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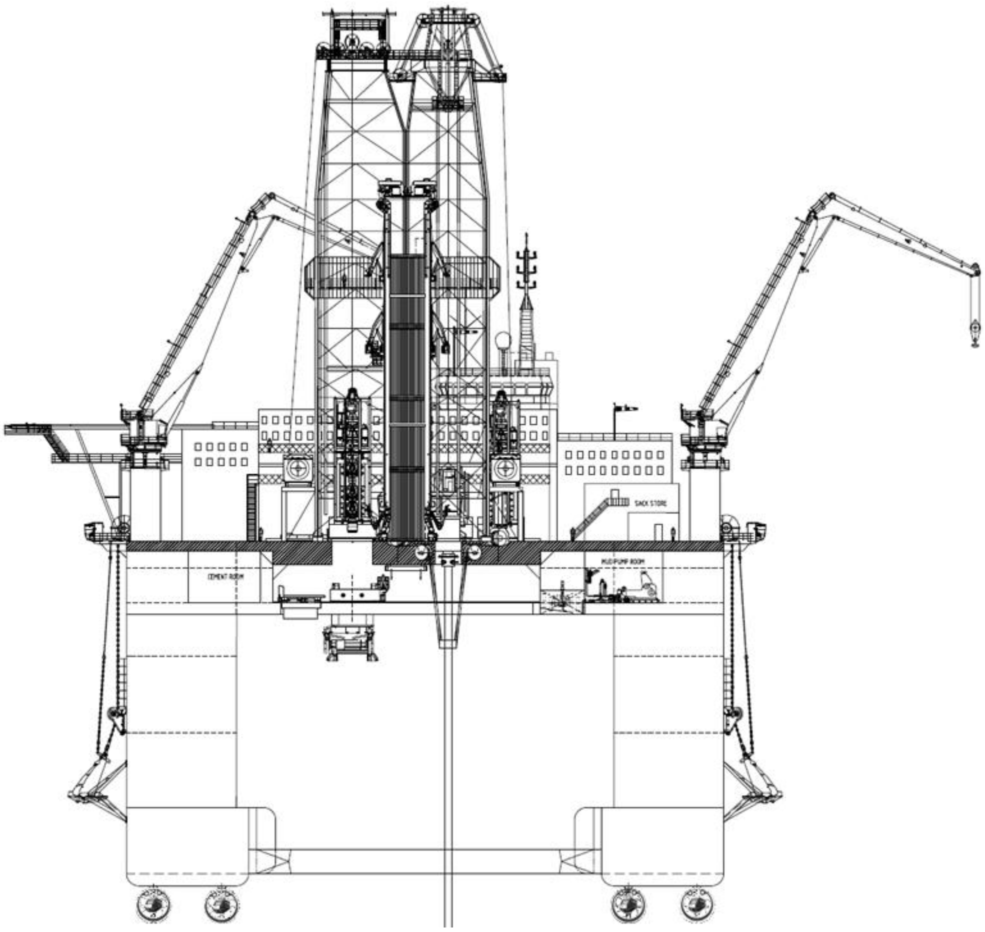

Flush Drill Floor

A conceptual design that lowers the vertical center of gravity on semi-submersible offshore drilling rigs

Master of Science Thesis within Product Development-Mechanical Engineering

Joakim Andersson & Mikael Ahlstedt

Department of Technology Management and Economics
Division of Operations Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2014
Report No. E2014:019

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Conceptual drawing of the resulting conceptual flush drill floor design, produced in AutoCAD 2012.

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ABSTRACT

The performance of a semi-submersible drilling rig depends among other factors on its payload, while the manufacturing cost is strongly correlated to the weight of the rig. Thus to increase competitiveness, GVA aims to maximize the payload to weight ratio of their drilling rigs. One possible way to do so is to lower the vertical center of gravity of the rig, which leads to a snowball effect of possible weight reductions. This project has investigated one specific way to lower the vertical center of gravity of GVA’s drilling rigs, where the drill floor structure, which normally is raised ten meters above the main deck level, is lowered so that it is flush with the main deck.

The goal of the project was to design a conceptual flush drill floor semi-submersible drilling rig capable of the same drilling operations as the conventional GVA 7500 drilling rig. The project involved creative product development work as well as conceptual design in computer aided design software. Through an initial literature review, it was decided to direct the development efforts on just five sub-systems of the drilling rig, where the majority of the development time was spent on developing a handling system for the large and heavy blowout preventer, since it had to be completely redesigned to allow for a flush drill floor design.

The end result was a conceptual design of a flush drill floor semi-submersible drilling unit that uses a completely novel blowout preventer handling system, which involves a second drilling tower and a drill floor with an opening through which the blowout preventer can be deployed. All other functions on the drilling rig could be performed with slightly modified but standard components. The design work has focused on feasibility/universality of the concept, so that the resulting design can be used on an as wide range of drilling rigs as possible, although being restricted to rigs large enough to handle two drilling towers. The conceptual design lowered the vertical center of gravity, and thereby increased the metacentric height (GM), by 0.5 meters compared to a conventional GVA rig. The GM of a typical GVA rig is between one and two meters, thus 0.5 meters is a significant increase that has the potential to contribute to large weight reductions of future GVA semi-submersible drilling rigs.

Keywords: Semi-submersible, drilling rig, vertical center of gravity, metacentric height, drill floor, flush drill floor, blowout preventer.

ACKNOWLEDGEMENTS

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Finally we would like to thank our supervisor at Chalmers University of Technology, Associate Professor Lars Trygg, for his valuable feedback and help with matters related to this report.

Gothenburg

2014-05-09

Joakim Andersson & Mikael Ahlstedt

LIST OF ABBREVIATIONS

BHA	Bottom hole assembly
BOP	Blowout preventer
CAD	Computer aided design
C&K	Choke & kill
DSM	Design structure matrix
LMRP	Lower marine riser package
LUW	Light unit weight
MDO	Multidisciplinary design optimization
POOH	Pull out of hole
Semi-Sub	Semi-submersible drilling rig
VCG	Vertical center of gravity
X-mas tree	Christmas tree

Contents

1 INTRODUCTION

This chapter introduces the reader to the development problem by describing the company for which the thesis is written and the rationale for the development project. Thereafter, a problem analysis is presented, which leads to the research questions to be answered by the report. Finally, project limitations are described and an outline of the remaining report is presented. The Oil and Gas industry is well known for its nomenclature, which might be confusing at first sight. However, the terminology will be introduced with proper descriptions in a brief introduction to oil and gas drilling in chapter 2.2, and the reader might want to go back to this chapter after having learnt the terminology.

1.1 GVA CONSULTANTS

GVA Consultants (henceforth GVA) has its origins in the Götaverkan Arendal shipyard in Gothenburg, Sweden. Since its shipbuilding days, GVA has been transformed into an engineering firm that designs and provides licensed technology for offshore and marine solutions. More than 1100 projects in engineering services such as conceptual design, basic design, detailed engineering, fabrication etc. have been completed by GVA over the last 20 years. GVA is well known in the offshore industry, and the company builds its reputation on its innovative, cost-efficient, safe and environmentally sound design solutions (GVA Consultants, 2013a).

GVA operates globally, with projects successfully delivered across the world. The product markets in which GVA are active are: semi-submersible drilling units; semi-submersible accommodation units; semi-submersible floating production units; drill ships; floating production, storage, and offloading units and renewable energy projects (GVA Consultants, 2013b). The services provided by GVA include front-end engineering design, model tests, classification society approval, detailed engineering support, fabrication support, commissioning and marine operations support and upgrades/conversions of existing units (GVA Consultants, 2013c).

This thesis project has been conducted at GVA's department for drilling technology, a sub division of GVA's product category for semi-submersible drilling units (henceforth semi-subs/rigs). GVA introduced their sensational four column design of semi-subs in 1980 with the Treasury Saga drilling rig. Since then, GVA has relied on the four column design for most of their semi-subs (GVA Consultants, 2013d).

1.2 BACKGROUND

Driven by high oil prices and depleting hydrocarbon deposits onshore, the offshore oil and gas industry is experiencing high growth rates. Further, shallow water exploitation approaches completion, which leads the oil companies to explore for oil and gas on deeper waters and in harsher conditions. Both of these trends lead to increasing costs and challenges in the drilling process, which calls for increased efficiency and safety (Lloyd's, 2011).

The performance of a semi-sub is among many other factors a function of its weight bearing capacity (payload), drilling capabilities and hydrodynamic properties. A high payload is desirable since it enables the rig to carry more equipment and reduces the logistics efforts. A high payload motivates a higher day-rate for the rig, which for the class of semi-subs considered in this report are in the range of 500’000-600’000 US dollars per day (IHS, 2014). The manufacturing cost of a semi-sub is mostly a function of the structural weight. Thus to increase competitiveness, GVA aims to maximize the payload to weight ratio of the rig while maintaining drilling capabilities and hydrodynamic properties. As will be shown in chapter 2.6, one way to allow for a more lightweight design, while keeping hydrodynamic and stability properties constant, is to reduce the vertical center of gravity (VCG) of the rig. A possible way of lowering the VCG is to lower the drill floor, which is normally raised approximately ten meters above the main deck. However, there are reasons for why current semi-subs are not designed with such flush drill floor. Most importantly, it is rather complicated to design the drilling arrangement in such a way that all tasks can be performed as efficiently as for a conventional rig. The drilling arrangement must accomplish a wide variety of tasks, implying that it must be flexible and adaptable to different operations. Further, space is constrained, which adds the challenge of actually finding room for all of the necessary components and operations.

1.3 PURPOSE

The purpose of this master thesis is to develop a conceptual drilling arrangement for a flush drill floor semi-sub in order to lower the vertical center of gravity, which has the potential to reduce the overall platform weight. The result of the thesis will be a conceptual flush drill floor design that enables the redesigned semi-sub to perform the same operations as a conventional one, in order to assess the feasibility of the flush drill floor concept and motivate whether or not further development should be conducted.

1.4 PROBLEM ANALYSIS AND PROJECT OBJECTIVES

Lowering the drill floor to the main deck level will affect the drill floor layout, but also many other sub-systems, which imposes several difficulties from an engineering perspective. Perhaps most importantly, the blowout preventer (BOP) will no longer fit between the drill floor and the lower deck, thus it must likely be stored on the main deck. A BOP cannot normally be moved from the main deck into the derrick (drilling tower) and further down into the sea. To accommodate such operation, an entirely new BOP-handling system is required. Additionally, the Christmas tree (X-mas tree) (production valve system on top of the finished well) must be handled in a similar way to the BOP.

Another sub-system that will potentially be affected by a flush drill floor design is the riser tensioning system. While drilling, the well is connected to the drilling rig with a long tube, called riser, to enable circulation of drilling mud. In order for the riser not to buckle or stretch by the wave-induced movement of the rig, the riser must be held fairly constantly stretched. Different methods exist for tensioning the riser, and although they might not necessarily need to be redesigned, their functionality must be considered for a flush drill floor design.

A trip saver system enables the rig to pull the BOP from the wellhead and hang off the BOP/riser-package in a dedicated place on the rig without taking it up to the surface. This function is useful if several wells are to be drilled from the same location, since it can save several days of drilling operations when operating in deep water. When one well is finished, the BOP and riser is held by the trip saver system and moved to the side of the moon pool and out of the way of the initial drilling operations of the next well (the top-hole sections are generally drilled without a BOP). When using a flush drill floor design, the size of the cellar deck (outside area of the lower deck) can potentially be decreased since it no longer needs to store the BOP. Although a decreased size of the cellar deck has several advantages, it can complicate trip saving.

The mud return system is another sub-system whose functionality must be ensured. When the mud exits from the diverter inside the drill floor, the remaining flow back to the mud pits (tanks) is driven by gravity. However, if the drill floor is lowered to the main deck level, gravity cannot drive such flow through the system, since some components of the mud return system are also located on the main deck. Thus the entire mud return system must either be lowered compared to the current designs, or a pressurized system needs to be developed.

With this problem analysis in mind, the following research questions/objectives were defined:

1. Develop a drill floor layout that works with a flush drill floor design.
2. Develop a BOP/X-mas tree handling system that works with a flush drill floor design.
3. Ensure that the flush drill floor design is compatible with a riser tensioning system.
4. Ensure that the flush drill floor design is compatible with a trip saver system.
5. Ensure that the flush drill floor design is compatible with a mud return system.

All in all, these objectives can be defined as: Develop a flush drill floor drilling arrangement that can perform the same drilling operations as a conventionally designed raised drill floor, using the GVA 7500 semi-sub as a benchmark.

1.5 LIMITATIONS

A semi-submersible drilling rig is a large and complex product, which includes many sub-systems that are related in different ways. To consider all such sub-systems would be too time-consuming for a Master's thesis project, and most systems would not be affected by a flush drill floor at all. Thus to focus development efforts where they are best used, the sub-systems described in the problem analysis were defined as the project's design space, and other areas would be taken as given from a generic GVA drilling rig, more specifically the GVA 7500 semi-sub, which will be described in Chapter 2.4. The thesis project will investigate the feasibility of a flush drill floor design, which has the potential to reduce the rig weight, the project will not consider any other methods to reduce the rig weight. The actual weight savings from a flush drill floor will not be calculated, since it would require a complete and detailed rig design, which is outside the scope of this project. The project will however give an indication of whether or not a flush drill floor design is a feasible way of achieving the desired weight reduction, or if GVA should focus on finding other weight saving methods.

1.6 REPORT OUTLINE

Chapter 2, which follows next, introduces the topic to the reader and presents the theoretical framework of the report.

Chapter 3 describes and motivates the methodical approach taken to the development project.

In chapter 4, the development efforts of the sub-system development phase of the project are presented.

Chapter 5 presents the system level design development process and the resulting design.

The assessment of the project objective is presented in chapter 6 by showing VCG calculations of the new design, compared to the benchmark GVA 7500 semi-sub.

Chapter 7 revisits the research questions and discusses to what degree they have been satisfied, as well as reflecting on the methods used in the project.

Chapter 8 concludes the thesis by describing the major findings as well as recommendations for future work.

2 THEORY

This chapter first introduces the reader to the oil and gas industry in chapter 2.1, followed by a presentation of the foundations of oil and gas drilling in chapter 2.2, thereafter chapter 2.3 briefly explains the design of semi-subs in general. In chapter 2.4, the GVA 7500 semi-sub is used to illustrate key areas of the drilling rig. Chapter 2.5 describes the sub-systems included in the design scope of this thesis in order to give a theoretical base for further development. Finally, chapter 2.6 presents one of the most foundational equations for hydrodynamic stability followed by VCG calculations of the benchmark rig in chapter 2.7, which describes the potential benefit of a lower VCG.

2.1 THE OIL AND GAS INDUSTRY IN A GLIMPSE

Oil and gas reserves are spread across most parts of the globe, although being more concentrated in certain areas. More than 50% of the world's oil reserves are located in the Middle East, where Saudi Arabia alone holds 19% (Deutsche Bank AG, 2010).Russia holds 5% of the world's oil reserves and 23% of the world's gas reserves. 10% of the world's oil reserves are located in Africa, with both on- and offshore assets. About 25% of the oil reserves are located in the Americas, where oil is found onshore in the form of conventional oil reserves, shale oil and Canadian oil sands. Further, large quantitates of oil are located offshore outside Canada, USA, Mexico and Brazil among other countries (Deutsche Bank AG, 2010).

The industry is dominated by large companies, in fact several oil and gas companies are among the most highly valued companies in the world. The very largest oil and gas companies, called the "supermajors", are the international oil companies ExxonMobil (USA), British Petroleum (Great Brittain), Royal Dutch Shell (The Netherlands), Chevron (USA), ConocoPhillips (USA) and Total (France). The supermajors are challenged by a large quantity of state owned national oil companies such as Saudi Aramco (Saudi Arabia), Gazprom (Russia), Petrobras (Brazil) and CNPC (China) (Deutsche Bank AG, 2010).

The largest oil field in the world was discovered in Saudia Arabia in 1948, the giant Ghawar field held recoverable reserves of 126 billion barrels of oil, more than twice the size of the second largest oil field, the Greater Burgan in Kuwait, discovered in 1938. While the two largest oil fields are both located onshore, the third largest oil field, the Safaniyah field discovered in Saudi Arabia in 1951, is an offshore field in the Persian Gulf. The fourth largest oilfield in the world is the onshore field North/South Rumaila, discovered in Iraq in 1953.

The three largest offshore oil fields to date were discovered in the Persian Gulf during the 1950s to 1960s. The fourth largest offshore oil field was discovered in 2000 in the Caspian sea outside Kazakhstan. The fifth largest offshore oil field is the deep-water oil field Lula outside Brazil, which was discovered as recently as in 2007 and has not yet been fully developed (Pentland, 2013). The deep water discovery in Brazil led to a large increase in demand for drilling rigs with a drilling capacity of 3000 meters, of which there in 2008 existed only 21, at the time 80% of them were operating in Brazil (Caroll, 2008). However, deep water oil drilling is performed at several other places of the world, most notably in the Gulf of Mexico and outside West Africa. The deep-water trend has been strong in the 2000s, in 2000 there were 44 deep water (>400 m) oil and gas fields in production, whereas in 2007 the figure had already increased to 157 (Shukman, 2010). The geographical areas of the world in which deep-water drilling is performed are shown in Figure 2-1 below, along with an illustration of the significant increase of the deep-water oil and gas production during the years 2000 to 2007.

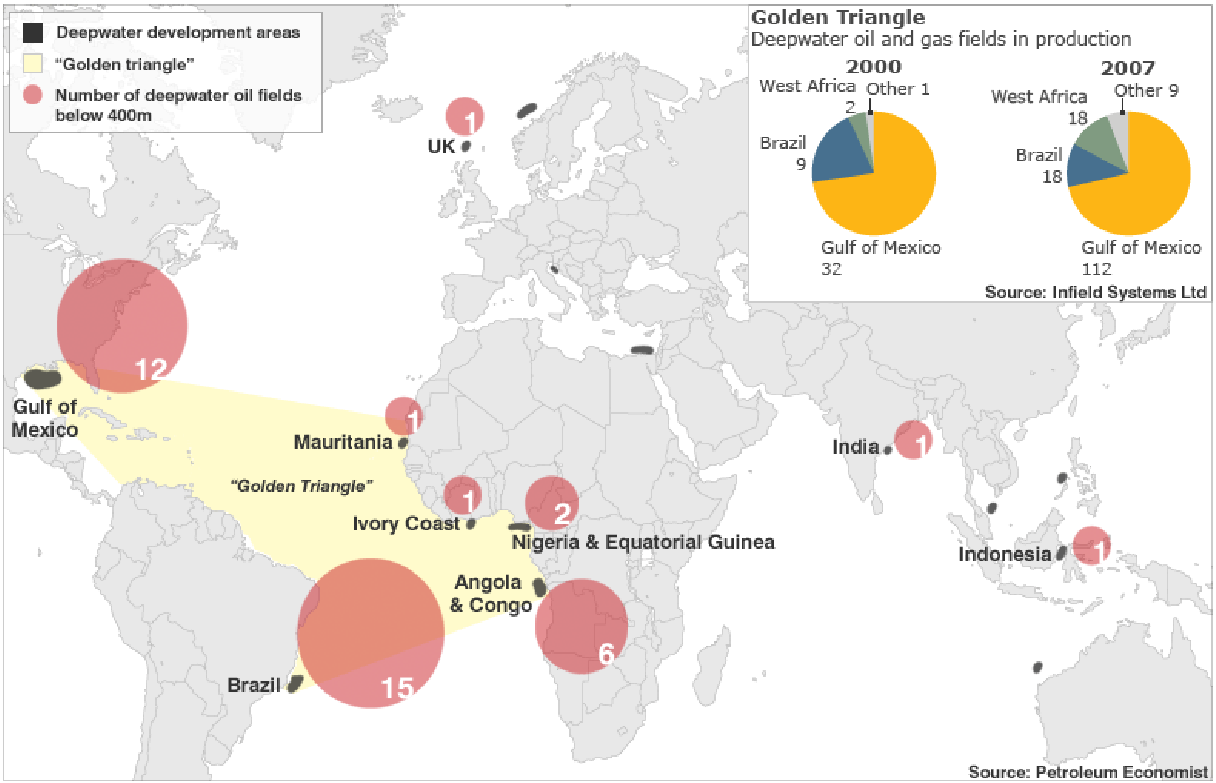

FIGURE 2-1- DEEP-WATER DRILLING ACTIVITIES IN DIFFERENT PARTS OF THE WORLD, SOURCE: (SHUKMAN, 2010).

2.2 A BRIEF INTRODUCTION TO THE OFFSHORE DRILLING PROCESS

Drilling for oil and gas is a complex and expensive process, especially offshore. The process has been refined throughout history, and today the dominating method is rotary drilling (Prassl, 2006). The hydrocarbon reservoirs are usually located several thousands of meters below the earth's surface. Additionally, the water depths can reach up to 3000 meters, which implies that several challenges must be overcome on the way down to total depth. The main systems/equipment of a generic drilling rig is shown in Figure 2-2.

