slamming in case of cargo hanging over barge deck shall be considered.	Pt.2 Ch.2 Sec.2
- Where	Route of transportation, coastal or open sea.	
- When	Climatic conditions at time of tow	Pt.1Ch.3 Sec.2
- How	Single tow with one or more tugs (multibarge, see 2.3)	
Towing Equipment - Towing line - Barge suitability	Arrangement and equipment for towing. Towline connections, Minimum Breaking Load (MBL)Emergency towing arrangement	Pt.2 Ch.2 Sec.3
	Relevant Barge Certificates to be presented. Consider barge cargo capacity, deck load and need for grillage arrangements to distribute support loads.	
	Sea fastening arrangement to be based on barge motion analysis and strength calculations.	Flowchart & Pt.2Ch.2 Sec.2
	Barge intact and damage stability to be checked.	Flowchart & Pt.1Ch.2 Sec.5
- Tug suitability	Relevant Tug Certificates to be presented. Sufficient bollard pull for intended tow to be documented.	Pt.2 Ch.2 Sec.3
Towing Operation	Marine Operation Manual to be worked out and followed.	Pt.1 Ch.2 Sec.4
	This shall include weather criteria.	Flowchart
	Procedures to obtain reliable weather forecast	

Appendix 4 General for all operations

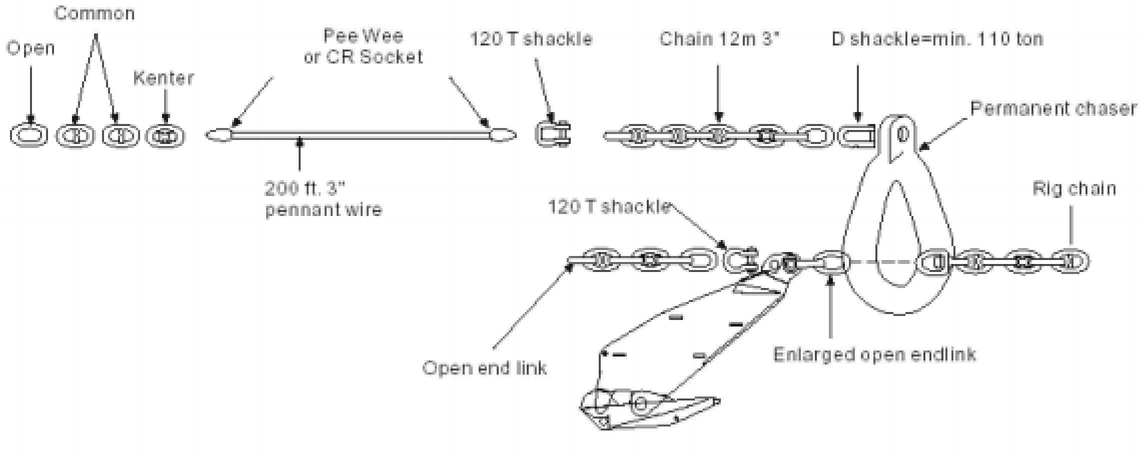
(Source: NORSOK Standard, Marine Operations, J-003, Rev. 2, August 1997)

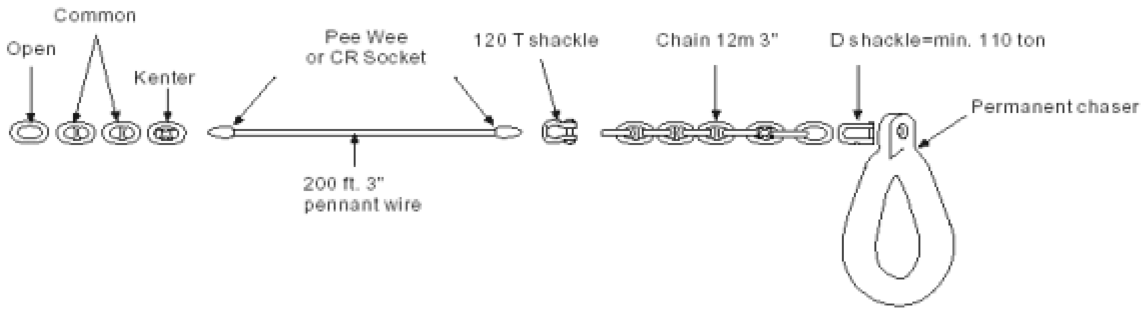


FLOWCHART

Appendix 5 Drawing of permanent rig chaser pendant system with and without anchor