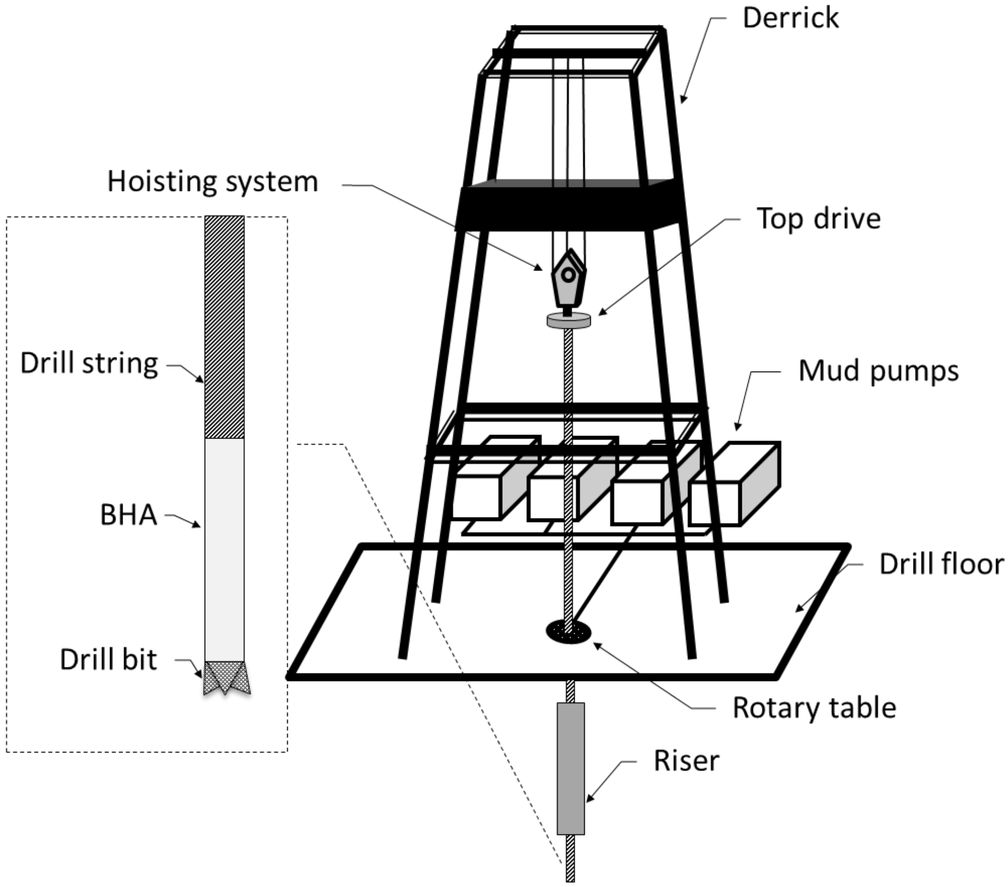

FIGURE 2-2 - MAIN EQUIPMENT OF A GENERIC DRILLING RIG.

Put very simply, a drilling rig consists of a tower (derrick) with a block and tackle that through the use of a hoisting system holds the weight of the drill string and moves it up and down (see Figure 2-2). The lowest part of the drill string is the drill bit, which does the actual cutting of the rock. On top of the bit is the bottom hole assembly (BHA) which includes measuring sensors, direction control devices etc. The BHA is connected to the drilling rig by plain drill pipes. The rotating motion is created either by a rotary table/kelly bushing or by a top drive, which turn the uppermost part of the drill string. A top drive is a hydraulic motor threaded to the top of the drill pipe that is connected to the vertical hoisting system, this approach is dominating for offshore units since it allows several joints of drill pipe, called stands (usually 3x or 4x drill pipe singles), to be drilled in one motion.

While drilling, drilling mud is constantly circulated through the drill pipe to the drill bit and back up to the rig through the space between the borehole’s outer diameter and the drill pipe (annulus). If the well is drilled offshore, a riser pipe connects the well and the rig. The mud is circulated in an almost closed loop system, driven by powerful mud pumps and stored in mud pits on the rig.

The critical functions of the mud are (Prassl, 2006):

- Transport cuttings from the bottom of the hole to the rig's shale shakers, which separate the cuttings from the mud.
- Cool and lubricate the drill bit.
- Seal off permeable rock formations to avoid inflow of hydrocarbons to the formation or outflow of drilling mud to the formation, called lost circulation.
- Ensure that the drilling is performed while overbalanced, i.e. that the pressure inside the borehole is slightly larger than the formation pressure. If the formation pressure is larger than the borehole pressure, hydrocarbons will be forced into the borehole and up to the surface, which in worst case results in a blowout (uncontrolled flow of oil to the surface, which was the cause for the tragic BP accident in the Gulf of Mexico in 2010).
- Keep cuttings static when rotation of the drill pipe is stopped, so that the cuttings do not fall down to the bit and makes it stuck.
- Transmit hydraulic power to bottom hole motors that can be used for directional drilling.

While drilling, the drilling mud is considered to be the first and main safety barrier between the well and the rig, thus a reliable mud circulation system is crucial for the drilling operations. A more thorough description of the mud system for offshore units is provided in chapter 2.5.3.

An oil and gas well is drilled in several sections with different sizes of casings. A casing is a hollow steel tube placed permanently in the hole to act as a barrier between the formation and the borehole. Its primary functions are (Prassl, 2006):

- Isolate porous formations with different pressure levels.
- Prevent fresh water zones from contamination with the drilling mud.
- Protect the hole from caving in.
- Support the weight of the wellhead equipment.
- Provide exact dimensions for subsequent testing, completion and production equipment.

As can be seen in Figure 2-3 below, the hole usually starts off with a diameter of approximately 36”, which eventually becomes as small as 7” or 5.5” in the final section. The drilling procedure is as follows:

- Drill section to its final depth.
- Pull drill string out of hole (POOH).
- Run in hole with casing and cement tool.
- Pump cement into the hole annulus to fix it to the formation and completely seal off the annulus.
- Repeat with smaller diameter until total depth.

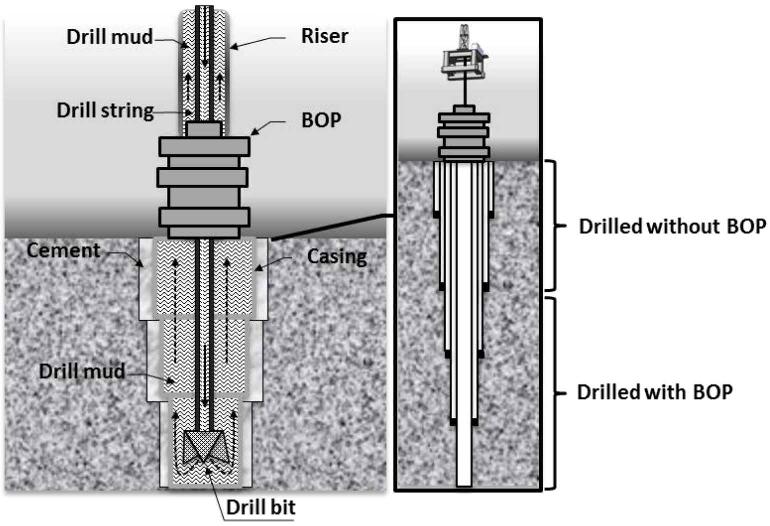

FIGURE 2-3 - SCHEMATIC WELL DESIGN OF OFFSHORE WELLS.

Throughout most of the drilling process, a blowout preventer (BOP) is fitted on top of the well. A BOP is a large steel structure, 10-20 meters tall and weighing approximately 300-500 metric tons, on which several pairs of hydraulic rams are fitted. The purpose of the BOP is to quickly close these rams in order to seal off the well in case of any well control problems. The BOP is the final safety barrier, and is not actively used during normal drilling operations. In the Gulf of Mexico accident mentioned above, the BOP should have prevented the accident, although due to a series of unfortunate events, it failed to fully close its rams. Driven partly by increased attention to safety concerns following the accident, and partly due to the trend of drilling in deeper waters (up to 3000 meters), where temperatures and pressures are higher (>10’000 PSI), the oil companies require increasingly powerful BOPs. This implies that the BOPs become increasingly large, which requires deep water drilling rigs to be equipped with BOP handling system capable of the increased BOP sizes (approximately 20 meters, 500 tons) (Lloyd's, 2011).

When total depth of the well is reached, the hole is either prepared for production in what is called a completion phase, or if the well’s purpose was to explore for oil, some tests are performed and the well is then typically plugged and abandoned. For production wells, the last operation is to place a X-mas tree on top of the finished well. The X-mas tree is typically a 50 metric ton steel structure about 4-8 meters tall that contains the production valves used to operate the production of the well. Except for the handling of the X-mas tree and BOP, neither of the post drilling activities will have a significant impact for this thesis, thus they will not be described further.

2.3 CONVENTIONAL SEMI-SUB DESIGN

There are several kinds of offshore drilling rigs, including jack-ups, drill ships, submersibles, semi-submersibles and stationary/fixed platforms. This thesis is based on semi-submersibles, which are mobile, half floating drilling rigs designed to maintain good stability and sea keeping properties. The term semi-submersible stem from the drilling rigs' ability to partly submerse itself when located at the drill site, although still remaining afloat. Fully submersible drilling rigs submerses completely so that they rest on the seabed when at the drill site. A semi-sub generally consists of a number of decks stacked on top of several columns, which in turn are supported by two floating pontoons (see Figure 2-4). Almost all drilling rigs have a drill floor (top deck) raised about ten meters above the main deck, in order to fit a BOP beneath the drill floor. The BOP commonly rests on the lower deck, which is the lowest level of the rig that is used in normal operations. Inside the deck box, a "tween deck" is located between the lower deck and the main deck. The deck box height (height from the cellar deck to the main deck) is typically 8-10 meters.

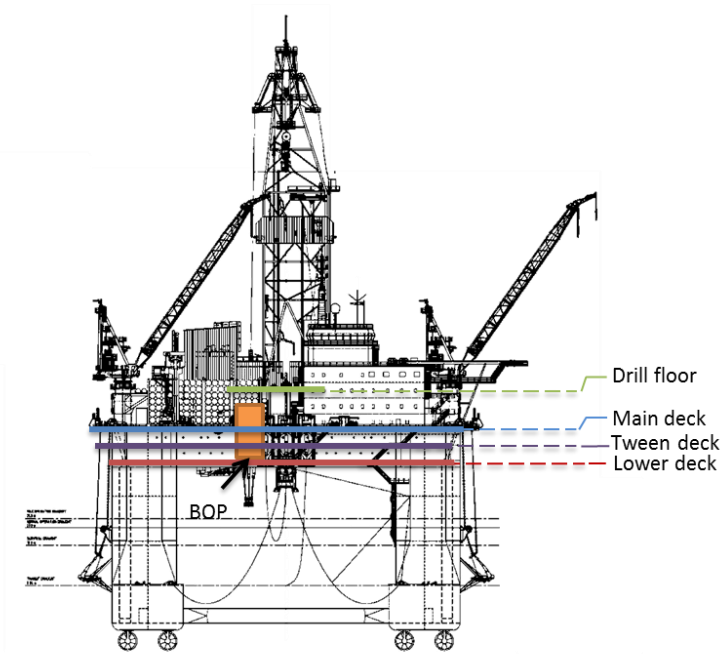

FIGURE 2-4 - SIDEVIEW OF A GVA 7500 SEMI-SUB ILLUSTRATING DIFFERENT DECK LEVELS.

While drilling, the semi-sub fills its ballast tanks, located in the pontoons, with seawater, and thus submerses itself so that approximately half the height of its legs is covered by water. When the rig transits between drilling locations, it empties its ballast tanks so that only a part of the pontoons are submersed. During very harsh weather conditions that do not enable any drilling activities to take place, a semi-sub can go into survival draught. Ballast water is then pumped from the ballast tanks so that the rig decreases its draught, in order to increase the air gap (the distance between the sea level and the lowest part of the cellar deck) to prevent waves from hitting the deck box structure.

When the rig is at the drill site, it remains stationary by being anchored, in shallow waters, or by dynamic positioning for deeper waters. Dynamic positioning uses a sophisticated control system to steer the speed and direction of the rig's thrusters in order to keep it stationary even in harsh conditions. The typical thruster capacity is 8 x 4.2 MW.

A semi-sub is designed for a wide variety of tasks and sub-systems, and to consider them all is outside the scope of this report. Thus for the purpose of this report, the design space was limited to include the sub-systems: Drill floor layout, BOP/X-mas tree handling system, riser tensioning system, mud return system and trip saver system. Other parts of the rig such as the accommodation area, engine rooms and helicopter deck could certainly be affected by a flush drill floor design, although not as significantly as the previously mentioned sub-systems.

2.4 The GVA 7500 semi-submersible drilling rig

This project has been based on a generic GVA drilling rig, more specifically, the GVA 7500. The number 7500 reflects the rig's deck load capacity in metric tons at operational- and survival draughts. The rig can operate at water depths of up to 3000m and can drill ultra-deep wells of up to 12 000m. It has a deck-box upper hull, which houses the three decks: Lower deck, tween deck and main deck. The deck box is supported by four square columns which in turn are supported by two pontoons, connected to each other by two horizontal bracings. Drilling wise it can be ordered with a double derrick to increase the operational efficiency. Regardless of derrick specification, it allows for offline stand-building (using a pipe racking system to connect individual drill pipes (singles) into lengths of four drill pipes, called stands) as well as offline casing-building. For a full specification of the GVA 7500, see Appendix A.

To introduce the vocabulary used in the following chapters, some key areas of the drilling rig are presented as the bold red lines in Figure 2-6 - Figure 2-9. Although the GVA 7500 has been used to illustrate the areas, they will exist in a similar manner for most conventional semi-subs. Figure 2-5 below shows the rig in a front view, subsequent chapters will include top view drawings of the different deck levels for the GVA 7500 with a single derrick design.

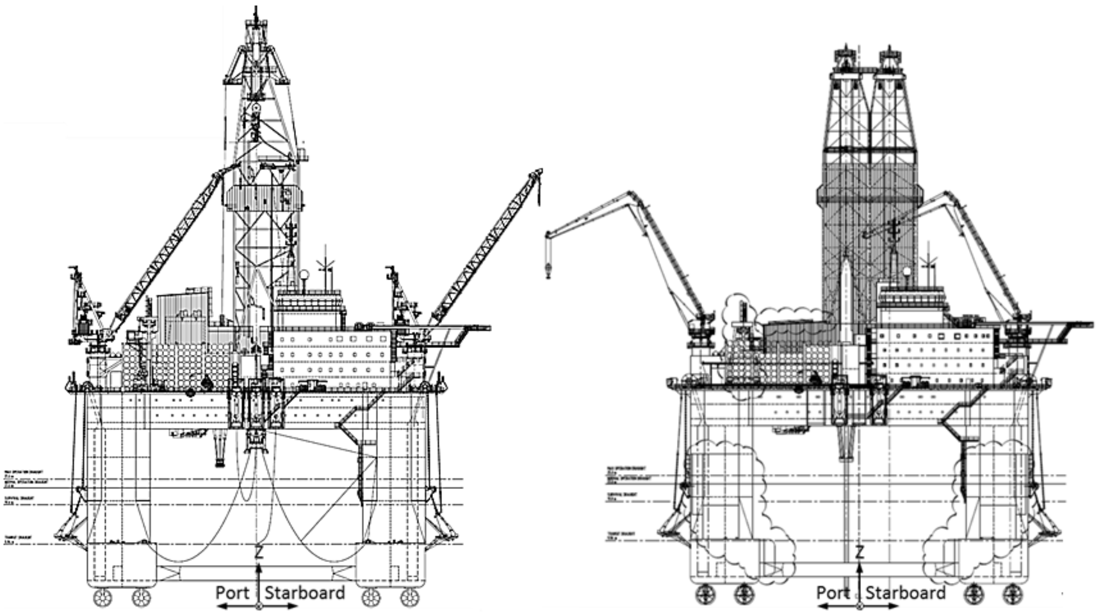

FIGURE 2-5 - FRONT VIEWS OF GVA 7500 WITH SINGLE DERRICK & DOUBLE DERRICK.

2.4.1 DRILL FLOOR LEVEL LAYOUT

In addition to the front views in Figure 2-5, a top view of the highest deck level is shown in Figure 2-6 below.

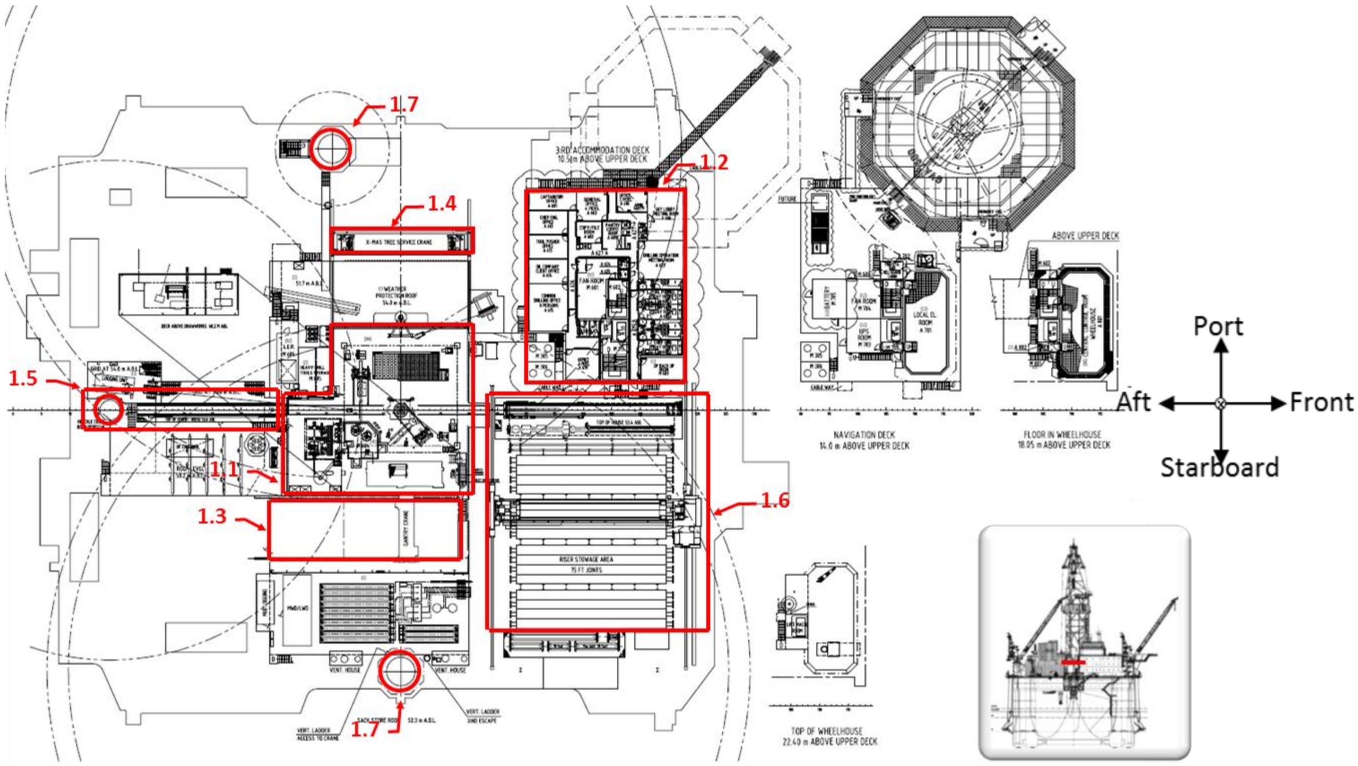

FIGURE 2-6 - KEY AREAS OF THE DRIL FLOOR LEVEL LAYOUT.

Area 1.1 shows the drill floor area, this area will be the main focus of this report, and is described in chapter 2.5.1.

Area 1.2 is the top floor in the living quarter unit, which is clearly seen in Figure 2-6 above. This unit contains a number of office spaces and a hospital, as well as the individual bedrooms.

Area 1.3 and area 1.4 shows the service cranes for BOP handling and X-mas tree handling, they will be further described in chapter 2.5.2.

Area 1.5 shows the pipe handling components. The circle is the base of the crane that lifts pipe to and from the “catwalk”. The catwalk is a channel on which drill pipe singles can be transported from the pipe deck (located on the main deck) to the drill floor and subsequently be used in the drilling operations.

Area 1.6 is the gantry crane used to transport riser pipes from the riser storage area on the main deck to the catwalk on drill floor level.

Area 1.7 (2x) are the bases for the pedestal cranes that move objects on the main deck and between the main deck and supply vessels, they are better seen in Figure 2-5. The pedestal cranes will not be directly affected by a flush drill floor design and will not be considered further in this report.

2.4.2 MAIN DECK LEVEL LAYOUT

The main deck is where most outside activities not directly involved in the drilling takes place. A top view of the main deck level is shown in Figure 2-7.

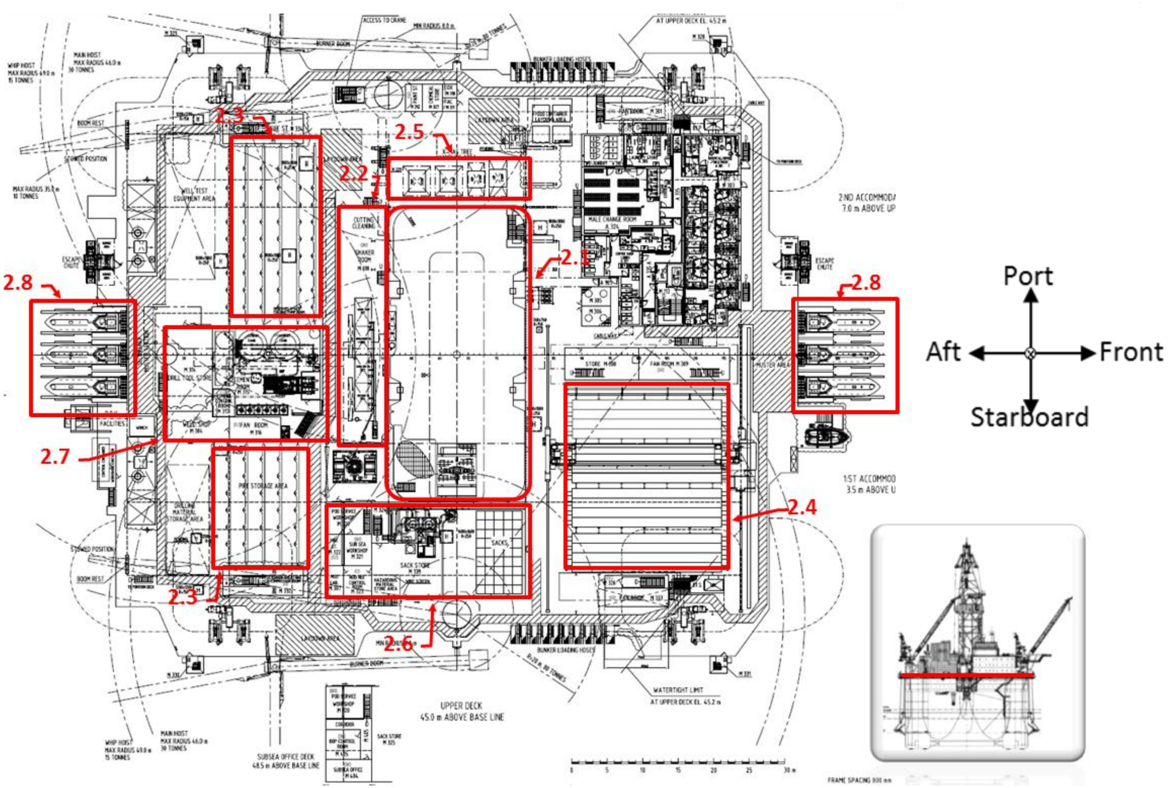

FIGURE 2-7 - KEY AREAS OF THE MAIN DECK LEVEL LAYOUT.