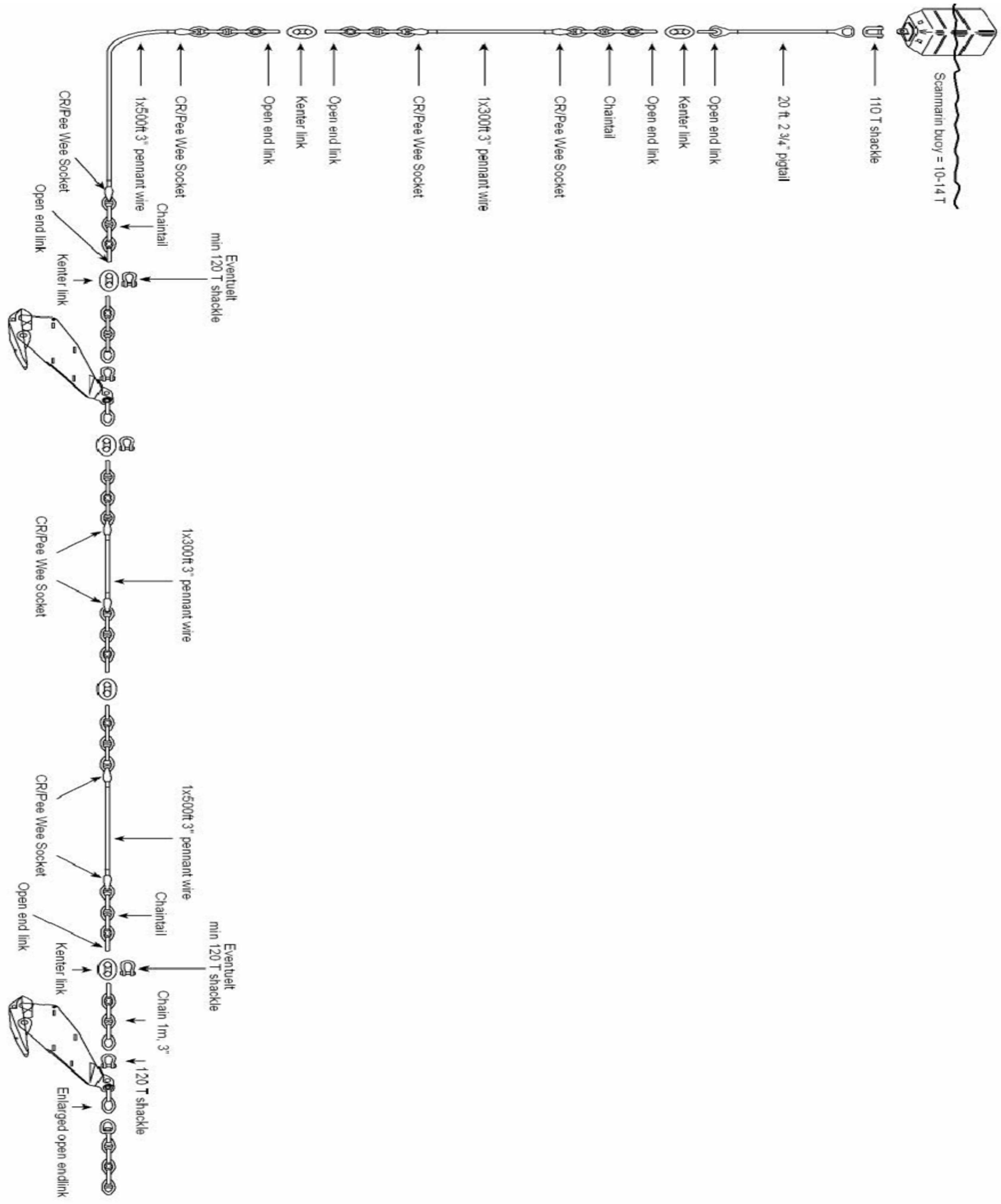
(Source: OLF/NSA Guidelines for Safe Anchor Handling and Towing)
Enclosed is a drawing of the recommended design of the installation's pennant wire system with and without anchor and with associated equipment.
NOTE: Open end link here means open common link