Area 2.1 shows the area where the BOP is stored and serviced. The rectangular pocket in the center area is the moon pool, which is a hole in the deck structure. The crosshair in the center of the drawing shows the location of the well center.

Area 2.2 is the shaker room, this is where the return mud is separated from the cuttings, gas, silt and sand. This area will be further explained in chapter 2.5.3.

Area 2.3 (2x) are the pipe decks. This is where the drill pipe and casing singles are stored when they are not being used.

Area 2.4 is the riser storage area. When the riser is not used, the individual riser pipes are stacked on top of each other in this area, which is better seen in Figure 2-5.

Area 2.5 is the X-mas tree handling area, it will be further explained in chapter 2.5.2.

Area 2.6 is the sack store, where drilling mud constituents are stored and mud mixing systems are placed.

Area 2.7 is a house that primarily consists of the cement room, which includes tanks, pumps and equipment for mixing and pumping cement.

Area 2.8 are the lifeboat muster stations, these will not be directly affected by a flush drill floor and will thus not be considered further in this report.

2.4.3 TWEEN DECK LEVEL LAYOUT

The tween deck is fully contained inside the deck box hull. A top view drawing of the tween deck is shown in Figure 2-8 below.

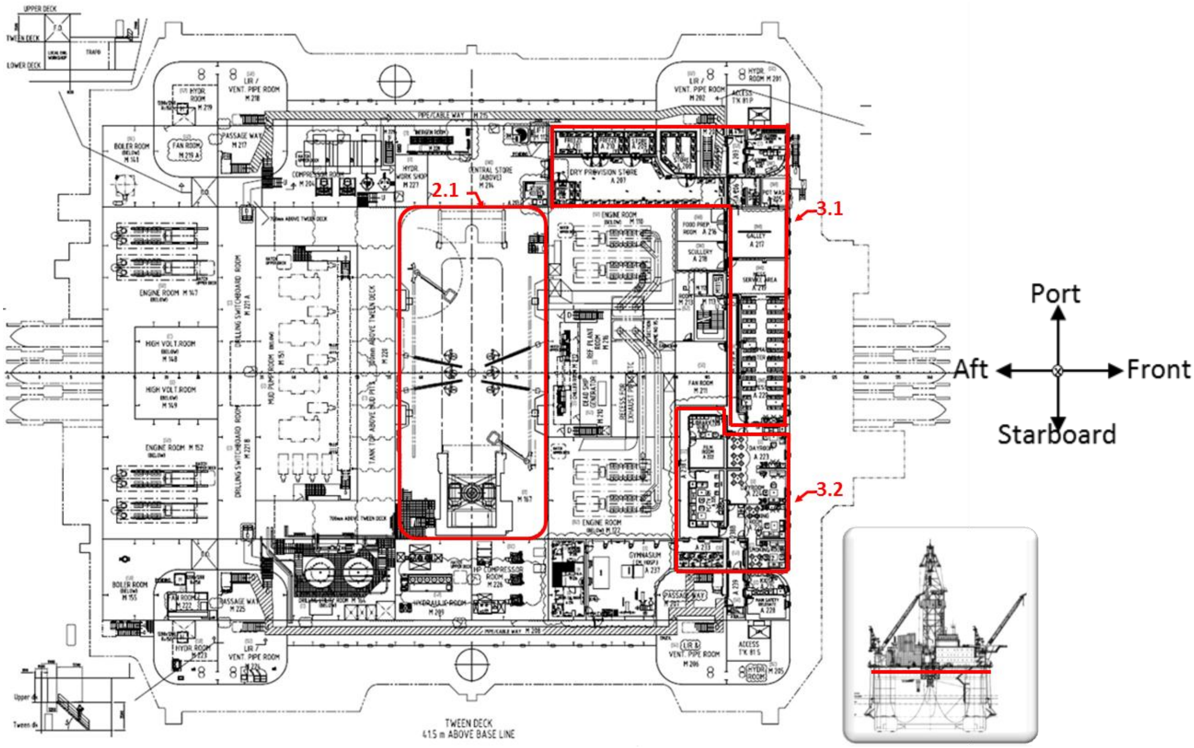

FIGURE 2-8 - KEY AREAS OF THE TWEEN DECK LEVEL LAYOUT.

Area 3.1 contains the kitchen and its stores etc. as well as the mess area.

Area 3.2 includes various day rooms, such as a library, a sauna and a gym.

2.4.4 LOWER DECK LEVEL LAYOUT

The lower deck is similar in layout to the tween deck, although it also includes an outside deck, called the cellar deck, in connection to the moon pool. The layout is shown in Figure 2-9 below.

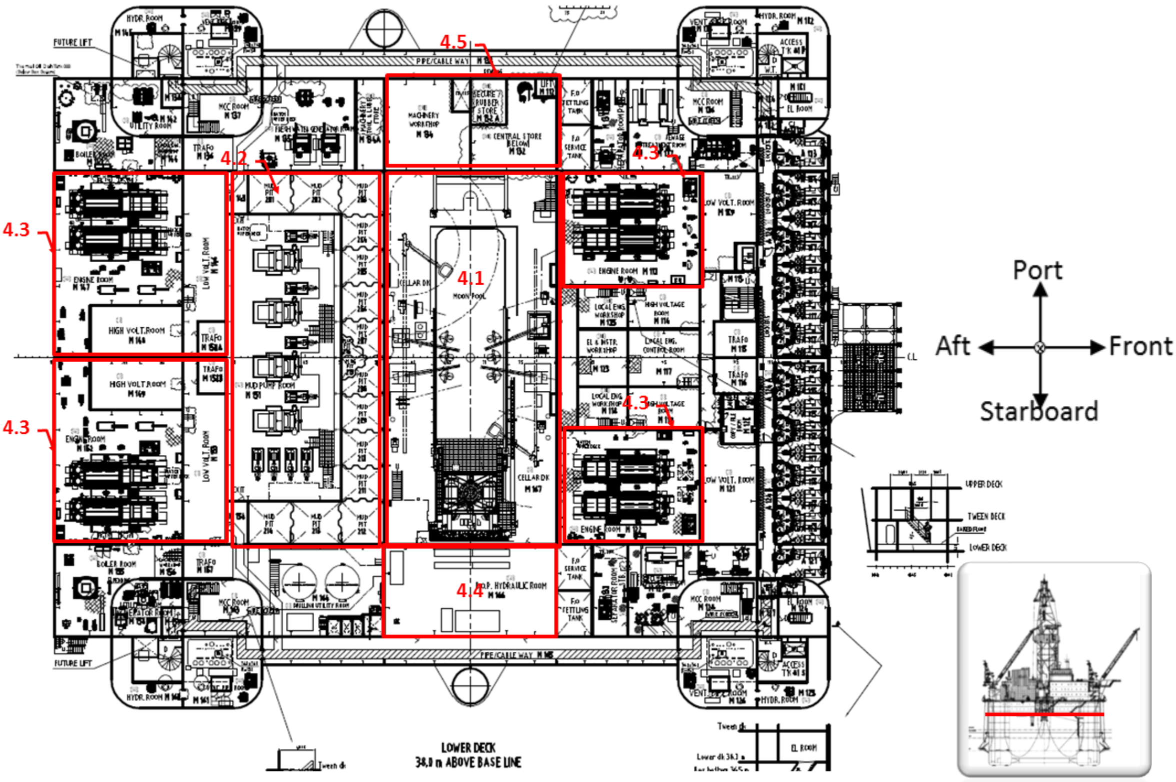

FIGURE 2-9 - KEY AREAS OF THE LOWER DECK LEVEL LAYOUT.

Area 4.1 is the cellar deck. In this view, the rails for the BOP trolley can be seen to cover half the length of the moon pool. Traditionally, the cellar deck is where the lower stack of the BOP is tested while not in use. The cellar deck is also used when installing the X-mas tree and where installation and maintenance work is performed on the riser tensioners and the BOP pod lines (multiplex cables that control the BOP).

Area 4.2 is the mud pump room, which includes mud pumps and mud pits. No floor or roof separates the lower and the tween deck level in the mud pump room. A more thorough description of the mud pumps will be given in chapter 2.5.3 below.

Area 4.3 (4x) are the engine rooms. As for the mud pump room, no floor or roof separates the lower and the tween deck level due to the height of the components located there. The diesel powered engines generate approximately 8 x 5.5 MW in order to power all the sub-systems of the rig.

Area 4.4 is the BOP hydraulics room, where all the valves that control the BOP are located.

Area 4.5 contains a machinery workshop and a storage area.

2.5 THE SUB-SYSTEMS OF INTEREST

This chapter presents the intended use of the sub-systems that are most significantly affected by a flush drill floor design, and also describes how the particular systems are designed on the GVA 7500 semi-sub.

2.5.1 DRILL FLOOR LAYOUT

Almost for all drilling rigs, the drilling arrangement is located on a dedicated drill floor, raised approximately ten meters above the main deck, as seen in Figure 2-4 above. The drilling arrangement includes a number of key components that are present on more or less any drilling rig. A principal schematic side view of a drill floor is shown in Figure 2-10.

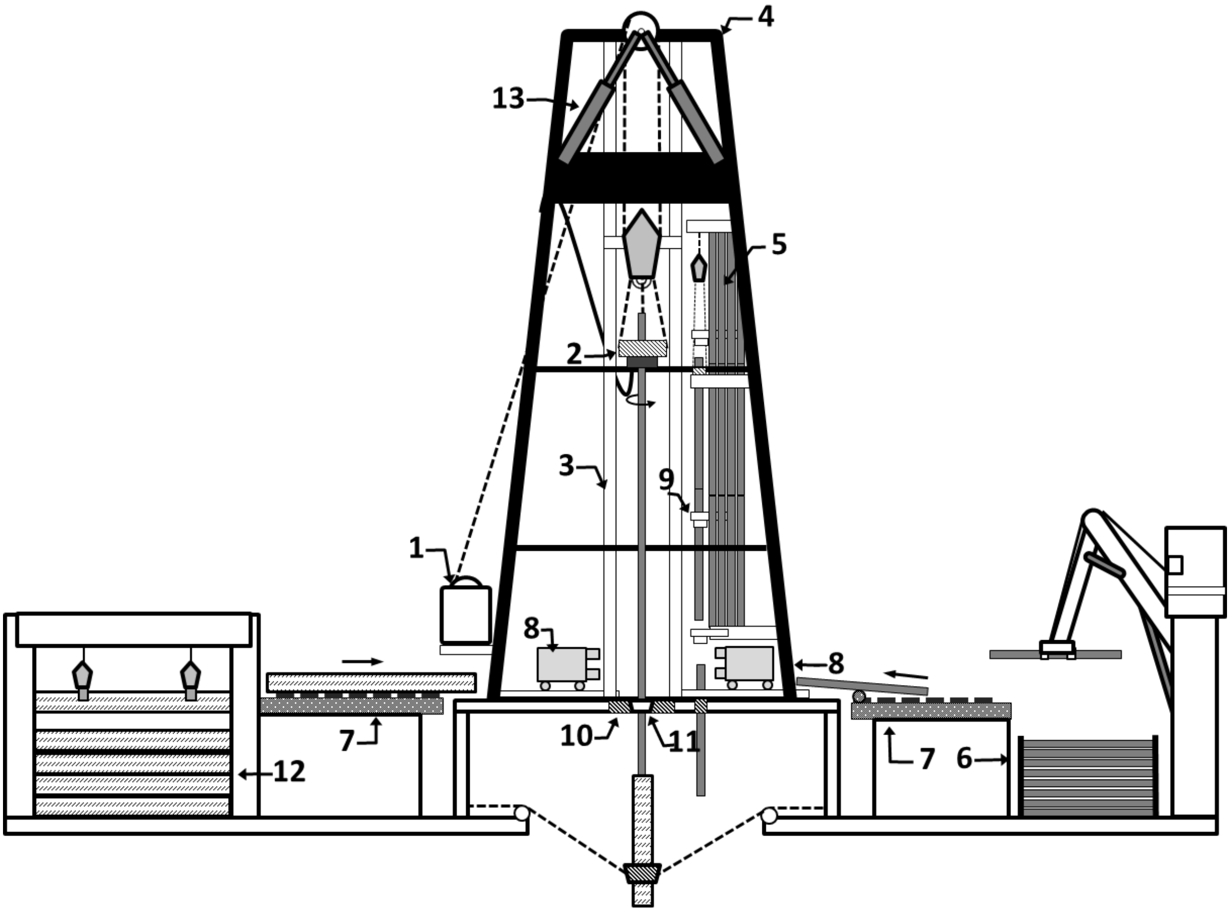

FIGURE 2-10 - KEY COMPONENTS OF THE DRILLING ARRANGEMENT.

As can be seen in Figure 2-10, a draw-work [1] holds the top drive [2] and allows it to travel on its guide rails [3] almost for the entire height of the derrick [4]. The top drive rotates and holds the weight of the drill string, while also feeding the drill pipe with drilling mud through a swivel, which allows the mud to be pumped into the rotating pipe. The derrick also contains a setback [5] for drill pipes built into stands.

When building stands, pipe is collected from the pipe deck [6] and is transported to the drill floor by the catwalk [7]. Individual drill pipes are built into stands by the iron roughneck [8], which screws the threaded pipe ends together. Finally, a pipe handling system [9] puts the stand into its designated place in the setback.

During drilling operations, a stand is drilled down until its upper end is almost level to the rotary table [10]. Then, a slip [11] is pressed in place between the drill pipe and the rotary table in order to hold the weight of the drill string when the top drive disconnects. The top drive is raised to the top of the derrick, a new stand is collected by the pipe handling system from the setback and connected to the drill string by the iron roughneck. The top drive is then connected to the new stand and drilling continues.

Casing is built in a similar way to drill pipe and is usually stored at the pipe deck, whereas riser pipe is stored in its designated riser storage area [12].

The process of building riser is different to building pipe or casing since riser joints are not threaded together. Instead, each riser joint is typically equipped with end-flanges that must be bolted together. In order to hold the riser pipe when the top drive disconnects, a tool called a spider is used, and it works similarly to the slip [11] for drill pipes. The riser pipes also include parallel high pressure choke and kill (C&K) lines that are stabbed together. These lines are connected to the BOP stack and are only used if a well has to be “killed”. In case of drilling into highly pressurized gas zones, the BOP closes the well annulus and the overpressure is regulated by injecting high density “kill”-mud into the well, which by gravity prevents the oil/gas flow. Usually the “kill” mud can be lead through the drill string, but if the BOP has cut of the drill string in order to completely close the well, the “kill”-mud is diverted to the kill line. The choke line is used to allow mud and potential gas to return to the surface in a controlled manner, the gas is then either separated or burned.

The cylinders on top of the derrick [13] in Figure 2-10 are derrick mounted compensators that counteract the wave induced motion of the rig so that the drill string is not stretched or buckled. Alternatively, although not as common, draw-works with a built in active compensation system can be used.

The drilling arrangement (excluding pipe deck and riser deck) on the GVA 7500 rig is shown in Figure 2-11.

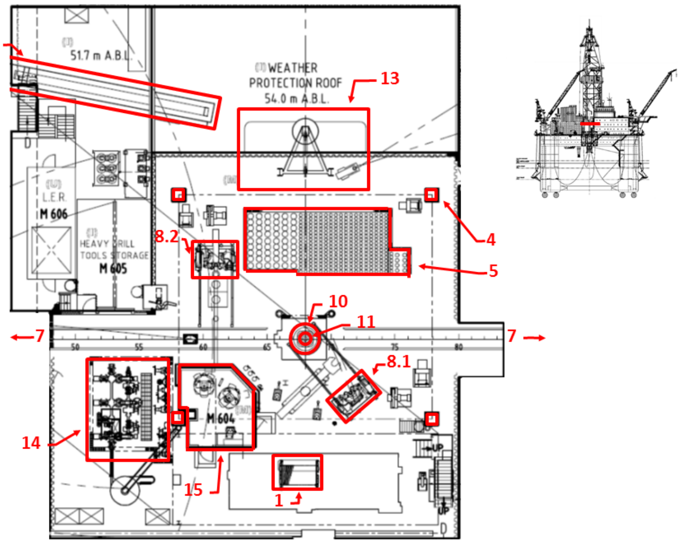

FIGURE 2-11 - TOP VIEW OF GVA 7500'S DRILLING ARRANGEMNET.

The previously described components are shown in Figure 2-11 with the same notations as before. As can be seen, the drill floor extends outside the derrick (only its four support points are shown). As can be seen in Figure 2-11, the GVA 7500 has two iron roughnecks. The roughneck that is not located at the well center, roughneck [8.2], is used for offline stand building. In collaboration with the pipe system (not pictured), the secondary roughneck can build stands while drilling operations are performed in the well center. The GVA 7500 also allows for offline casing building, by using the tertiary catwalk [7] capable of transporting casing, a separate handling system [13] and a third roughneck located on the cellar deck (not pictured). The C&K lines are controlled by different high pressure valves, which are integrated into the C&K manifolds [14]. The same area also includes mud and cement manifolds. All drilling operations are directed by the driller and the assistant driller, who work from the driller's cabin [15].

2.5.2 BOP/X-MAS TREE HANDLING SYSTEM

BOPs used for offshore drilling typically consist of a stack of several preventers, which include both ram type preventers and annular preventers. The BOP is divided into two separable parts, the lower stack and the Lower Marine Riser Package (LMRP). The lower stack includes the ram preventers and the wellhead connector. The LMRP's primary purpose is to control the lower stack, although it also includes at least one annular preventer. The LMRP typically constitute one third to half of the total height of the BOP and is placed on top of the lower stack.

On conventional semi-subs, the BOP is stored in the moon pool on the cellar deck. It is generally moved to and from the well center on a trolley, as seen in Figure 2-12. For rigs with one BOP, it can be stored permanently on the trolley, whereas for rigs with several BOPs, a crane is used to move them from their storage positions to the trolley (see Figure 2-13). The BOP must be tested on the rig prior to being deployed, testing requires the use of certain test stumps, which differ for lower stacks and LMRPs. The lower stack is usually tested on a test stump on the cellar deck, while the LMRP is normally tested separately on a test stump on the main deck. If the LMRP is tested on the main deck, a crane is required to transport it to the lower stack.

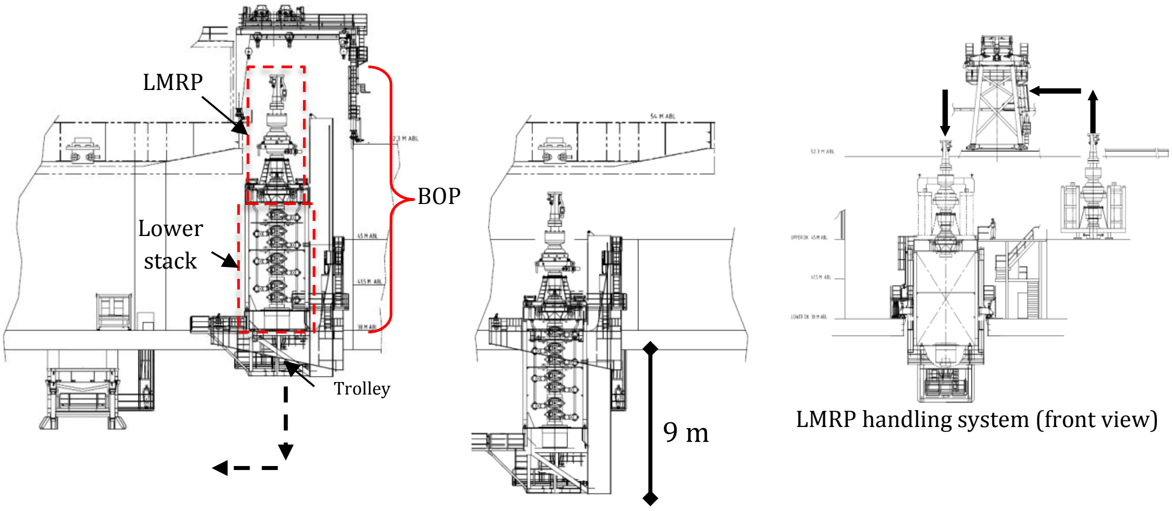

FIGURE 2-12 - BOP HANDLING SYSTEM FOR THE GVA 7500 WITH ONE BOP ON A FORK LIFT TROLLEY.

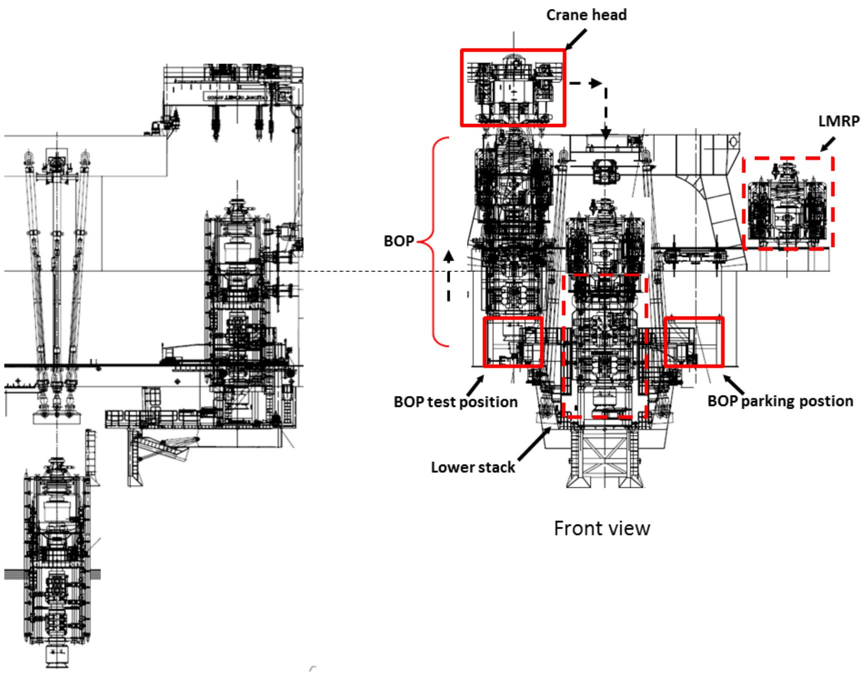

FIGURE 2-13 - BOP HANDLING SYSTEM FOR THE GVA 7500 WITH TWO BOPS.

The GVA 7500 semi-sub can be specified with either one or two BOPs. Figure 2-12 shows a one BOP specified rig, both with the BOP in its parked position and when positioned at the well center. As can be seen, it has been lowered nine meters by a hydraulic cylinder when it is located under the well center compared to when in its storage position.

When installing the BOP, it is first moved to the well center (middle part of Figure 2-12) where POD lines are installed. Thereafter, the first riser joint is connected to the BOP and it is lowered to the sea. Until a significant part of the BOP has been submerged, it must be guided by a guide structure so that the BOP or the lifting equipment is not damaged by the wave motion in the so called “splash zone”, which is the area ± 5 meter from the water line. When out of the splash zone, the BOP is lowered to the seabed by continuously adding riser joints. Throughout the process, work is performed on the cellar deck to ensure that the POD lines are correctly attached to the riser.

The X-mas tree is installed in a similar way, although it is typically stored and tested on the main deck (area 2.5 on Figure 2-7). When the X-mas tree is ready for use, a gantry crane lowers it to a X-mas tree trolley in the moon pool. Whether or not the same gantry crane as that for the BOP can be used depends on the design on the rig. The GVA 7500 stores the X-mas trees and the BOPs on different sides of the moon pool, and thus they need separate lifting equipment. Since the X-mas tree must be deployed when the BOP is either on its trolley or “trip saved” on the same trolley, the X-mas tree and the BOP also require separate moon pool trolleys. Contrary to the BOP, which is lowered to the seabed by adding riser joints, the X-mas tree uses plain drill pipes in combination with guide wires that steer it into its correct position. When the X-mas tree has been installed, the drill pipes are taken up to the surface and the well is ready for production.

2.5.3 MUD CIRCULATION SYSTEM

The mud circulation system is the composition of all equipment and components that are used to circulate and control the drilling mud. As mentioned in chapter 2.2, the mud is reused throughout the drilling process and its properties are crucial for the drilling operations. This implies that the mud and its properties constantly need to be controlled and maintained while drilling is performed. Figure 2-14 below describes the main components of the mud circulation system on an offshore rig as well as the mud’s way through the drilling process.

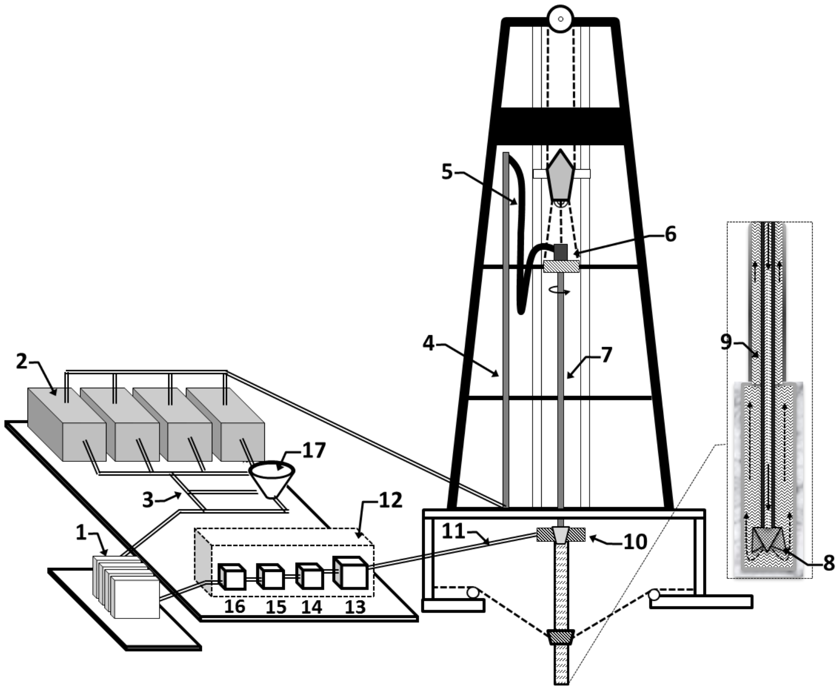

FIGURE 2-14 - KEY COMPONENTS OF THE MUD CIRCULATION SYSTEM.

The drilling mud is mixed into its desired properties and then placed in the mud pits [1]. While drilling, the mud pumps [2] pump the mud from the mud pits, via the suction line [3] and up the standpipe [4], which reaches approximately halfway up the derrick. From the standpipe, the mud travels through a rotary hose [5] and into a swivel [6], on the top drive. Thereafter the mud is pumped down the entire drill string [7] and exits through nozzles in the drill bit [8]. The mud is then pumped back up through the annulus [9] to the diverter [10] below the drill floor. The diverter normally leads the mud to the return line [11], but in the case of overpressure or a blowout, it can lead the mud and potential gas overboard to avoid a catastrophe. The return line leads the mud to the shaker room [12]. In there, the mud is processed by; shale shakers [13], which separate cuttings from the mud; a desander [14] that removes sand from the mud; a desilter [15] to remove fine grained materials and a degasser [16] that separates gas from the mud. When the mud has passed through the shaker room, it is led back to the mud pits, and the cycle is complete. In case of a need to do on the fly adjustments of the properties of the mud, it can be led through the mud mixing hopper [17] rather than the suction line (Prassl, 2006). The mud mixing system is separate to the normal return system, by the fact that it is pressurized, and thus will not be limited by a flush drill floor design, and therefore not considered further in this thesis.

For the mud to be transported in the non-pressurised part of the system, between the diverter and the mud pits, the components have to be placed at different potential heights in order to transport the mud by gravity. To compensate for wave induced roll and pitch of the rig, these components has to be placed at a vertical distance which would allow a relative inclination of at minimum 6-7 degrees (typical value for GVA drilling rigs). A flush drill floor design will change the relative heights of the mud return components, and thus it can prove a challenge to implement a gravity driven system. Figure 2-15 below show the main deck and the cellar deck of the GVA 7500 semi-sub with the mud circulation components marked by the same numbering as for the just described general case.

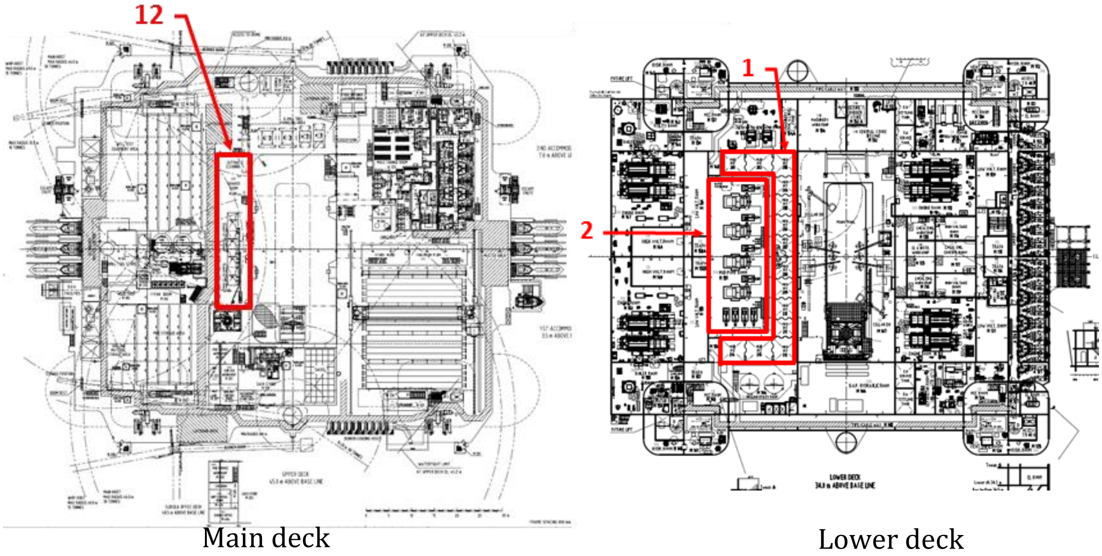

FIGURE 2-15 - MUD SYSTEM COMPONENTS ON GVA 7500.

2.5.4 RISER TENSIONING SYSTEM

While drilling offshore, the well is connected to the drilling rig by the riser, which enables circulation of the drilling mud. In order for the riser not to fracture by the wave-induced movement of the rig, the riser must be held fairly constantly stretched. That is commonly achieved by two principally different designs, both used on GVA semi-subs. The traditional way is to use a wire-line riser tensioning system consisting of steel wires, idler sheaves and pneumatic/hydraulic cylinders as seen in the leftmost part of Figure 2-16 below. The wires are connected to controlled hydraulic cylinders, often placed outside the drill floor, and are guided down through the moon pool by idler sheaves and eventually connects to the riser through a riser tensioner support ring (International Association Of Drilling Contractors, 2000).

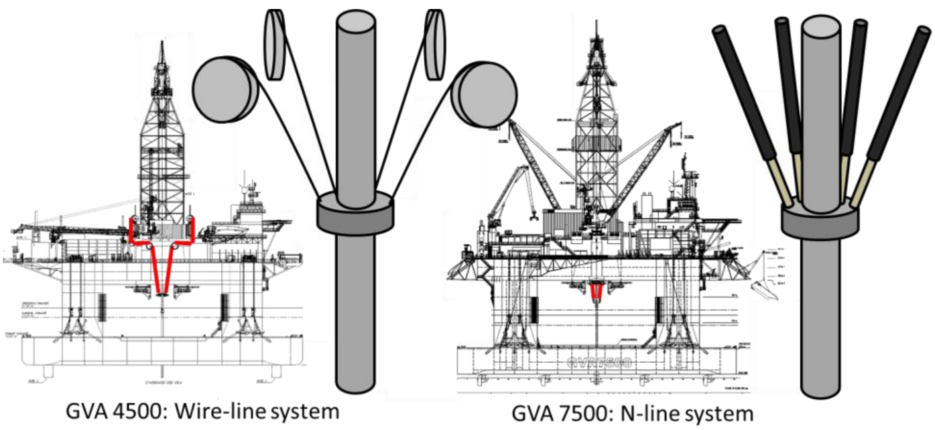

FIGURE 2-16 - RISER TENSIONING SYSTEMS OF GVA 4500 AND GVA 7500.

An alternative solution is the N-line system, also known as direct acting tensioner system, shown in the rightmost part of Figure 2-16. Instead of using compensated wires, the support ring is attached directly to hydraulic cylinders that are controlled to compensate for wave-induced movement of the rig. The system provides a more compact solution with lower VCG, while the wire-line system is a more well-known and technology proven system. The wire-line system is for instance used on the GVA 4500, while the N-line system is available on the GVA 7500. The N-line cylinders can be placed on a trolley that runs beneath the drill floor, which enables the N-lines to also act as a trip saver (see the next chapter).

Different drilling contractors have different preferences with regards to riser tensioner systems, thus for a conceptual development project like this, the resulting concept should optimally be able to handle both designs to make the concept as flexible as possible.

2.5.5 Trip saver system

When drilling offshore production wells, it is common to drill multiple wells from the same location. Since the top section of each well is drilled without a BOP, when one well is finished, the BOP must be moved out of the way for the initial drilling operations of the next well. To avoid having to bring the riser and the BOP up to the surface and then redeploy them for each well, an apparatus called a trip saver can be used (SBM Offshore, 2013). To trip save the BOP/riser package, the BOP is first lifted to a safe distance above the well head, thereafter the riser is hung off on the trip saver device, which is then skidded as far as possible away from the well center.

There are two principally different trip saver system designs, which are strongly related to the riser tensioner system. If the riser tensioner system is of the wire-line concept, trip saving is usually performed by hanging off the riser in a trolley in the moon pool. The trolley can either be dedicated to trip saving, or the riser can be hung off on either the BOP trolley or the X-mas tree trolley, if specified with a trip saving function. Figure 2-17 below shows a generic design where the riser is hung off on the BOP trolley.

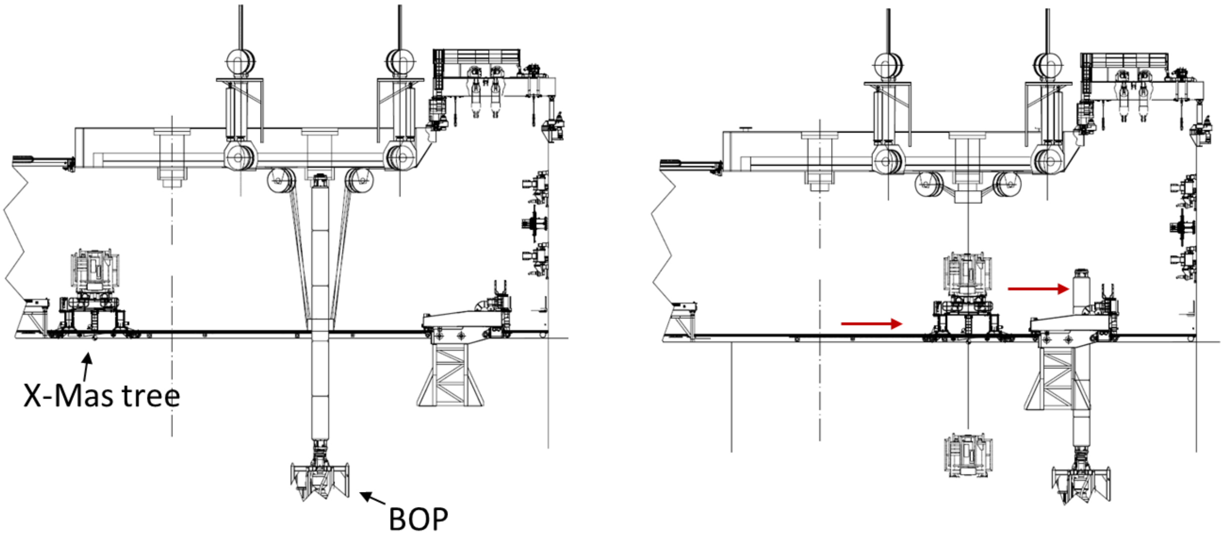

FIGURE 2-17 - TRIP SAVING SYSTEM USING THE BOP TROLLEY ON A RIG WITH WIRE-LINE TENSIONERS. NOTE: ONLY A PART OF THE BOP IS SHOWN.

Alternatively, if an N-line riser tensioning system is used, the N-line cylinders can be attached to the drill floor on a moveable trolley, so that the entire N-line/riser package can be moved together. Figure 2-18 below shows the GVA 7500 semi-sub with the BOP/riser package trip saved according to the N-line approach.

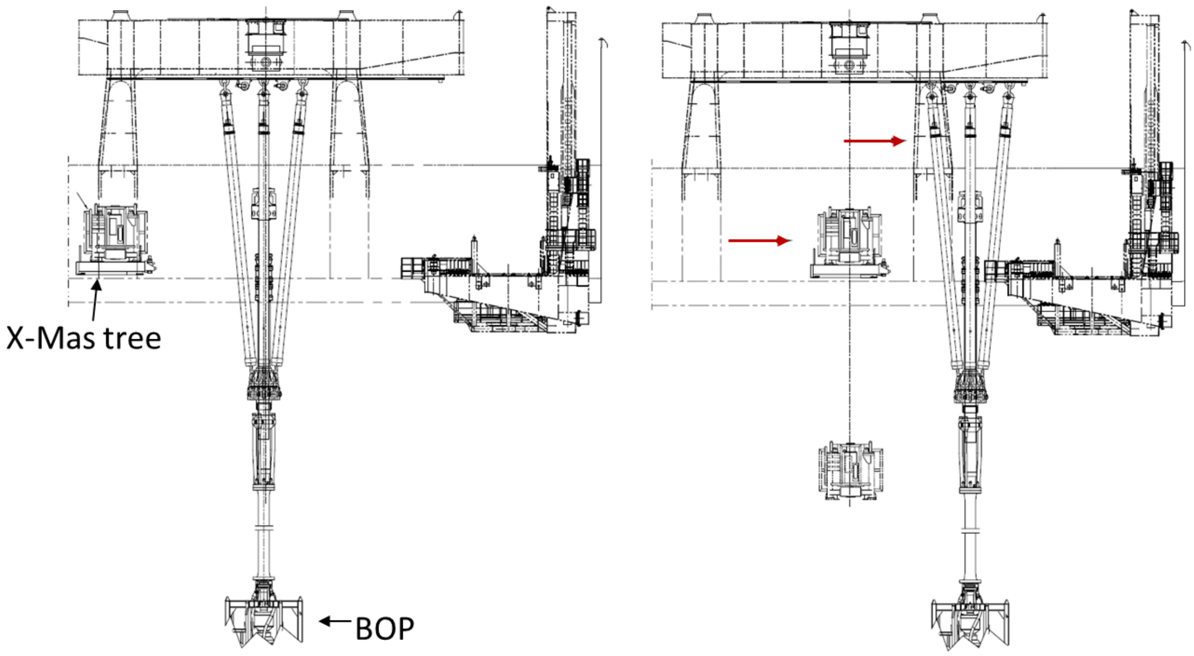

FIGURE 2-18 - TRIP SAVING SYSTEM INTEGRATED WITH N-LINE RISER TENSIONERS ON THE GVA 7500 SEMI-SUB. NOTE: ONLY A PART OF THE BOP IS SHOWN.

2.6 SEA KEEPING PROPERTIES

A floating body is defined as stable if it returns to its initial position when exposed to a disturbance, which would be the case for an operating semi-sub. The distance between a body's center of gravity (KG) and its metacenter (KM) is called the metacentric height (GM), which is a measure of a body's initial static stability for small displacements (Lautrup, 2011).

$$Metacentric\ height \qquad GM = KM - KG \tag{2-1}$$

The centers are measured from a point at the floating body's keel, which explains the K in all designations. Figure 2-19 below describes the different centers. The center of buoyancy (KB) is defined as the geometrical center of the displaced water volume (V), caused by the floating body. When the body rotates around its KG, the water volume displaced by the body is changed, which for small angles implies that KB is horizontally transformed. The new position of KB (KB_1) determines the metacenter (KM), which is defined as the intersection point between the new vertical axis through the KB_1 and the vertical axis of KB in its initial position. As shown in Figure 2-19, KG and KB are in line when the body is not exposed to any disturbances.

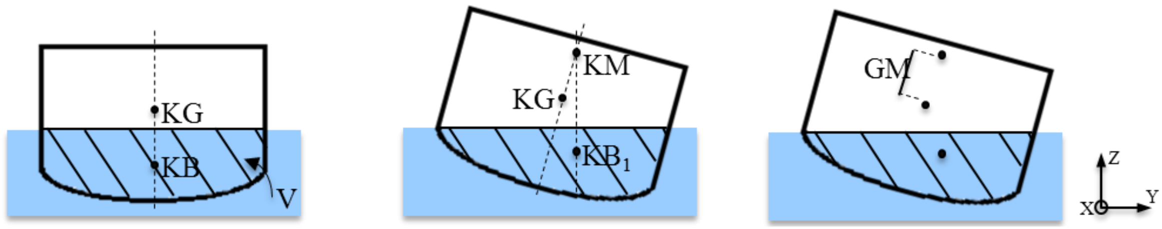

FIGURE 2-19 – DEFINITION OF THE STABILITY RELATED CENTERS. KG –CENTER OF GRAVITY, KB –CENTER OF BUOYANCY, KM – METACENTER.

For a body to be stable, the metacentric height (GM) needs to be positive, which means that the metacenter is above the center of gravity. If GM is zero, the body is in neutral equilibrium, which means that the body will keep the new position when exposed to a disturbance. If GM is negative, the body is unstable, meaning that the body will heel over following the slightest disturbance (Lautrup, 2011).

It can be derived that the greater the GM, the more stable is the body. However, there is a limit to how large the GM should be. A large GM is, except from increased stability, also associated with shorter periods of rolling (see Figure 2-20), which means that the body will return faster to its initial position (Lautrup, 2011). For passengers on a Semi-sub, this would imply a more uncomfortable and bumpy stay. Therefore, the height of the GM is a compromise between stability and comfort. A typical GM for a GVA semi-sub is between 1 and 2 meters.

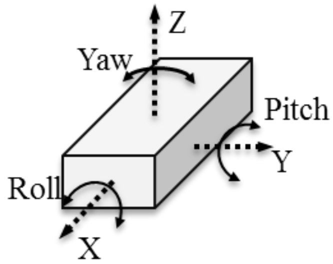

FIGURE 2-20 - DEFINITION OF ROTARY MOVEMENTS.

It can be shown that the Metacenter (KM) can be calculated as

$$KM = KB + \frac{I}{V} \tag{2-2}$$

Where *I* is the second moment of area in the water section plane and V is the volume of the displaced water (Lautrup, 2011). To ensure that the body is stable in all directions, the smallest *I* should always be calculated. In many cases this would be calculated along the X-axis, due to the dominating ship design with long and slender hulls. For submersed semi-subs, *I* will be fairly equal in the X and Y direction due to the symmetry of the columns, which are the only parts that cross the waterline at operating and survival draught. By combining equation 2-2 and equation 2-1, one gets the final expression of GM.

$$GM = KB + \frac{I}{V} - KG \tag{2-3}$$

By studying equation 2-3, it can be seen that by reducing the center of gravity (KG) it is possible to either reach a larger metacentric height (GM), or to decrease the second moment of area (*I*) in order to keep the same sea keeping properties. As previously mentioned, increasing GM is not always a goal in semi-sub design. However, the possibility to decrease *I* can have several positive effects, most important is its relation to the weight of the rig. As seen in Figure 2-21 below, *I* can be reduced by either reducing the sectional area of the rig’s columns, and/or by using a narrower spacing of the columns. Both modifications would reduce the rig’s weight, which would allow the pontoons to be smaller, which in turn would reduce the weight even more. As can be noticed, the reduction of *KG* would generate a positive snowball effect that leads to a reduction of weight and thereby manufacturing cost.

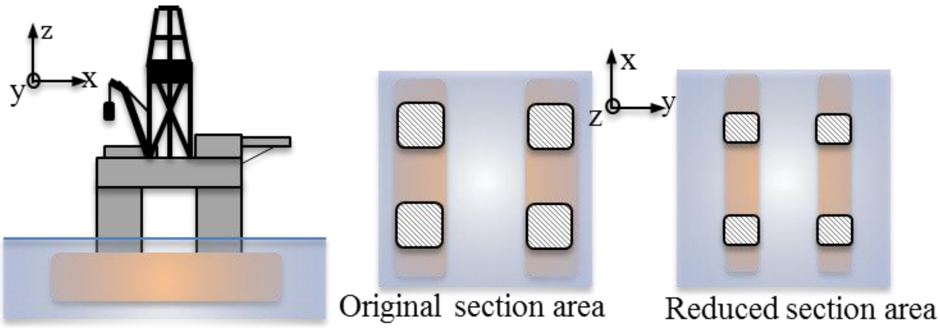

FIGURE 2-21 - EXAMPLE OF HOW THE COLUMNS CAN BE MODIFIED IN ORDER TO DECREASE THE SECOND MOMENT OF AREA IN THE WATERLINE PLANE.