Appendix 6 Drawing of piggyback system

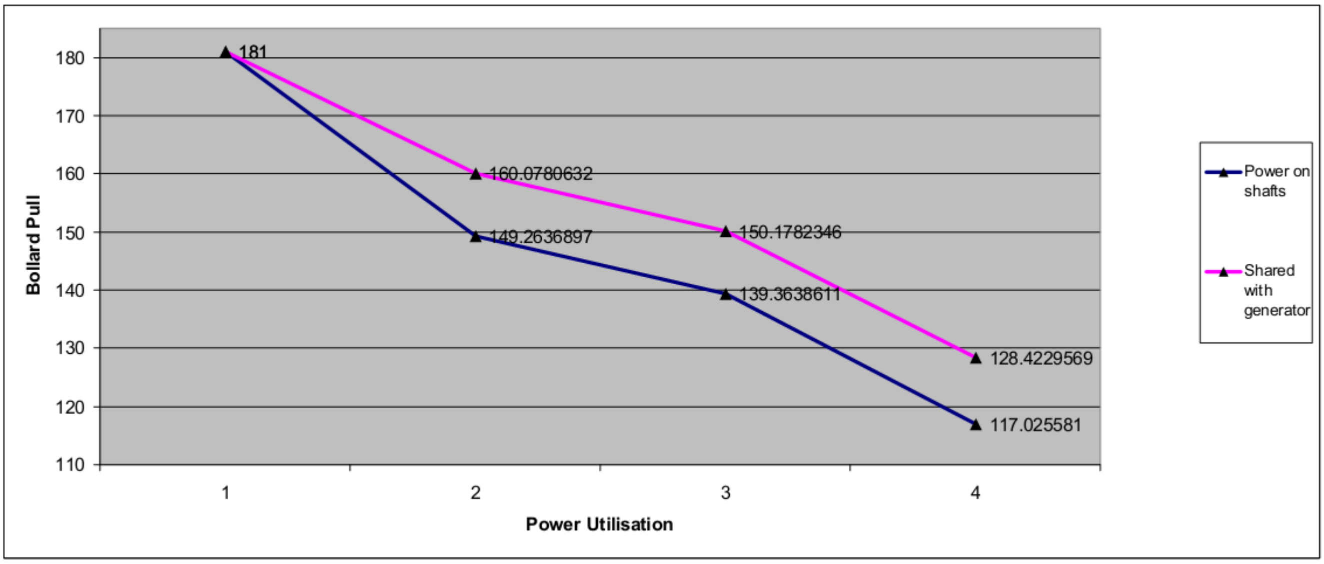
(Source: OLF/NSA Guidelines for Safe Anchor Handling and Towing)
Recommended design of piggyback system - with associated equipment.
NOTE: Open end link here means open common link