Since the just mentioned reduction of I is conditional on a reduction in KG in order not to affect the rig's sea-keeping abilities, one must first provide a solution for decreasing the KG of the rig. One such approach is to lower the drill floor, which constitutes a large part of the rig's total weight. Thus if the challenges of a flush drill floor can be overcome, large cost reductions can be achieved.

2.7 VERTICAL CENTER OF GRAVITY

The VCG of a semi-sub is measured from the bottom of the keel, and is calculated as the average of each individual components's mass multipliced by its distance from the keel, divided by the total mass of all components. The VCG is similar to the KG used in the equations above, although the VCG is only defined in the vertical direction, whereas KG is determined in three dimensions. In equation 2-4 below, m_i is each components individual weight and r_i is the vertical distance from each individual component's center of gravity to the keel of the rig.

$$VCG = \frac{\sum_i m_i * r_i}{\sum_i m_i} \tag{2-4}$$

Table 2-1 below shows the aggregated weights and VCGs of individual major categories of the GVA 7500 semi-sub (specified with a double derrick). In the bottom row, LUW means light unit weight, and is defined as the weight of the semi-sub without any drilling equipment etc. The drilling category, which weighs almost 3500 tonnes, is the second heaviest except for the structural category. Included in the drilling category is for example the derrick, catwalks, pipe racking tools, top drive etc. Since the weight of the drilling category constitutes almost 10% of the entire rig weight, and the VCG of the drilling category is the highest of all categories, a reduction of the VCG of the drilling category would have the potential to reduce the total VCG by a significant amount. For example, if the VCG of the drilling category is lowered to 47 meters, ceterus paribus, the total VCG is reduced from 31.65 meters to 30.5 meters. A decrease of VCG (=KG) in equation 2-3 of 1.15 meters is significant, since the GM of a GVA semi-sub is typically 1-2 meters, which reflects the potential improvements of a flush drill floor design.

TABLE 2-1 – VCG SUMMARY FOR THE GVA 7500 SEMI-SUB.

Discipline	**Weight [tonnes]**	**VCG [m]**
Structural	18 782.0	24.25
HVAC	519.8	46.03
Mechanical	1 742.3	27.44
Drilling	3 464.0	57.42
Piping	1 877.7	34.19
Electrical	1 749.0	33.83
Steel Outfitting	2 429.7	39.68
Architectural	993.3	46.33
Paint	197.5	23.01
Subtotal	**31 755.3**	**31.38**
Fluid	532.5	32.94
Mill & Weld	93.9	24.25
Correction For Inclination	-170.4	-19.35
LUW	**32 211.4**	**31.65**

In addition to the VCG of the LUW, the VCG is also affected by the amount of equipment on board and by different load cases from different drilling operations, although not to an as large degree as for the different categories in Table 2-1.

3 METHOD

This chapter describes the development approach and reasoning that have been applied during the project. Although this chapter dwells slightly into the theory of product development, it shall be noted that this thesis is not about product development per se, but rather about the particular development challenge of a flush drill floor semi-sub.

3.1 PRODUCT DEVELOPMENT PROCESS

In order to plan and coordinate the project, a development process was developed in accordance with the generic product development process, presented by Ulrich and Eppinger (2012). The development process described by Ulrich and Eppinger (2012) consists of the following steps, presented in their chronological order of execution: Planning, concept development, system-level design, detail design, testing and refinement, production ramp up. This project includes the first three steps, and will thus end after the system-level design. The outputs of the system-level design are a geometric layout of the product, functional specifications of the product's sub-systems and a preliminary assembly process (Ulrich & Eppinger, 2012, p. 15). In this project, the outcomes will include a geometric layout and sub-system specifications, but will not include the manufacturing process.

A semi-sub can be described as a large product including many different sub-systems (decks, equipment, facilities, etc.), which are combined and designed with complex interactions. This implies that the generic development process has been adapted to focus on a sub-system-level, where the traditional concept development phase has been replaced by a sub-system development phase, with more focus on product architecture and sub-system level as recommended by Ulrich and Eppinger (2012, p. 21). The following phases for the project were selected; Literature review, Sub-system development, System level design, Assessment and Documentation, as can be seen in Figure 3-1.

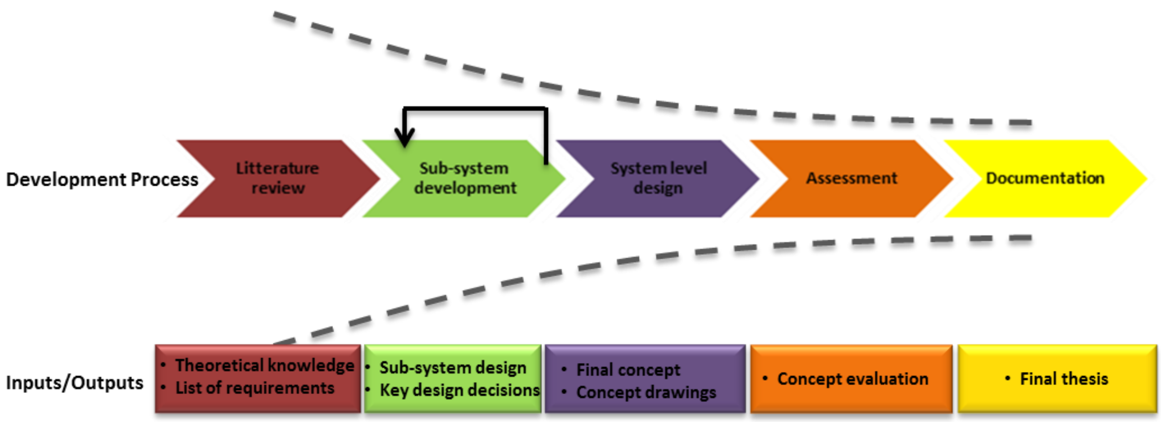

FIGURE 3-1 - THE PRODUCT DEVELOPMENT PROCESS OF THIS PROJECT.

The process can be seen as convergent, where the initial phases are characterized by a wide perspective of the problem. The perspective was progressively narrowed down to focus on details and single solutions along with increasing knowledge of the problems at hand. As will be described later, a sequential design strategy has been used during the project, where the sub-system development phase consists of different iterative cycles.

3.2 LITERATURE REVIEW METHOD

The literature review phase was set up to acquire knowledge about the development problem and the existing design space. The phase was decomposed into tasks focused on learning about how the drilling process works, important drilling activities and operations, existing solutions and patents. Knowledge was gathered from both external and internal sources. In this context, external sources refer to sources outside the company such as books, existing patents, the Internet etc. Internal sources refer to drawings, educational movies, presentations and documentation within GVA.

The literature review proved to be slightly challenging due to a lack of good information sources. For general drilling theory and for hydrodynamics etc., finding useful information from books and articles was generally straightforward. However, information about semi-sub specific components etc. proved to be more or less non existant in conventional literature. Thus to find relevant information about the sub-systems that were to be developed, other information sources had to be used. A combination of existing patents, competitor- and sub supplier product information and internal GVA sources were studied, which eventually led to sufficient knowledge of the subject in order to accomplish the development project.

Since the thesis was based on the GVA 7500 semi-sub, a large part of the literature review phase consisted of studying GVA internal documents and drawings about that rig. However, studying old design documents was unintuitive, and did not provide an easy to grasp picture of the development challenge at hand. Fortunately, more in depth knowledge could be extracted from frequent meetings and discussions with experienced GVA engineers that had taken part in the development of the GVA 7500 and/or similar rigs. Information was collected from the GVA engineers through frequent and unstructured interviews. Unstructured interviews are typically used when the interviewers have limited previous knowledge about the subject, and after the initial question has been asked takes a character close to a normal conversation. An advantage of unstructured interviews is that the interviewee will talk about what he/she thinks is most important, which was very useful for this project (Bryman & Bell, 2011). A potential disadvantage is of course that the interviewee might give biased or imprecise answers. However, such risk was deemed small in this case, and when cross-checking the information between different interviewees and information from drawings etc., the interviewees proved to be trustworthy. Most interviews were held together with the GVA employees Mr. Bernt Erik Westre, Sr. Technical Professional Leader – Mechanical and Ms. Emma Joelsson, Engineer – Drilling. Further, one interview was held with Mr. Inge Peterson, now retired GVA engineer and inventor of a patented solution for a flush drill floor semi-sub design.

Except for books, articles and interviews, information was also gathered from competitors' product sheets. Relevant competitor rigs were the Huisman Orion and the Henry Goodrich semi-subs, since they are designed with a flush drill floor. However, no detailed information about engineering data etc. was found for neither of the rigs, and the information that was found was used more for inspirational purposes than for data collection in the general sense. Company product sheets were also studied about specific components on the rig that could possibly be used on the resulting concept. Most prominently, information about drilling equipment was obtained from product sheets from Aker Solutions and National Oilwell Varco, which both are frequent collaboration partners to GVA.

Two deliverables were the result of the literature review phase: The theory in chapter 2 of this report and a list of requirements for the development project, seen in Appendix B. The list of requirements was constructed in collaboration with GVA engineers. Some key requirements had been decided by GVA in advance of the project, and some requirements/desirables were decided after the literature review. Most requirements stem from the fact that the conceptual drilling rig must be able to perform the same operations as the GVA 7500 semi-sub. Additionally, the concept should be as unconstrained and flexible as possible, thus it was decided that it should be capable of handling as universal drilling equipment specifications as possible. Therefore, the design was required to handle the largest possible BOPs and X-mas trees, thereby it would be easy to convert to handling smaller ones. With regards to trip saver systems and riser tensioner systems, it was decided that it should be capable of handling different specifications of existing solutions rather than relying on special solutions. For the mud return system, it was deemed desirable to be able to use an as standardized design as possible, i.e. mud return by gravity should be possible. A list of requirements that focuses on universality/flexibility would ensure a conceptual design that is not over-specified, which would allow for the resulting design to be used on an as wide range of operations as possible.

3.3 SUB-SYSTEM DEVELOPMENT METHOD

A semi-sub can in many respects be classified as a multidisciplinary system. A multidisciplinary system is a complex system of interactive disciplines, where design parameters and design objectives contradict each other (Stevens, et al., 1998). Multidisciplinary design optimization (MDO) is one way to develop optimal sub-system configurations of multidisciplinary systems, where there are three dominating strategies, which are described below (Weck & Willcox, 2010).

All-in-one strategy - All sub-systems are treated as one large system, which is optimized in one single development process. The strategy is mainly used when sub-systems have an interdependent relationship, meaning that each sub-system requires the others sub-systems' output in order to be optimized. I.e. the sub-systems are coupled and cannot be treated separately. The strategy may be complex and time consuming for bigger projects but gives the opportunity to find the purely optimal solution. The all-in-one strategy can be seen as a flowchart in Figure 3-2.

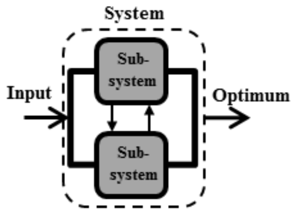

FIGURE 3-2 - ALL IN ONE MDO STRATEGY.

Sequential strategy – The sub-systems are optimized sequentially in multiple development cycles. When one sub-system has been optimized, its output will be the next sub-system's input. The strategy is used when there is a sequential dependency between sub-systems. It reduces design flexibility and thereby reduces the complexity of the development problem. However, since the sub-systems are optimized separately, the strategy may give a sub-optimal solution. A flowchart of the sequential strategy is seen in Figure 3-3.

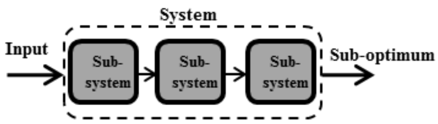

FIGURE 3-3 - SEQUENTIAL MDO STRATEGY.

Decomposed strategy – The system is decomposed into sub-systems, which are treated separately and developed in parallel to each other. The strategy can be used when the sub-systems can be developed independently, which reduces the complexity of the development process. Each sub-system's optimum is combined into the system, potentially creating a sub-optimal solution analogously to the sequential strategy. A flowchart of the decomposed strategy can be seen in Figure 3-4.

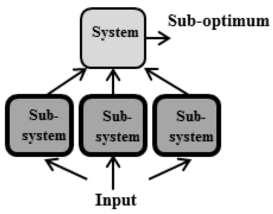

FIGURE 3-4 - DECOMPOSED MDO STRATEGY.

One way to guide the choice of design structure is to investigate the task dependencies in a design structure matrix (DSM) (Ulrich & Eppinger, 2012). A DSM has the project tasks both on its leftmost column and on its top row, with identical ordering. The remaining entities in the matrix are used to describe task dependencies by either marking them with an x, or leaving them blank. Due to symmetry, the diagonal will always be marked by an x. For tasks that must be performed sequentially to another task, the relation will be marked by an x below the diagonal. For tasks that must be performed simultaneously, i.e. coupled tasks, the relationships are marked by an x both below and above the diagonal. Tasks that are independent, i.e. they can be performed without consideration to each other, have no marks linking them in the DSM. By sorting the tasks according to their sequential dependencies, the final DSM is obtained (Ulrich & Eppinger, 2012).

A DSM for the sub-system development tasks in this project is shown in Table 3-1 below. As can be seen in this matrix, the drill floor layout and the BOP/X-mas tree handling sub systems are coupled. All other sub-systems are sequential to the BOP/X-mas tree handling sub system. The riser tensioner and the trip saver sub systems are coupled, and the mud system is independent to all other sub-systems than the BOP/X-mas tree handling sub-system. It shall be noted that these specifications are coarse, and represent simplifications to allow project planning. In reality, all systems are interrelated to some degree, thus it is foolish to assume complete independence for any sub-systems.

TABLE 3-1 - DESIGN STRUCTURE MATRIX OF THE SUB-SYSTEMS TREATED IN THE DEVELOPMENT PROJECT

	BOP/X-mas tree handling	**Drill floor layout**	**Riser tensioner**	**Trip saver**	**Mud system**
BOP/X-mas tree handling	x	x			
Drill floor layout	x	x			
Riser tensioner	x		x	x	
Trip saver	x		x	x	
Mud system	x				x

With the DSM in Table 3-1 in mind, one can see that the project's first efforts should be to develop the BOP/X-mas tree handling and the drill floor layout system. This follows the natural process of semi-sub development, where the rig to some degree is designed according to the BOP specifications, due to its large size and critical functions. It can be argued that the BOP/X-mas tree handling sub-system is one of the most important parts of the architecture of the rig, for which the other sub-systems must be adapted to.

The derivation of the sub-system dependencies shown in Table 3-1 suggests a combination of a sequential approach and an all-in-one approach. Thus the process was sequenced by first developing the BOP/X-mas tree handling and the drill floor layout sub-systems according to an all-in-one approach, where the development started more or less from scratch. Thereafter the riser tensioner and the trip saver sub-systems were developed simultaneously in a quite different manner to the BOP/X-mas tree sub-system development, by focusing on adapting existing solutions to the outputs of the BOP/X-mas tree sub-system rather than designing completely new solutions. Finally, the mud return sub-system was developed analogously to the riser tensioner/trip saver sub-systems. The project approach is clearly sequenced, although two of the three sequences are treated as "all-in-one", where several sub-systems are developed simultaneously due to their coupled dependencies. The process is described in Figure 3-5 below.

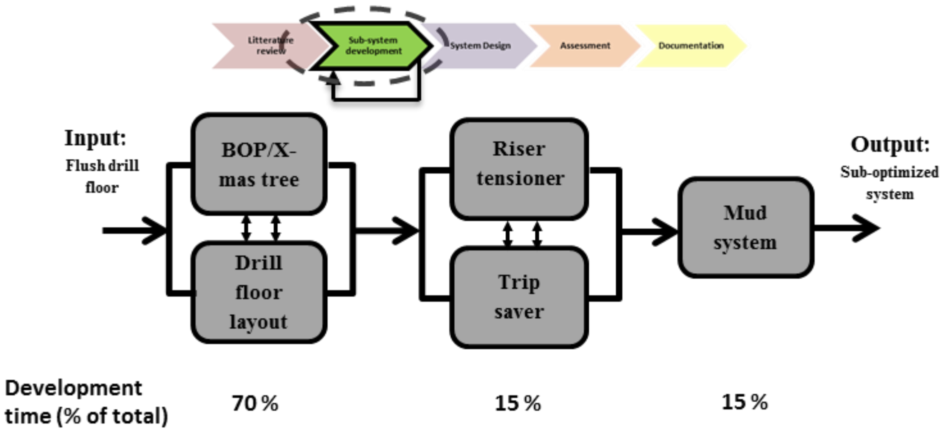

FIGURE 3-5 - THE SUB-SYSTEM DEVELOPMENT STRATEGY.

The sequential approach can be criticized since it can potentially result in a sub-optimal design. However, for this project the drawbacks are outweighed by the benefits of the design strategy. Since a semi-sub is a complex product with many sub-systems, a complete all-in-one approach would be time consuming, and focus can potentially be lost in the process. Further, since all sub-systems are dependent on the BOP/X-mas tree handling, it is natural to develop that sub-system first. The other sub-systems are more flexible in their design, and can thus be designed according to the design of the BOP/X-mas tree and the drill floor layout designs. Finally, if the BOP/X-mas tree handling cannot be satisfactorily designed, the concept of a flush drill floor design will be unfeasible, so that development of other sub-systems would be redundant. (Caroll, 2008)

As can be seen in Figure 3-5, most of the development time was spent on the first sequence of the sub-system development phase, where the BOP/X-mas tree and the drill floor layout sub-systems were conceptualized. The BOP/X-mas tree sub-system was developed more or less from scratch, while the later sequences only needed adoption of conventional solutions to suit the flush drill floor design.

When relevant information had been obtained and the literature review phase was finished, the creative part of the product development started with brainstorming of possible solutions to the BOP/X-mas tree handling problem. Sketches of different design solutions were discussed, developed and iterated within the project group. When the basic ideas had been transformed into more concrete design concepts, they were presented for GVA engineers who provided constructive criticism and design considerations. Eventually, after several iterations of brainstorming and design meetings with GVA engineers, the concept designs converged to a set of different ideas that all were more or less feasible. To give an indication of which sub-system concept that was the most promising, a selection matrix was used. In a selection matrix, the concepts are evaluated according to how well they satisfy the applicable requirements and desirables in the list of requirements, where each criterion from the list of requirements has been weighted according to its importance. The criterions used were taken from the list of requirements (Appendix B) that were applicable to the BOP/X-mas tree handling sub-system. The concepts were then rated on a relative performance scale of 1-5 for all criterions, where 5 is the best performance. Dependent of the weight of the criterion and the performance grade, each concept get a score that can be compared to the scores of the other concepts (Johannesson, et al., 2004). To determine the relative importance for each criterion, a weight decision matrix was used, where each criterion was weighted to each other and got a final weight on a scale of 1-5 (Johannesson, et al., 2004). The weight decision matrix and the selection matrix are presented along with the developed concepts in chapter 4.1. The selection matrix provided a rather clear winner, and after a long meeting with GVA engineers discussing pros and cons of each concept, it was decided that it indeed was the most promising one.

When the winning concept for the BOP/X-mas tree handling and the drill floor layout sub-systems had been decided, it was used as an input for the next sequence of the sub-system development phase. In the second sequence, the trip saver sub-system and the riser tensioner sub-system were developed simultaneously. Due to the fact that the winning concept of the BOP/X-mas tree sub-system did not radically restrict the use of conventional solutions for these sub-systems, it was decided that standard solutions should be used. The process of adapting such standardized systems was however not trivial, and required several iterations in order to find room for all components and ensure that all drilling operations could be conducted. Each design iteration was discussed in detail with GVA engineers with much experience of similar problems, and the process continued until the design was deemed functional by the GVA engineers.

The last sequence in the sub-system development phase consisted of development of a functional mud return system. The design approach was analogous to the one used in the second sequence, although slightly heavier modifications of the standardized system needed to be performed than for the trip saver/riser tensioner sub-systems.

3.4 System level design method

When all winning sub-systems had been chosen and developed, they were mixed into a complete system. In the system level design phase, all sub-systems and their relations were developed in more detail by computer aided design (CAD) drawings of the applicable areas. Drilling components and their dimensions and locations were determined in an iterative manner, while analyzing operational procedures for applicable drilling operations in order to ensure feasibility of the design.

The system design development started with taking the hull dimensions etc. from the GVA 7500 semi-sub, and then adding the relevant components one by one (while ensuring that the components were designed with the same dimensions as on the GVA 7500). The process was iterated eight times, with a design meeting with GVA engineers followed after each iteration, until the final design was defined. The system design phase took in total about six weeks, and great care was taken to ensure the feasibility of all relevant drilling operations.

3.5 Assessment method

The assessment phase consisted of center of gravity calculations in order to compare the new design to the reference design of the GVA 7500 semi-sub. Further, the operational procedures for applicable drilling operations were assessed by GVA engineers to evaluate whether or not drilling operations had been adversely affected by the flush drill floor design. Ideally, it would be good to test the concept, however no such resources were at disposal due to the large size and cost of the product.

4 SUB - SYSTEM DEVELOPMENT

This chapter presents the results of the development of each sub-system, in the order of their development as described in Figure 3-5 above. The development method has followed the method outlined in chapter 3.

4.1 BOP/X-MAS TREE HANDLING AND DRILL FLOOR LAYOUT

Five concepts with different complexity, flexibility and novelty were generated for the BOP/X-mas tree and drill floor layout sub-systems according to the process described in chapter 3.3. To guide the choice of the best concept, a subset of the relevant requirements in the list of requirements in Appendix B and design objectives given by design meetings with GVA engineers were aggregated into six evaluation categories according to Table 4-1 below.

TABLE 4-1 - AGGREGATION OF REQUIRMENTS INTO EVALUATION CATEGORIES.

BOP evaluation criteria	**Category**
Component cost	Cost
Complexity of design changes (unproven/non existing technology)	Cost
Complexity of splash zone protection	Cost
Convenience of POD line operations	Operational efficiency
Offline riser building capability	Operational efficiency
Time for BOP to move to well center	Operational efficiency
Total time for BOP deployment	Operational efficiency
Time for X-mas tree to move to well center	Operational efficiency
Total time for X-mas tree deployment	Operational efficiency
Potential to prepare BOP / X-mas tree for installation before drilling is stopped	Operational efficiency
Possibility to lift LMRP, BOPs and X-mas trees without stopping drilling operations	Operational efficiency
Number of potentially dangerous lifts	Safety
Time for BOP in splash zone	Safety
Size of moon pool	Space consumption
Efficient use of space on main deck	Space consumption
Convenience of BOP testing	testability
Convenience of X-mas tree testing	testability
Potential weight reduction (except for effect of VCG reduction)	Weight reduction potential

The evaluation categories were then weighted according to their relative importance by a weight decision matrix seen in Table 4-2, where the most important categories are green and the least important ones are red. As can be seen from Table 4-2, the highest weight has been given to the operational efficiency criterion, which is motivated by the high day rates for semi-subs. The weight reduction potential is defined as the potential to reduce weight except for the indirect weight loss of structural gains from a flush drill floor. Thus this requirement can be considered as potential for reduced weight in excess of that weight lost due to the flush drill floor design, which for example can be obtained by using the same equipment for several tasks etc. The reason for the high weight of this criterion is that the purpose of the project is to allow for weight reduction of the rig, and the outcome would be adversely affected if the concept requires heavy and specially designed equipment in order to work. The third highest weight was given to the testability constraint, which relates to how easily the BOPs and X-mas trees can be serviced and tested on the rig. Since the concepts differ in regards to the placements of the BOPs and the X-mas trees, this criterion can potentially differ rather much to the existing design. If the concepts are worse than today's design (similar to concept C), the flush drill floor concept loses feasibility, which explains the relatively high weight of this criterion. The safety criterion and the cost criterion were considered to be the fourth most important. The cost criterion relates to the expected cost of the drilling arrangement for the concepts, where a lower cost means a higher score. The safety criterion relates to how safely the drilling operations can be performed, with a special focus on how many heavy lifts that must be performed for BOP/X-mas tree deployment. Space consumption was considered to be the least important criterion. The reason for the low importance of the safety criterion and the space consumption criterion was mainly because the concepts differed very little with respect to these criteria. The cost criterion however differed rather much between the concepts, but since the drilling arrangement is only a part of the total cost of the rig, and all concepts are expected to be cheaper than today's design due to the lighter weight of the flush drill floor design, the cost criterion was ranked relatively lowly.

TABLE 4-2 - WEIGHT DECISION MATRIX.

Criterion	A	B	C	D	E	F	SUM	SUM/TOT	SCALE 1-5
A - Cost (Lower cost => higher value)	-	0	0,5	0,5	0,5	0	**1,5**	10,0%	**2**
B - Operational efficiency	1	-	1	1	1	1	**5,0**	**33,3%**	**5**
C - Safety	0,5	0	-	1	0	0	**1,5**	10,0%	**2**
D - Space consumption	0,5	0	0	-	0	0	**0,5**	3,3%	**1**
E - Testability	0,5	0	1	1	-	0	**2,5**	16,7%	**3**
F - Weight reduction potential	1	0	1	1	1	-	**4,0**	**26,7%**	**4**
							15	**100%**	

The weighted criteria were used to form the selection matrix seen as Table 4-3 below, where green represents a high rank and red represents a low rank. A description of all individual rankings follows in the sub-chapters below along descriptions of each developed concept.

TABLE 4-3 - THE SELECTION MATRIX FOR THE BOP/X-MAS TREE AND DRILL FLOOR LAYOUT SUB-SYSTEMS.

Criterion	Concepts											
	Weigth	Ideal		Concept A		Concept B		Concept C		Concept D		Concept E
		Grade	Total	Grade	Total	Grade	Total	Grade	Total	Grade	Total	Grade	Total
A - Cost (Lower cost => higher value)	2	5	10	4	8	3	6	4	8	2	4	2	4
B - Operational efficiency	5	5	25	2	10	2	10	4	20	5	25	1	5
C - Safety	2	5	10	3	6	3	6	2	4	3	6	2	4
D - Space consumption	1	5	5	5	5	1	1	3	3	3	3	4	4
E - Testability	3	5	15	3	9	3	9	4	12	5	15	2	6
F - Weight reduction potential	4	5	20	4	16	1	4	2	8	3	12	4	16
Total		85		54		36		55		65		39	
Total/Total_Ideal		1,00		0,64		0,42		0,65		0,76		0,46	
Ranking				**3**		**5**		**2**		**1**		**4**	
Further development				No		No		**Yes**		**Yes**		No	

4.1.1 CONCEPT A - THE GVA PATENT INSPIRED CONCEPT

This concept is based on a GVA patent from 2009 (Petersson, 2009), which uses the main hoisting system to deploy the BOP through a removable rotary table and diverter in the derrick. Its working principles for installing both the BOP and the X-mas tree follows the steps described below, numbers refer to Figure 4-1.

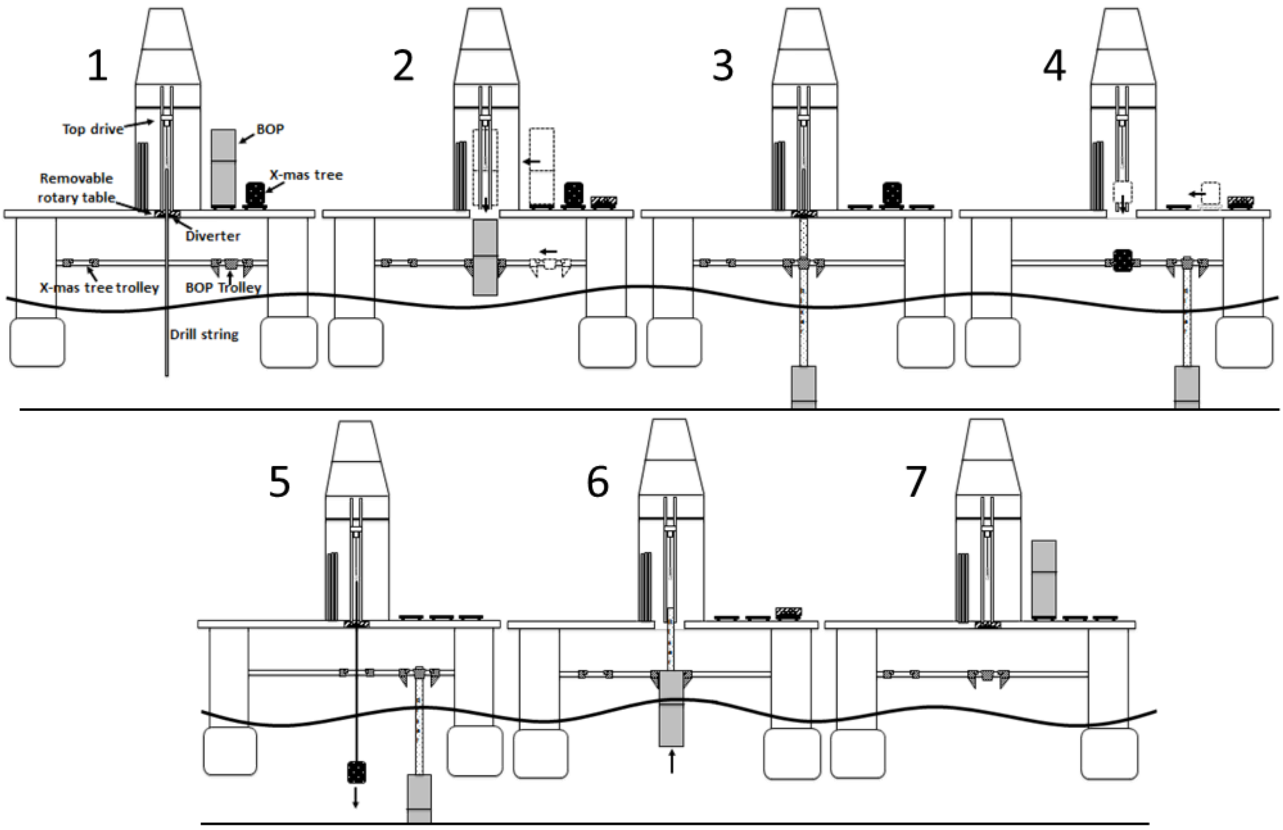

FIGURE 4-1 - PRINCIPLES OF CONCEPT A.

1. When the top hole is drilled and casing has been set, the drill string is POOH.
2. A square part of the drill floor, which contains the diverter and the rotary table, is picked up by the top drive and placed on a designated trolley, which transports it outside the derrick. The BOP, which has already been tested and prepared for use, is transported on the same skidding system to the well center, through an opening in the derrick. The hoisting system lowers the BOP through the hole in the drill floor until it is clear of the lowest part of the drill floor structure. It is then hung off on a trolley in the moon pool.
3. The removed part of the drill floor is replaced. The first riser pipe is installed, the BOP is released from its trolley and lowered towards the seabed by continuously adding riser pipe. The BOP has been landed and the riser pipe is completely installed.
4. When drilling is finished, BOP and riser are trip-saved to make room for X-mas tree. The square part of the floor is moved, and the prepared X-mas tree is skidded to the well center. The hoisting system lowers the X-mas tree through the hole until it is clear of the lowest part of the drill floor structure. It is then placed on its trolley in moon pool and the removable floor is replaced.

5. The first drill pipe is installed, the X-mas tree is released from its trolley and lowered towards the seabed by continuously adding drill pipe.
6. The X-mas tree is installed on the finished well and the drill pipe is POOH. The BOP/riser package is skidded to well center and lifted onboard.
7. Drilling finished

This concept relies on the fact that the rotary table and the diverter can be removed with the removable part of the drill floor. However, as was found out in the interview with the inventor of the patent, no such solution exists. Since the BOP and the X-mas tree are deployed through the main well center, the design does not require any separate lifting equipment or an auxiliary well. Thus this concept can potentially be light weight and applicable to rigs with varying designs. As can be seen in Table 4-3 above, the concept receives a good score in weight reduction possibility due to the fact that it requires very few components for the BOP/X-mas tree handling system, which also explains the high rank in the cost criterion. The concept receives a top score in the space consumption criterion since the cellar deck can be built very small when it does not have to fit the BOPs and neither the BOP nor the X-mas tree must be skidded in the moon pool. The concepts loses slightly in the testing criterion since the entire BOP can only be lifted at the well center, which requires the drilling operations to be stopped for every such lift. This lifting restriction also partly explains the low score in the operational efficiency criterion. However, worse yet is the fact that the diverter line must be connected/disconnected each time a BOP or X-mas tree is lowered to the sea bed. Safety wise, the concept is one of the better ones, mainly because the BOP does not need to be skidded while in the moon pool, where wave induced movement can damage the BOP and/or its handling equipment since it will be in the splash zone.

4.1.2 Concept B - The outside derrick concept

This concept is similar to concept A, with the difference that the drill floor is now located outside the derrick in order to provide more space for the drill floor layout. The concept was inspired by a novel design of GVA's competitor Huisman. The Huisman Orion class of semi-subs does not have a traditional derrick. Instead, a steel column in the center of the rig holds two hoisting systems on the outside of the column, one on each side. However, one must not refrain from a traditional derrick only in order to place the hoisting system outside the derrick. This concept uses a normal, although slightly strengthened and off-centered, derrick, with a hoisting system that runs on guide rails outside the derrick, as seen in Figure 4-2 below. Its working principle for installing the BOP and the X-mas tree follows the steps described below, numbers refer to Figure 4-2.

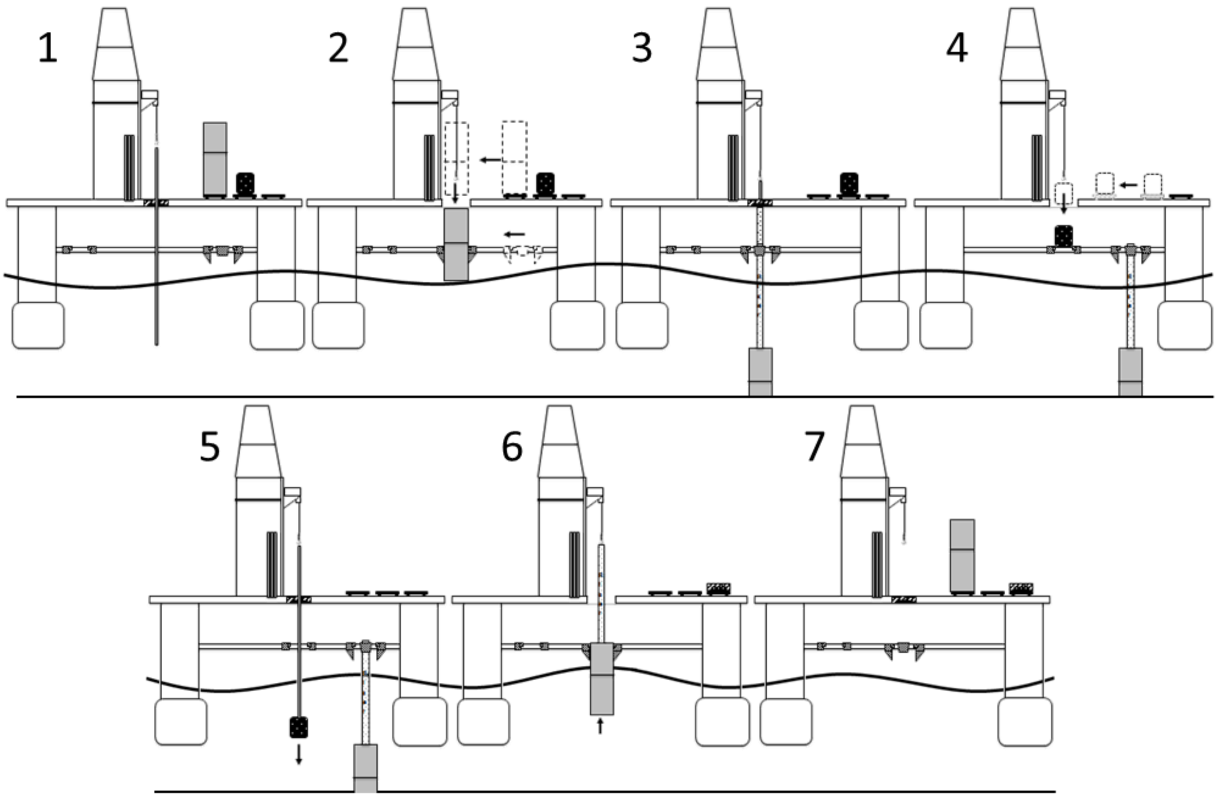

FIGURE 4-2 - PRINCIPLES OF CONCEPT B.

1. When the top hole is drilled and casing has been set, the drill string is POOH.
2. A square part of the drill floor, which contains the diverter and the rotary table, is picked up by the top drive and placed on a designated trolley, which transports it away from the well center. The BOP/X-mas tree, which has already been tested and prepared for use, is transported on the same skidding system to the well center, through an opening in the derrick. The hoisting system lowers the BOP through the hole in the drill floor until it is clear of the lowest part of the drill floor structure. It is then hung off on a trolley in the moon pool.
3. The removed part of the drill floor is replaced. The first riser pipe is installed, the BOP is hung off from its trolley and lowered towards the seabed by continuously adding riser pipe. The BOP has been landed and the riser is completely installed.
4. When all drilling operations have been completed, the BOP/riser package is moved away from the well center. The removable part of the drill floor is removed. The hoisting system lowers the X-mas tree through the hole until it is clear of the lowest part of the drill floor structure. It is then placed on its trolley in moon pool and the removable floor is replaced.
5. The first drill pipe is installed, the X-mas tree is released from its trolley and lowered towards the seabed by continuously adding drill pipe.
6. The X-mas tree is installed on the finished well and the drill pipe is POOH. The BOP/riser package is skidded to the well center and lifted onboard.
7. Drilling finished.

The working procedure is notably similar to the GVA patent inspired concept, thus the concept has an equally low rank of the operation efficiency criterion as Concept A. The benefit of working outside the derrick is primarily that the drill floor space can be made larger, and thus the drill floor will not be as crowded during BOP/X-mas tree operations. Moving the BOP to and from the well center can also be made easier since it is not restricted to pass through the derrick from only one direction. The drawbacks of the design are related to the design of the derrick. Since the derrick will by loaded off center, it will not be purely compressed by the weight of drill string, it will also be subjected to a moment. Due to this non optimal load case, the derrick would need to be strengthened, and thus made heavier than a traditional derrick, which explains the bad rank on the weight reduction possibility criterion for this concept. The reason for the bad rank of the space consumption criterion is that the space inside the derrick would, to some degree, be wasted, primarily since the setback can no longer be placed inside the derrick. The rank of the testability and the safety criterion follows directly from the similarity to Concept A. To improve the design, one could imagine having two hoisting systems, one on each side of the derrick, with an auxiliary well where the BOP/X-mas tree is deployed. However, such design would not allow the derrick to be placed off-center, and the well centers would thereby be located a rather long distance from the rig's center, which is not desirable.

4.1.3 CONCEPT C - THE SEPARATE CRANE CONCEPT

This concept is the least novel of the proposed designs in this thesis. It is based on the traditional BOP/X-mas tree handling system described in chapter 2.5.2 above, although modified to allow for a flush drill floor design. In this concept, the lower stacks of the BOPs are stored on the cellar deck, the LMRPs can either be connected to the lower stacks, or stored on the main deck, where they can be tested. Lifting of the LMRPs, X-mas trees and BOPS are performed by a dedicated gantry crane. The working principle for running the BOP and X-mas tree follows the steps described below, numbers refer to Figure 4-3.

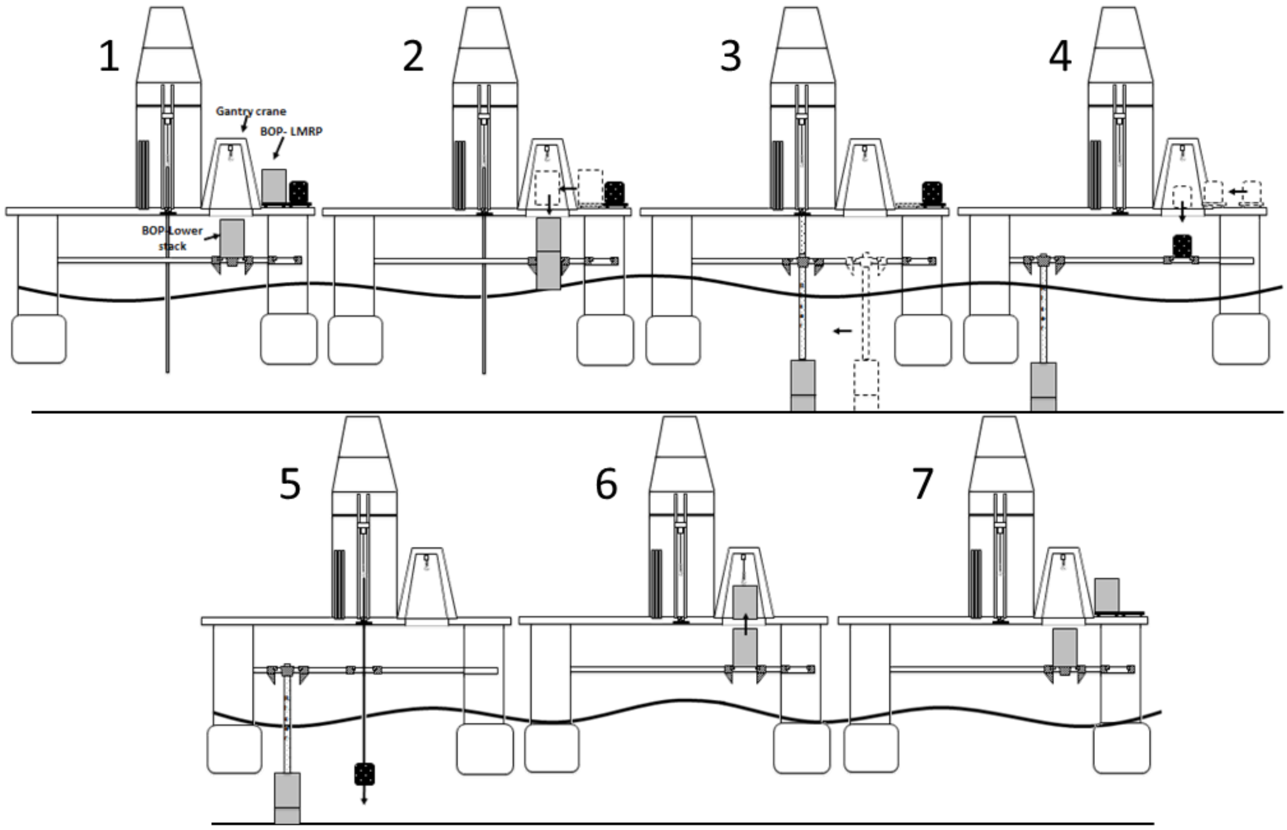

FIGURE 4-3 - PRINCIPLES OF CONCEPT C.

1. The LMRP is tested on the main deck, and the lower stack is tested on the cellar deck.
2. The gantry crane lifts the LMRP and places it on the lower stack. The entire BOP assembly is lifted onto the BOP trolley and hung off so that it is clear from the main deck.
3. When the top hole is drilled and casing has been set, the drill string is POOH. The BOP is transported on the BOP trolley, which also protects it from the splash zone by its guide rails. The first riser pipe is installed, the BOP is hung off from its trolley and lowered towards the seabed by continuously adding riser pipe. The BOP is landed and the riser is completely installed.
4. When all operations on the well are performed, the BOP/riser are hung off on the BOP trolley and transported away from the well center. The X-mas tree is lowered to the X-mas tree trolley by the gantry crane.
5. The X-mas tree is transported to the well center by the X-mas tree trolley. The X-mas tree is landed on the well head and the drill string is POOH.
6. The BOP/riser package is lifted onboard. The LMRP is disconnected from the lower stack.
7. The LMRP is placed on the main deck and the lower stack is placed on the cellar deck.