Appendix 7 Bollard Pull Calculations

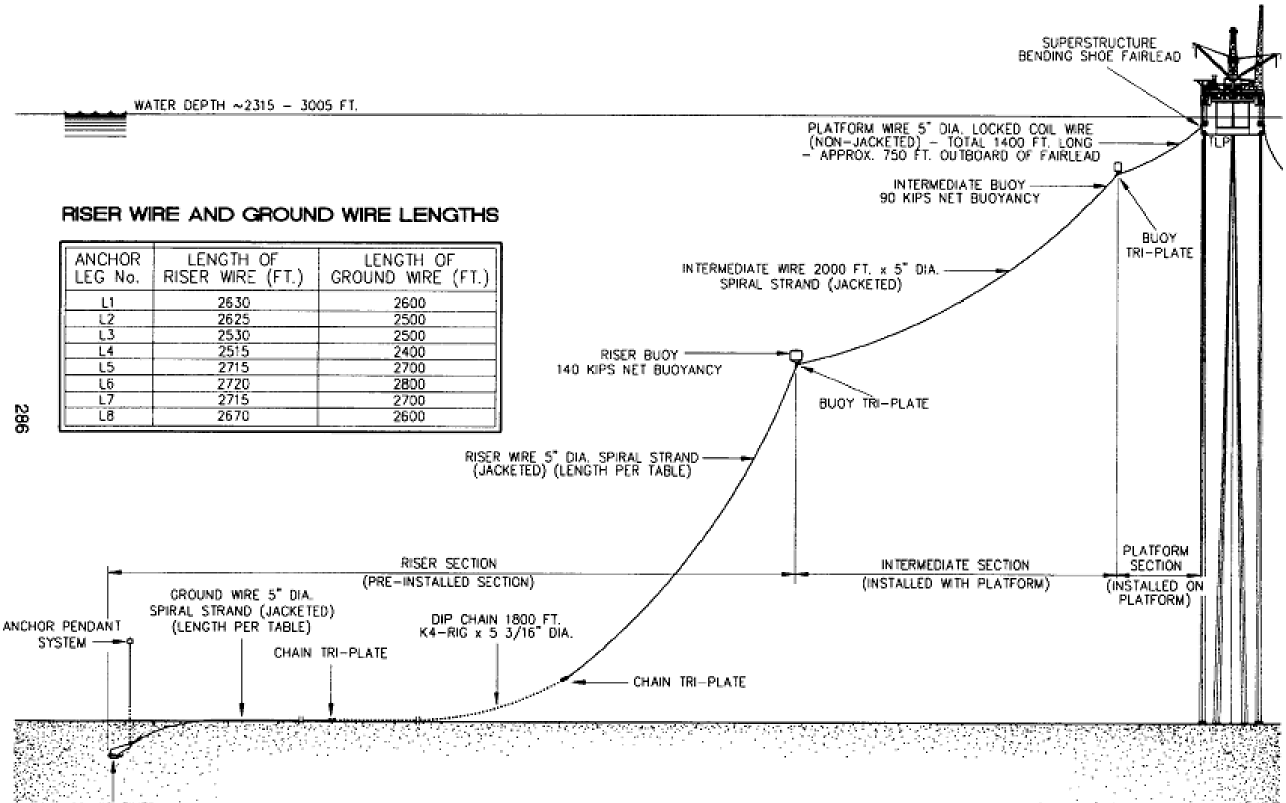
(Source: Marine safety forum, ANCHOR HANDLING MANUAL)
The Master is to ensure that all data contained in this section is relevant to the current scope of work.
A bollard pull reduction graph should be compiled and inserted here to show the following conditions based on the maximum bollard pull from the most recent bollard pull certificate.

	Winch P/P	Thrusters
Condition 1	Minimal	Minimal
Condition 2	4 x 50%	1 x 80%
Condition 3	4 x 50%	3 x 50%
Condition 4	4 x 100%	3 x 80%



Appendix 8 Elevation view of TLP lateral mooring system

Source: (Lohr, C. J., 1996 OTC 8146)

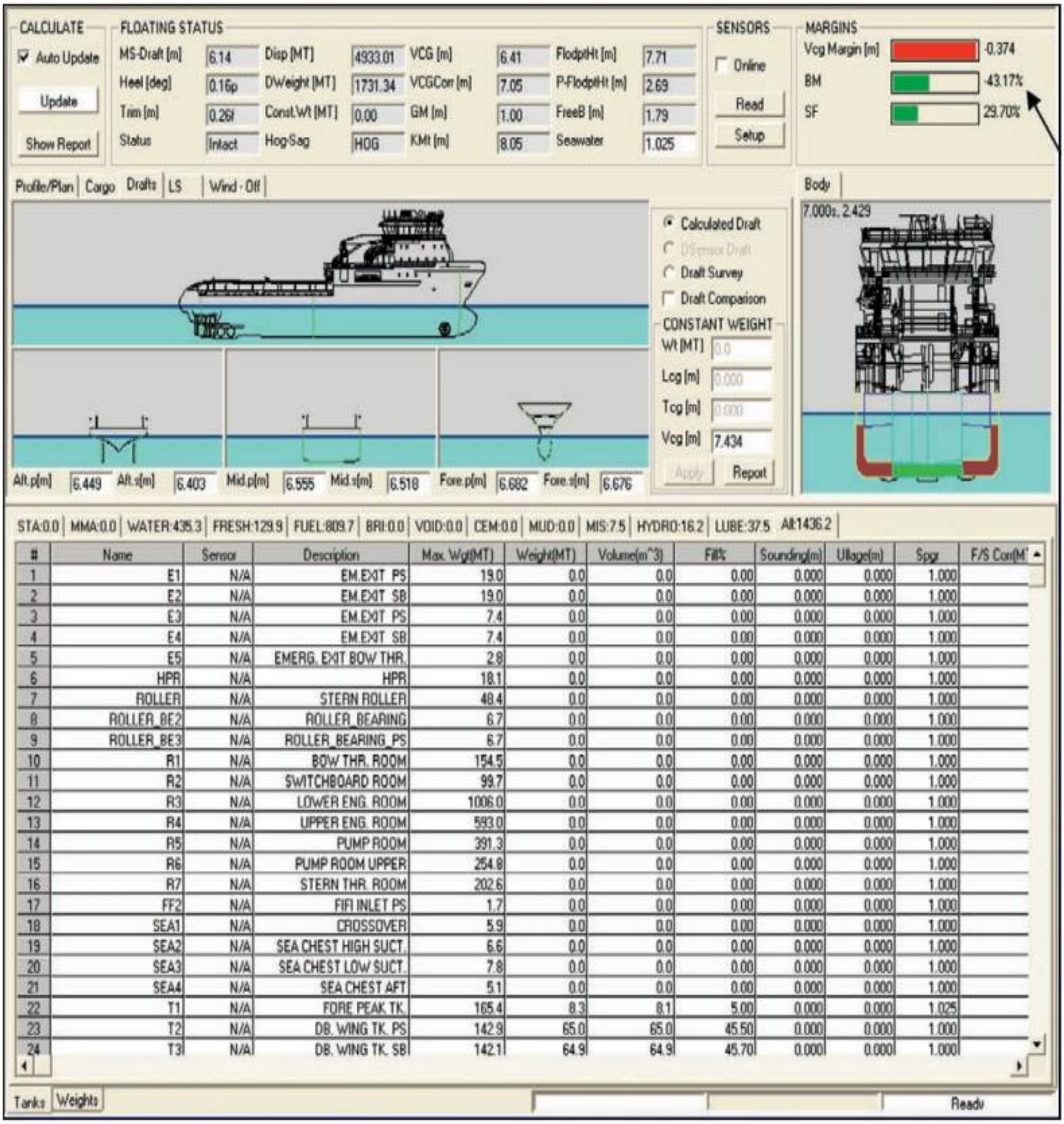


ANCHOR LEG No.	LENGTH OF RISER WIRE (FT.)	LENGTH OF GROUND WIRE (FT.)
L1	2630	2600
L2	2625	2500
L3	2530	2500
L4	2515	2400
L5	2715	2700
L6	2720	2800
L7	2715	2700
L8	2670	2600