This concept does not rely on an opening in the drill floor, and thus allows a traditional drill floor layout to be used without any modifications. Instead of using a removable rotary table, the LMRPS and X-mas tree are lowered through an opening in the main deck outside the derrick. This concept is almost identical to the BOP/X-mas tree handling systems on traditional semi-subs, although with one exception. To be clear of the main deck, the BOP must be hung off much lower on the BOP trolley than for a traditional semi-sub, with a raised drill floor. This implies that when the BOP is transported in the moon pool to the well center, it will likely be partly covered by water, and it will certainly be in the splash zone. Thus this concept relies on a strong guide for the BOP so that the handling system does not break by the forces of the waves in the splash zone. The long exposure to the splash zone explains why this concept is ranked lower with regards to safety than the other concepts. Storing the lower stacks in the cellar deck has two advantages: The moon pool is a natural place to service and test the lower stacks (no dedicated service structure needs to be built on the main deck) and since the lower stacks are positioned as low as possible, they will reduce the rig's center of gravity. However, the flexibility of moving the BOPs, LMRPs and X-mas trees on the main deck is lost, as is the potential to reduce the size of the moon pool, which explains the low rank of the space consumption criterion. If one for some reason would like to store the entire BOP on the main deck, it would be possible to equip this concept with a larger crane that would accommodate such lift. However, such crane would be heavier, and one would need a larger service structure for the BOP on the main deck. Contrary to the two previously described concepts, this concept does not require the diverter to be removed when deploying the BOP and X-mas tree, thus from an operational efficiency perspective, this concept is better. However, it requires dedicated lifting equipment and heavy splash zone protection equipment, which decreases the weight reduction potential. Since the concept almost exclusively rely on standardized components, it was considered to be among the cheapest of the generated concepts.

4.1.4 Concept D - The removable auxiliary well center concept

This concept is a development of the GVA patent inspired concept, with the aim to avoid the process of removing/installing the diverter when lifting the drill floor. One way to do so is to equip the rig with two well centers, one main well center that is designed like a normal drilling rig, and one auxiliary well center without a diverter, but with a removable floor. Rigs with two well centers are not uncommon, especially not for larger rigs. If one restricts the development to rigs with two well centers, most of the problems with the other concepts can be overcome, although with the drawback that the design will not be applicable to smaller drilling rigs. The working procedure for running the BOP and X-mas tree follows the steps described below, numbers refer to Figure 4-4.

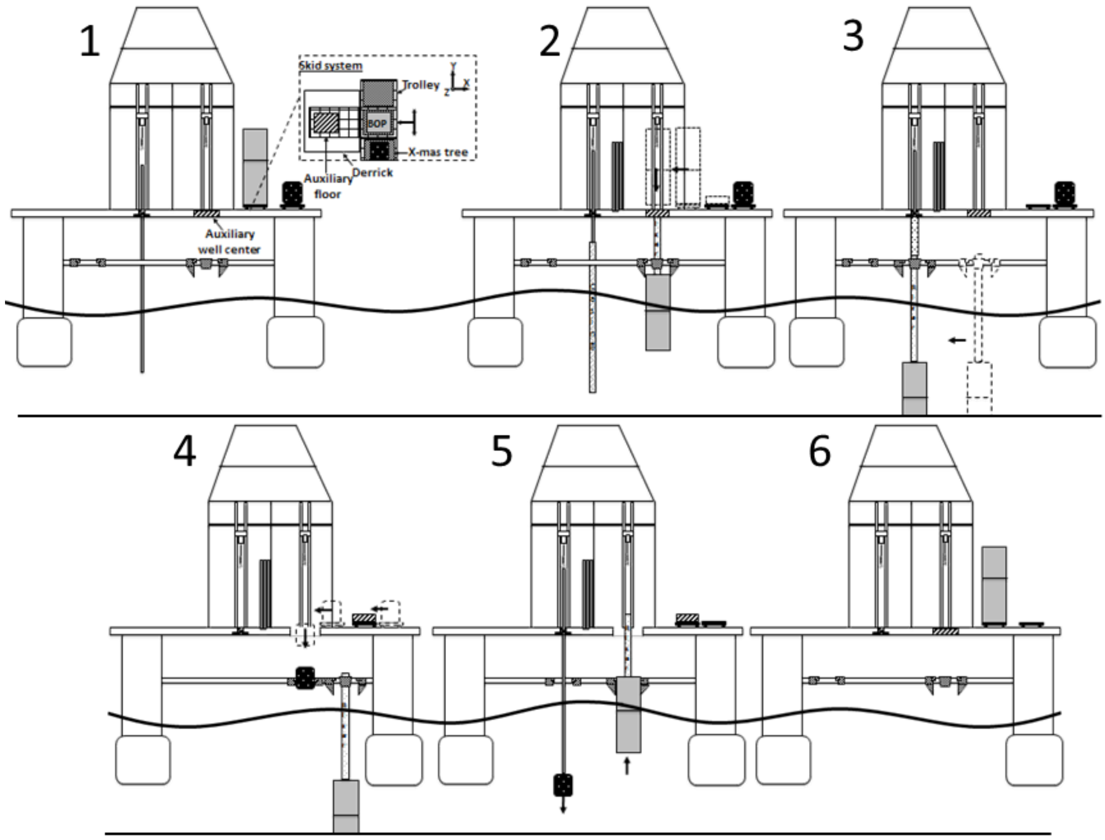

FIGURE 4-4 - PRINCIPLES OF CONCEPT D.

1. The removable floor is lifted by the auxiliary hoisting system and placed on a designated trolley, which transports it away from the well center (not pictured).
2. The entire BOP, which has already been tested on the main deck, is transported to the well center. The BOP is lowered through the opened drill floor and hung off on a BOP trolley in the moon pool so that it is clear from the drill floor. The removed part of the drill floor is replaced, and the BOP is lowered to the seabed by continuously adding riser pipe.
3. The drill string in the main well center is POOH (it has been drilling simultaneously to previous BOP operations). When all but one or two riser pipes have been installed, the BOP/riser is transported to the main well center. The last riser pipe is installed in the main well center and the BOP is landed on the well.
4. When all operations on the well are performed, the BOP/riser are hung off on the BOP trolley and transported away from the well center. The floor is once again opened, the X-mas tree is transported to the auxiliary well center and is lowered to the X-mas tree trolley in the moon pool.
5. The X-mas tree trolley is transported to the main well center and the X-mas tree is lowered to the seabed. If no more drilling operations are to be performed at the drill site, the BOP and riser is taken up to the rig by the auxiliary hoisting system.
6. The X-mas tree is landed, the drill string is POOH and the removable part of the drill floor is put back in place.

Since the auxiliary hoisting system can be used for several tasks, for example offline casing building, or even riser-less drilling if it is equipped with a rig heave compensator, the weight reduction potential remains at an average rank even though the concept requires a double derrick. The concept is considered as equally safe or safer than the other concepts, since the BOP will not have to be transported while in the splash zone. Additionally, this concept also has the benefit of the traditional concept that there will not be very large modifications to the drill floor layout, since the main well center has no removable floor. The ability to use rather standardized components should reduce the cost of the concept, although it is high regardless, since an extra derrick is required. The concept ranks averagely on the space consumption and the weight reduction criteria, since the extra derrick undeniably will add extra weight and take up extra space. Testability should be excellent, since drilling operations do not need to be stopped for lifting of the BOP, and the final tests can be performed at the well site just prior to deploying the BOP. However, these advantages come at the cost of limited design applicability. Only rigs large enough to handle the significantly increased derrick size due to the two well centers and hoisting systems can be considered for this design concept, which is discouraging from a universality/feasibility aspect of the concept.

4.1.5 CONCEPT E - THE MOVEABLE TOP DRIVE CONCEPT

This concept is similar to the removable auxiliary well center concept, but designed to reduce cost, size and weight by not using two hoisting systems/draw-works. Compared to the removable auxiliary well center concept, this design will be applicable to a wider range of semi-subs, since it does not require a derrick large enough to fit two hoisting systems. The working procedure for running the BOP and X-mas tree follows the steps described below, numbers refer to Figure 4-5.

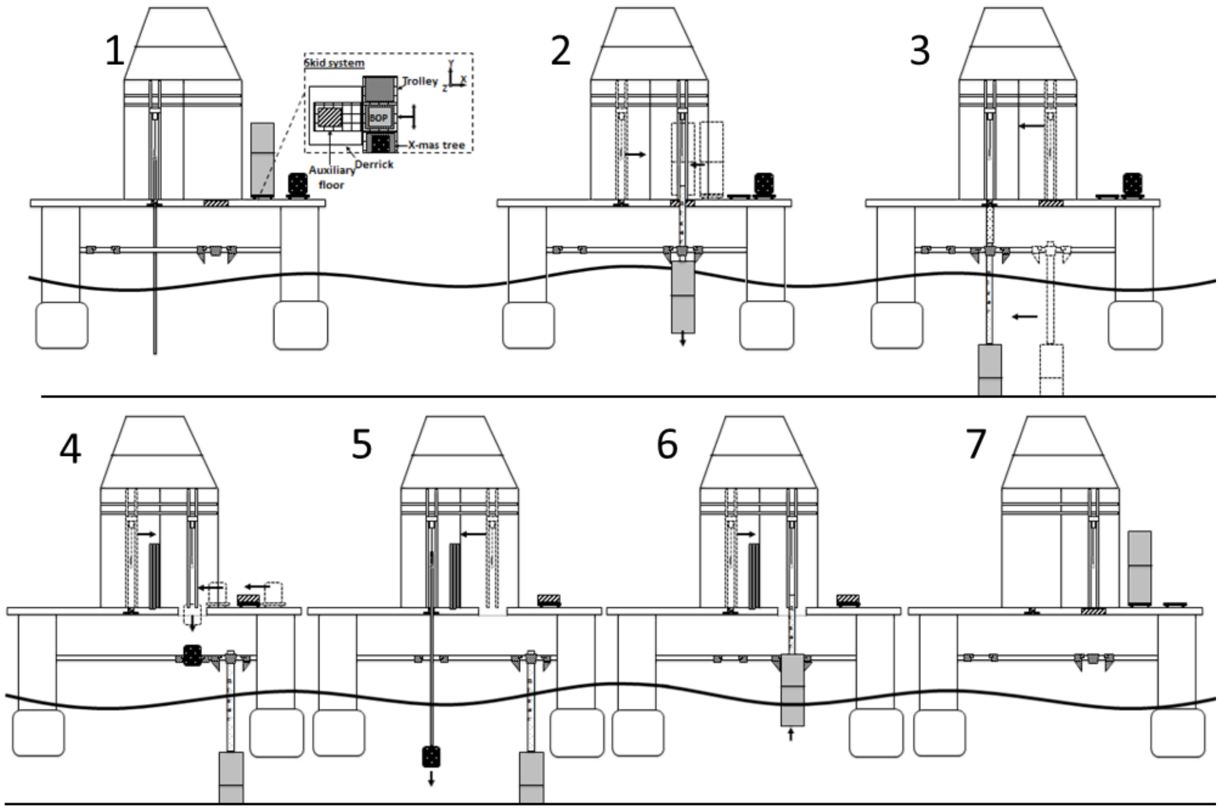

FIGURE 4-5 PRINCIPLES OF CONCEPT E.

1. The top hole section is finished and drill string is POOH at main well center.
2. The Top drive is moved to the auxiliary well center. The removable floor is lifted by the hoisting system and placed on a designated trolley, which transports it away from the well center (not pictured). The BOP, which has already been tested on the main deck, is moved to the auxiliary well center. The BOP is lowered through the open hole and hung off on the BOP trolley in the moon pool. The removable floor is reinstalled and the BOP is lowered to the seabed while continuously adding riser pipe
3. When all but one or two riser pipes have been installed, the BOP/riser is transported on its trolley to the main well center. The Top drive is moved to the main well center. The last riser pipe is installed in the main well center and the BOP is set down on the well.
4. When all operations on the well are performed, the BOP/riser are hung off on the BOP trolley and transported away from the well center. The Top drive is once again moved to the auxiliary well center. The floor is opened and the X-mas tree is lowered to its trolley in the moon pool.
5. The top drive is moved back to the main well center. The X-mas tree is moved to the well center. The X-mas tree is lowered to the seabed and lowered on the finished well using the main well center.
6. If no more drilling operations are to be performed at the drill site, the top drive is moved back to the auxiliary well center.
7. The BOP and riser is taken up to the rig.

While this concept shares several advantages to the removable auxiliary well center concept, it does not suffer from the drawback of only being applicable to large rigs. However, it shares some of the drawbacks of the single well center design concepts, for example; it cannot run offline riser and all drilling operations must be stopped when lifting the BOP, LMRP or X-mas tree. In addition, the top drive must be moved, which might be time consuming and requires a special draw-work and compensator system, which makes it rather expensive and inefficient. Due to the compactness and utilization of the same equipment for several tasks, it ranks highly on space consumption and weight reduction potential. However, testability suffers from the fact that the drilling operations must be stopped and the top drive moved in order to lift the BOP.

4.1.6 The winning concept

As can be seen in Table 4-3, Concept D had the highest score in the selection matrix, followed by concept C and concept A. In addition to the results from the selection matrix, general pros and cons of the different concepts were used in a decision meeting with GVA engineers, including the inventor of GVA's existing patent on a flush drill floor design. The list of pros and cons can be seen in Table 4-4 below. From the meeting, it was decided through a consensus decision that the most promising concept was indeed concept D, in line with the results of the selection matrix. The concept was further developed in the system level design, and a more thorough description of the resulting design can be seen in chapter 5.

TABLE 4-4 - PROS AND CONS OF THE DIFFERENT CONCEPTS.

PROS:	CONS:
Concept A	
Flexible: works for both double- and single derrick design.	Large modifications necessary to drill floor layout.
Potentially the most lightweight design.	Potentially time consuming operation to remove / install diverter lines.
No transportation of BOP in the moon pool, short exposure to the splash zone.	Drilling operations must be completely stopped when running the BOP/X-mas tree.
No separate lifting equipment for the BOP/X-mas tree.	Drilling operations must be stopped when lifting BOP.
	There will not be much free space on the drill floor when BOP/X-mas tree operations are performed.
Concept B	
Spacious and flexible drill floor layout.	Potentially time consuming operation to remove/install diverter lines.
No transportation of BOP in the moon pool, short exposure to the splash zone.	Drilling operations must be completely stopped when running the BOP/X-mas tree.
No separate lifting equipment for the BOP/X-mas tree.	Drilling operations must be stopped when mounting/dismounting the LMRP and thelower stack of BOP.
	Relatively heave derrick design.
	Unused space inside the derrick
Concept C	
Non-modified drill floor layout.	Drilling operations must be completely stopped when running the BOP/X-mas tree.
Low center of gravity.	Long exposure of the splash zone when the BOP is transported to the well center.
No need for dedicated service structures of the lower stack on the main deck.	Larger moon pool than other designs.
Lifting of LMRP, BOP and X-mas tree possible without stopping drilling operations.	
Concept D	
Small modifications to drill floor layout (on main well center).	Design is limited to rigs capable of handling a large derrick with two hoisting systems and well centers.
No transportation of BOP in the moon pool, short exposure to the splash zone.	Auxiliary hoisting system must be capable of handling the weight of the entire riser and BOP package, which can add weight and cost.
Possibility of running riser in the auxiliary well while drilling in the main well center.	
Concept E	
Small modifications to drill floor layout (on main well center).	Drilling operations must be completely stopped when running the BOP/X-mas tree.
No transportation of BOP in the moon pool, short exposure to the splash zone.	Drilling operations must be stopped when mounting/dismounting the LMRP and thelower stack of BOP.
No separate lifting equipment for the BOP/X-mas tree.	Draw works, hoisting system and compensator system requires special design.
	Lifting operations can be time consuming because of the need to move the top drive.

4.2 RISER TENSIONER AND TRIP SAVER

When the sub-system development of the BOP/X-mas tree handling and the drill floor layout sub-systems was completed, the resulting design was used as an input for the development of the riser tensioner and the trip saver sub-systems. In chapter 3.3, it was described that the conceptual semi-sub design should optimally work with as standardized components as possible for the riser tensioner and trip saver systems. This desire was strengthened by the realization that the resulting BOP/X-mas tree handling design did not affect the functionality of the riser tensioner and trip saver system to an as large degree as was first anticipated.

Of the two principal designs for riser tensioning described in chapter 2.5.4, the wire-line type requires more consideration in the concept development phase, since it requires more components to be placed on the rig. Further, it was considered as a more straightforward approach to retrofit N-line riser tensioners than wire-line tensioners, should one want to do so in the future. Analogously to the decision to design the rig for the largest possible BOPs and X-mas trees in order to ensure universality/feasibility of the design, it was decided to use wire-line tensioners for the rig. Since the wire-line tensioners are more restrictive with regards to finding space for all components, the reasoning was that if the design would work for wire-line tensioners, it would also be compatible with N-line tensioners

Since N-lines were not used for riser tensioning, the trip saving function could not be used with N-lines either. Therefore the remaining options were either to use a dedicated trip saver trolley, or to use the BOP trolley or the X-mas tree trolley for trip saving. Since the conceptual design of the BOP/X-mas tree handling sub-system allowed for X-mas tree deployment through the auxiliary well, it was considered favorable to use the BOP trolley for trip saving, so that the X-mas tree trolley is free to use for X-mas tree deployment when the BOP/riser package is trip saved.

According to the universality/feasibility discussion above, the conceptual design for riser tensioning and trip saving was decided as: Riser tensioning shall be performed by a traditional wire-line riser tensioning system, although with the components placed lower on the rig, along with the lowered drill floor. Trip saving shall be performed by hanging off the BOP/riser package on the BOP trolley. Figure 2-17 in chapter 2.5.5 is illustrating the principles of the selected concepts. When the conceptual design decisions for the riser tensioner and trip saver sub-systems had been taken, the development was finalized in the system level design phase described in chapter 5.

4.3 MUD RETURN SYSTEM

Similarly to the development of the riser tensioner and the trip saver sub-systems, the mud return system was developed with the objective of using standardized components. The most significant challenge was to find room for all components in the vertical direction. In chapter 2.5.3, it was described that the different components in the mud return system should be connected so that gravity can feed the mud from the diverter to the mud pits. Since the flush drill floor design lowered the diverter by approximately ten meters, designing a gravity driven mud return system became more challenging than for a conventional rig. After several failed iterations of trying to fit the existing mud return system of the GVA 7500 semi-sub on the new design, it was realized that in order to achieve a satisfactory design, larger changes were necessary. A schematic of the initial attempts to create a mud return system using the components and dimensions from the GVA 7500 semi-sub can be seen in Figure 4-6 below.

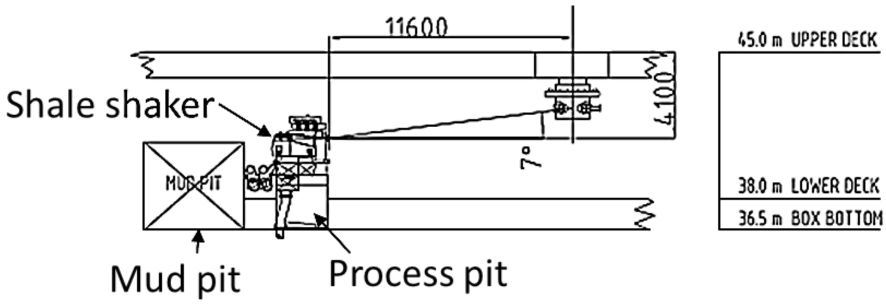

FIGURE 4-6 – INITIAL ATTEMPT TO FIT THE ORIGINAL GRAVITY BASED MUD RETURN SYSTEM.

In Figure 4-6, the horizontal distance from the center line would optimally be as short as possible to minimize the vertical distance. However, it could not be made shorter than 11600 mm since the size of the cellar deck had been decided by the development of the previous sub-systems. By keeping the original diverter and having a seven degrees inclination of the flow line, the vertical distance from the main deck to the shale shakers was already 4100 mm. Due to this, the process pits (degasser, desilter etc.) that follow after the shale shakers would be placed below the lower deck as can be seen in Figure 4-6. However, worse yet was the fact that there was no possibility at all for gravity to drive the mud from the process pits to the mud pits.

In order to solve the problem of finding vertical room for the mud return components, three key decisions was taken in a design meeting with GVA engineers. Firstly, it was decided that the deck box would be lowered by one meter, in order to increase the vertical space. Secondly, the active mud pits could be placed on the box bottom (the volume between the lower deck floor and the underside of the deck box, see Figure 4-7). The third decision was to use lower mud pits in order to have an overflow line between the process pits and the mud pits. As can be seen in Figure 4-7 below, these decisions enabled a gravity based system, where the vertical distance was enough to fit the components.

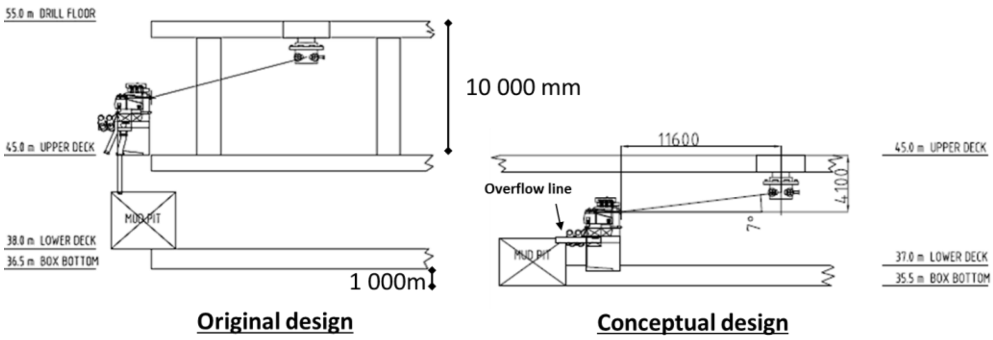

FIGURE 4-7 – COMPARISON OF THE MUD RETURN SYSTEM ON THE ORIGINAL DESIGN AND ON THE CONCEPTUAL FLUSH DRILL FLOOR DESIGN.

When the conceptual design of the mud return system was finished, it was used as an input to the system level design phase, where it was further developed as can be seen in chapter 5.

5 SYSTEM LEVEL DESIGN

This chapter first describes the work flow of the system level design phase, thereafter the results are presented with drawings of the applicable areas and descriptions of component choices etc. Thereafter, the BOP and X-mas tree deployment operations on the conceptual flush drill floor design are presented in schematic operation descriptions. The chapter is concluded by discussing possible specification alternatives for the semi-sub.

5.1 SYSTEM LEVEL DESIGN PHASE WORK FLOW

When the conceptual designs of each sub-system had been developed, they were combined and modified into an aggregated design in the system level design phase. Since most design decisions etc. had been taken in the sub-system development phase, the main objective of the system level design phase was to physically fit all sub-systems onto the drilling rig. To efficiently try different placement options, the CAD program AutoCAD 2012 was used throughout the system level design phase. Since hull dimensions etc. was taken as given by the GVA 7500 semi-sub, drawings for the GVA 7500 were first stripped from everything but the structural design. Thereafter, the new design was created by first adding the larger components and thereafter successively increasing the level of detail until all components had been added. A schematic of the process can be seen in Figure 5-1 below.