ELEVATION VIEW OF TLP LATERAL MOORING SYSTEM
(8 LINES – 2900 KIP MBS)

Appendix 9 The screen capture from load calculator on Bourbon Dolphin

(Source: Official Norwegian Reports, 2008, The Loss of the “Bourbon Dolphin” on 12 April 2007)



#	Name	Sensor	Description	Max. Wgt(MT)	Weight(MT)	Volume(m^3)	Fill%	Sounding(m)	Ullage(m)	Spgr	F/S Cor(M
1	E1	N/A	EM.EXIT PS	19.0	0.0	0.0	0.00	0.000	0.000	1.000	
2	E2	N/A	EM.EXIT SB	19.0	0.0	0.0	0.00	0.000	0.000	1.000	
3	E3	N/A	EM.EXIT PS	7.4	0.0	0.0	0.00	0.000	0.000	1.000	
4	E4	N/A	EM.EXIT SB	7.4	0.0	0.0	0.00	0.000	0.000	1.000	
5	E5	N/A	EMERG. EXIT BOW THR.	2.8	0.0	0.0	0.00	0.000	0.000	1.000	
6	HPR	N/A	HPR	18.1	0.0	0.0	0.00	0.000	0.000	1.000	
7	ROLLER	N/A	STERN ROLLER	48.4	0.0	0.0	0.00	0.000	0.000	1.000	
8	ROLLER_BE2	N/A	ROLLER_BEARING	6.7	0.0	0.0	0.00	0.000	0.000	1.000	
9	ROLLER_BE3	N/A	ROLLER_BEARING_PS	6.7	0.0	0.0	0.00	0.000	0.000	1.000	
10	R1	N/A	BOW THR. ROOM	154.5	0.0	0.0	0.00	0.000	0.000	1.000	
11	R2	N/A	SWITCHBOARD ROOM	99.7	0.0	0.0	0.00	0.000	0.000	1.000	
12	R3	N/A	LOWER ENG. ROOM	1006.0	0.0	0.0	0.00	0.000	0.000	1.000	
13	R4	N/A	UPPER ENG. ROOM	593.0	0.0	0.0	0.00	0.000	0.000	1.000	
14	R5	N/A	PUMP ROOM	391.3	0.0	0.0	0.00	0.000	0.000	1.000	
15	R6	N/A	PUMP ROOM UPPER	254.8	0.0	0.0	0.00	0.000	0.000	1.000	
16	R7	N/A	STERN THR. ROOM	202.6	0.0	0.0	0.00	0.000	0.000	1.000	
17	FF2	N/A	FIFI INLET PS	1.7	0.0	0.0	0.00	0.000	0.000	1.000	
18	SEA1	N/A	CROSSOVER	5.9	0.0	0.0	0.00	0.000	0.000	1.000	
19	SEA2	N/A	SEA CHEST HIGH SUCT.	6.6	0.0	0.0	0.00	0.000	0.000	1.000	
20	SEA3	N/A	SEA CHEST LOW SUCT.	7.8	0.0	0.0	0.00	0.000	0.000	1.000	
21	SEA4	N/A	SEA CHEST AFT	5.1	0.0	0.0	0.00	0.000	0.000	1.000	
22	T1	N/A	FORE PEAK TK.	165.4	8.3	8.1	5.00	0.000	0.000	1.025	
23	T2	N/A	DB. WING TK. PS	142.9	65.0	65.0	45.50	0.000	0.000	1.000	
24	T3	N/A	DB. WING TK. SB	142.1	64.9	64.9	45.70	0.000	0.000	1.000	

Appendix 10 The "Bourbon Dolphin" specifications

(Source: Official Norwegian Reports, 2008, The Loss of the "Bourbon Dolphin" on 12 April 2007)