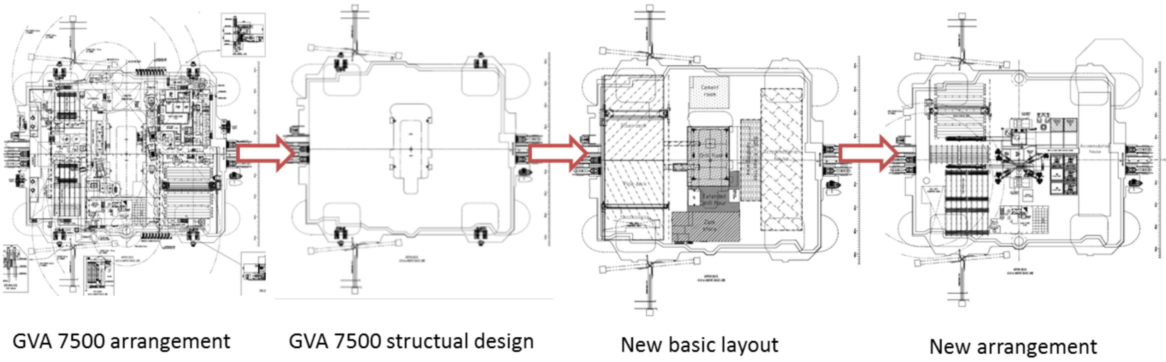

FIGURE 5-1 – WORK FLOW OF THE SYSTEM LEVEL DESIGN PHASE.

The process was iterated eight times in total, with design meetings with GVA engineers after each iteration. The design meetings were held to ensure that all operations could be performed as efficiently as possible, by discussing differences and similarities to how they are performed on the GVA 7500 semi-sub. Due to the interrelatedness of several components, the component placement was not intuitive, and the first design iterations differed substantially to each other. However, eventually the designs converged, and the process was stopped when no immediate weaknesses of the design compared to conventional semi-subs were found in the final design meeting. As an additional tool to ensure the functionality of the proposed designs, the dimensions of all affected areas or sub-systems were measured in AutoCAD on the GVA 7500 semi-sub. When designing the conceptual flush drill floor design, it was ensured that all of the affected areas or sub-systems were either the same size or larger than on the GVA 7500.

5.2 THE RESULTING DESIGN

This chapter will present the final drawings of the different deck levels on the rig similarly to how the GVA 7500 was described in chapter 2.4. Large scale drawings including labels of the components can be seen in Appendix C.

5.2.1 MAIN DECK LEVEL LAYOUT

A top view of the main deck is shown in Figure 5-2 below, the marked areas are the larger components on the main deck.

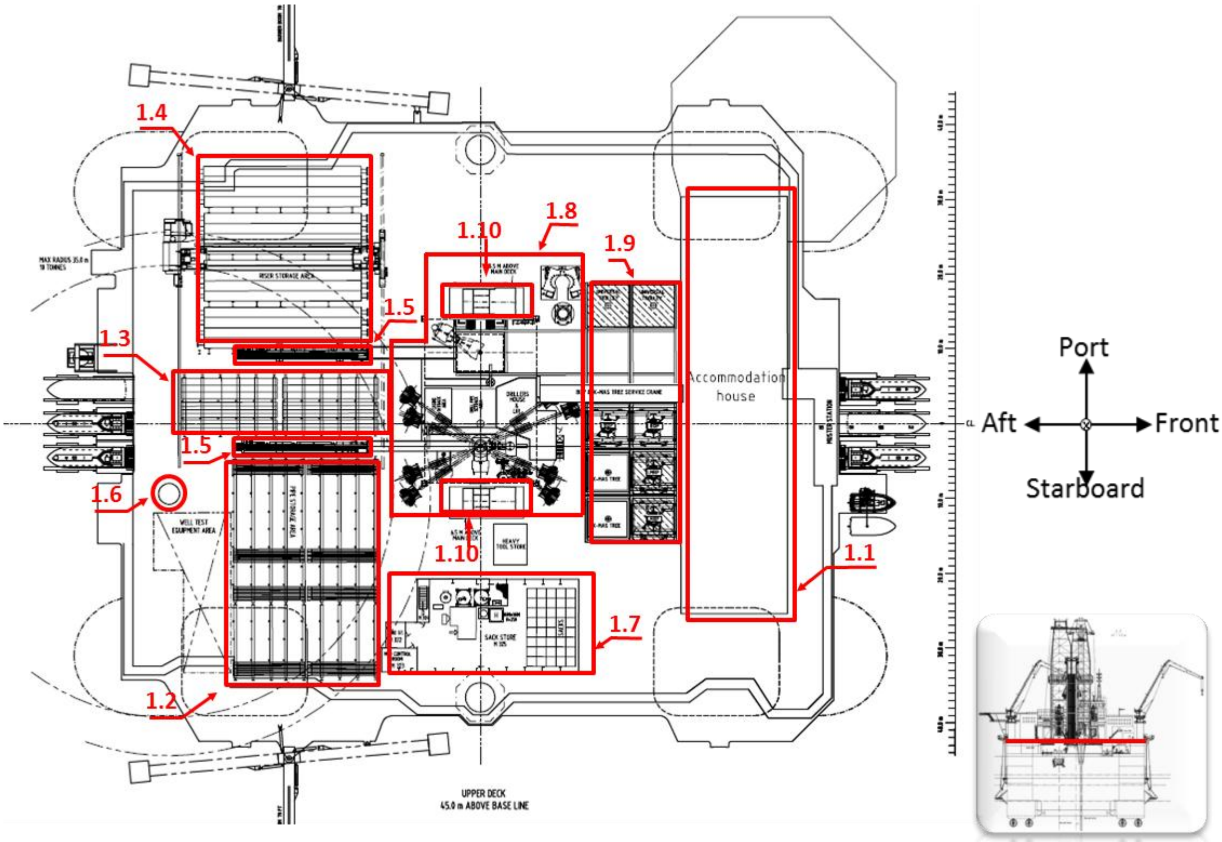

FIGURE 5-2 - TOP VIEW OF THE MAIN DECK LEVEL LAYOUT.

As can be seen in Figure 5-2, the accommodation house [1.1] is positioned in the opposite direction of the pipe storage area [1.2], the casing storage area [1.3] and the riser storage area [1.4] in order to balance the rig.

It was decided to keep all pipe and riser joints on one end of the rig, so that by using two parallel catwalks [1.5] (2x), all different types of pipe/riser could be fed to both the main well center and to the auxiliary well center. To transport the heavy riser joints, a gantry crane is used as can be seen in area [1.4]. For the lighter drill pipes and casing joints, a pedestal crane is used [1.6] in order to free the area between the base of the pedestal crane and the pipe deck [1.2], which otherwise would have been obstructed by the gantry crane rail.

The sack store [1.7] is placed immediately on top of the mud pump room (see Figure 5-5 below) in order to facilitate easy transfer of sacks containing drilling mud constituents to the mud pump room.

Area [1.8] is the drill floor, which will be shown in a separate drawing below. Between the drill floor [1.8] and the accommodation house [1.1] is the BOP/X-mas tree handling area [1.9]. By placing this area between the derrick and the accommodation house, the elevated access paths to the higher levels of the BOP are conveniently connected to the derrick and the accommodation house, so that no separate support structure must be used. Additionally, it is convenient for service personnel to walk straight out of the accommodation house to the BOP/X-mas tree service area. As can be seen in area [1.9], a fixed BOP crane is supported by the derrick and the accommodation house, which once again uses the existing structures rather than a separate support structure. The BOP crane allows for lifting of LMRPs and X-mas trees without having to transport them into the derrick. As can also be seen in area [1.9], the BOP/X-mas tree handling area contains two parallel skid rails, which allows the different trolleys to be moved around conveniently. There are two separate X-mas tree trolleys, two BOP lower stack trolleys, two LMRP trolleys and two universal trolleys. The universal trolleys are used to transport heavy equipment such as a riser spider to the auxiliary well center.

Area [1.10] (2x) are the draw-works, they are placed just outside the derrick, and are raised 6.5 meters above the main deck in order to give working space below them. The riser tensioner cylinders [1.11] (8x) are also placed as close as possible to the derrick, in order to use an as small as possible cellar deck (seen in Figure 5-5 below). Since the riser tensioner idler sheaves must extend below the main deck, the size of the cellar deck is defined by how far from the derrick the riser tensioner cylinders are placed (they do not fit inside the derrick).

A zoomed in drawing of the drill floor area [1.8] is shown in Figure 5-3 below.

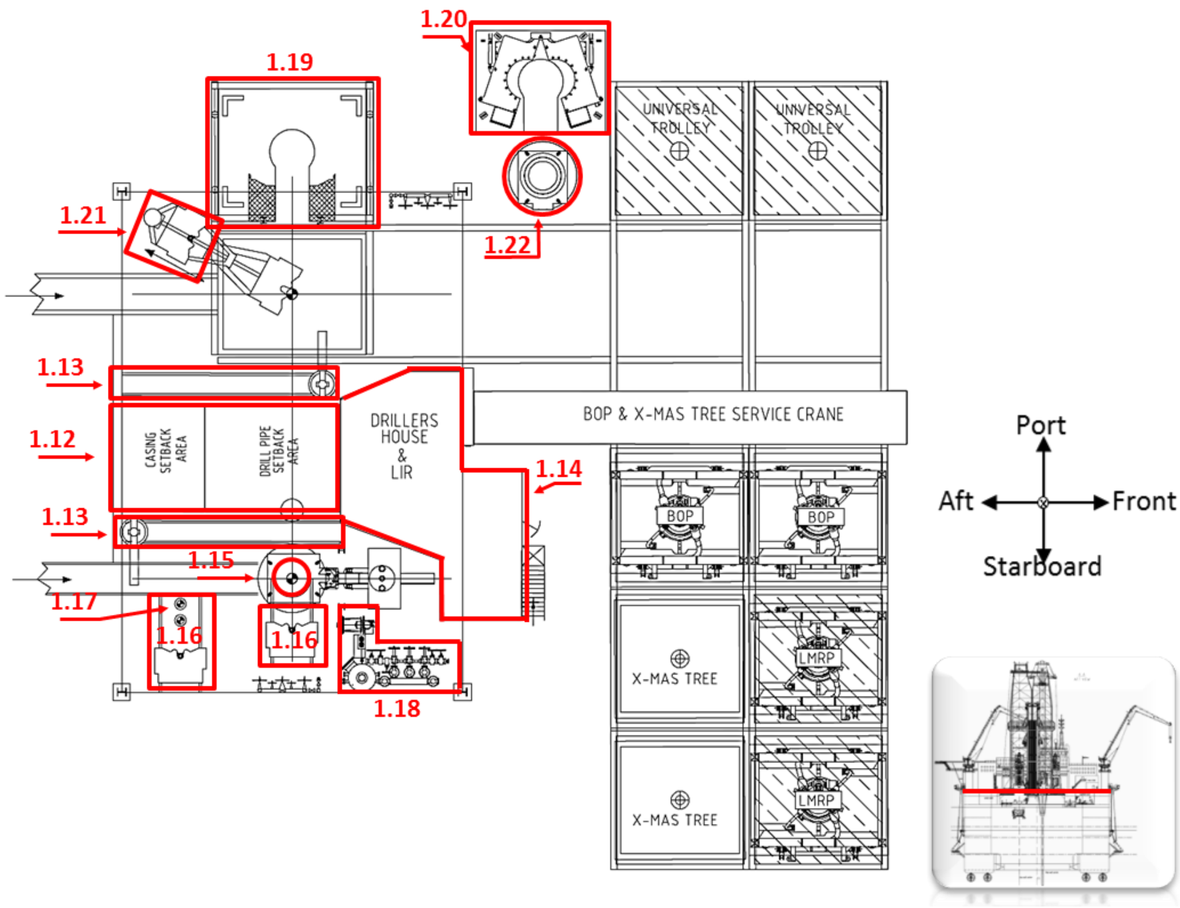

FIGURE 5-3 - TOP VIEW OF THE DRILL FLOOR LAYOUT AND THE BOP/X-MAS TREE HANDLING AREA.

As can be seen in Figure 5-3, the setback [1.12] is placed in the middle of the derrick, so that pipe can be delivered to both well centers, although the well centers use separate pipe handling equipment [1.13] (2x). The driller's house [1.14] is raised one floor so that the driller has good visibility to both well centers, and is placed towards the accommodation house for easy access. The main well center [1.15] has two iron roughnecks [1.16] (2x), one located in front of the mouse hole [1.17], which is used for offline stand building, and the other at the well center. The choke and kill manifold [1.18] is placed close to the driller's cabin so that the driller can monitor any operations of the different valves.

The removable floor [1.19] is seen in its extracted position, below the auxiliary draw-work (compare to Figure 5-2). To allow for quickly opening and closing the hole in the auxiliary well center, it was decided to let the removable floor be built as a trolley with a U-shaped groove so that it can be closed around any tubular in the well center. This design differs from the one proposed in the sub-system development phase, where the removable floor was designed as a solid steel square that had to be lifted by the draw-work and then be transported away on a trolley. Such heavy lifts often require the drilling operations to be stopped due to dropped object hazard (SBM Offshore, 2013), which would be avoided by letting the removable part of the drill floor be designed as a trolley. Further, by designing the removable floor trolley with a U-shaped groove, a spider insert [1.20] can be placed on the trolley so that the trolley can close around a riser joint immediately after the BOP has passed through the opening in the drill floor. Similarly, a dummy rotary table and slip insert [1.22] can be used for X-mas tree deployment (see a more thorough description in chapter 5.2.4).

Since the removable floor trolley will not be flush with the drill floor, a conventional iron roughneck that travels on rails could not be used, thus it was decided to use a pedestal roughneck [1.21] in the auxiliary well center. When the auxiliary well center is not used for deploying riser, the removable floor is fitted with the dummy rotary table and slip insert [1.22] which allows for stand building or even riser-less drilling, if the auxiliary well is equipped with a heave compensator.

A close-up of the derrick design in Figure 5-4 below shows the removable floor trolley in its retracted position. Note also from this figure that the auxiliary well uses draw-work compensation, whereas the main well center uses derrick mounted heave compensators. The heave specification is fully customizable, and different types were used in Figure 5-4 to show that the conceptual design is not restricted to either one.

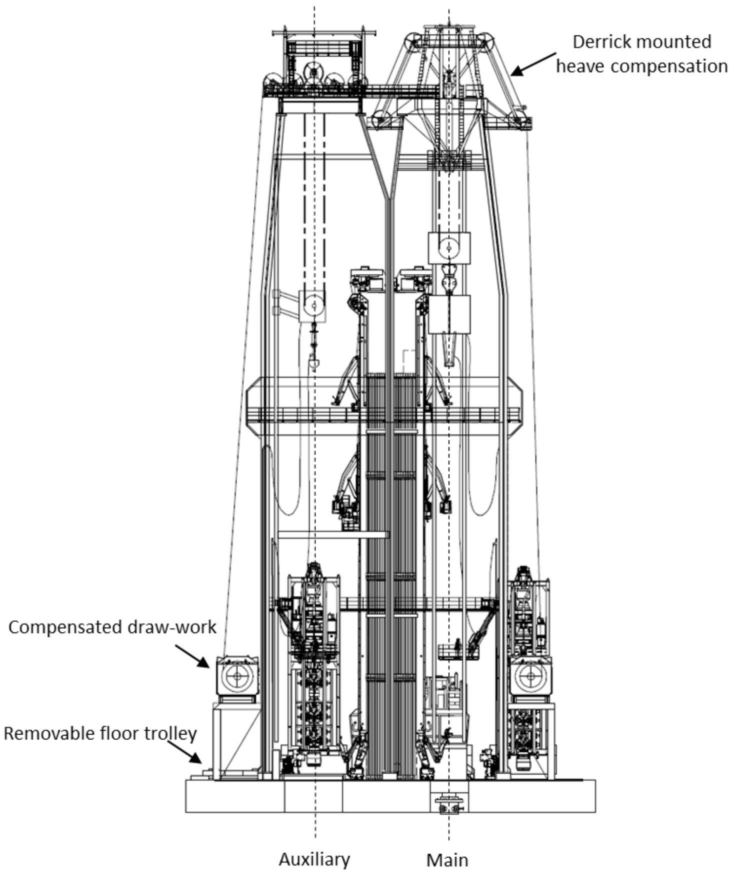

FIGURE 5-4 - THE DERRICK DESIGN WITH DIFFERENT KINDS OF COMPENSATOR SYSTEMS.

5.2.2 LOWER DECK LEVEL LAYOUT

A top view of the lower deck is shown in Figure 5-5 below. As can be seen in Figure 5-5, the width of the cellar deck [2.1] is to a large degree determined by the position of the riser tensioner cylinders [2.2] (8x). If N-lines would have been used for riser tensioning, the cellar deck could have been made more slender in the lower part of Figure 5-5. The length of the moon pool [2.3] and the cellar deck [2.1] is defined so that both the BOP trolley [2.4] and the X-mas tree trolley [2.5] can be accessed from both well centers. The shaker room [2.6] is placed as close as possible to the well center, so that the potential height loss due to the 7 degree angle of the return line (see Figure 5-8) is minimized. For the same reason, the active mud pits [2.7] are placed as close as possible to the shale shakers [2.6]. The reserve mud pits [2.8] are placed around the mud pump room [2.9] in an as concentrated way as possible.

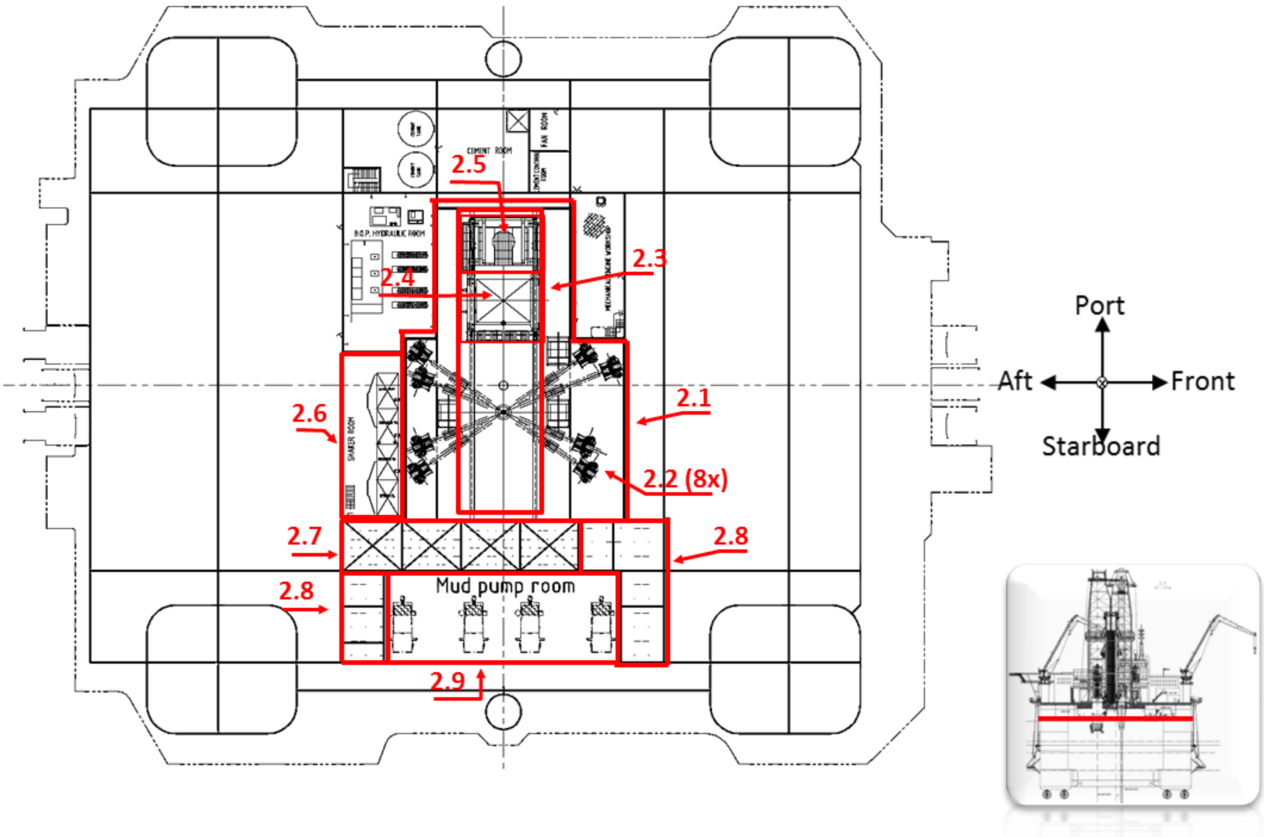

FIGURE 5-5 - TOP VIEW OF THE LOWER DECK LEVEL LAYOUT.

A zoomed in section view of the moon pool area on the conceptual semi-sub is shown in Figure 5-6. As can be seen in Figure 5-6, the riser tensioner idler sheaves [2.10] are placed as close as possible to the well center without interfering with the diverter. The X-mas tree trolley [2.5] is shown in its parking position. The BOP trolley [2.4] is placed below the auxiliary well center, and is ready for BOP deployment. The removable floor trolley [1.19] is in its retracted position and a BOP is placed in the auxiliary well center. Below the BOP trolley [2.4] is a guide base, which guides the BOP when it crosses the waterline so that the BOP handling equipment is not damaged in the splash zone.

A trip saver adapter [2.11] is shown in its parked position, where it hangs from below the drill floor. For space saving purposes, it was decided to use a trip saver adapter that can be placed on the BOP trolley when it is needed. Both of the alternatives of either having a separate trip saver trolley or having a BOP trolley with a built in trip saving function would increase the length of the moon pool. Using the X-mas tree trolley for trip saving was not an option for the chosen BOP/X-mas tree handling sub-system, since deployment of the X-mas tree requires that the X-mas tree trolley is free to use (see a description of X-mas tree deployment in chapter 5.2.4). However, since the auxiliary well center can be used for offline casing building, the X-mas tree trolley can be used to hang off casings and drill pipe, which is why the X-mas tree trolley has a U-shaped groove as seen in Figure 5-5 above.

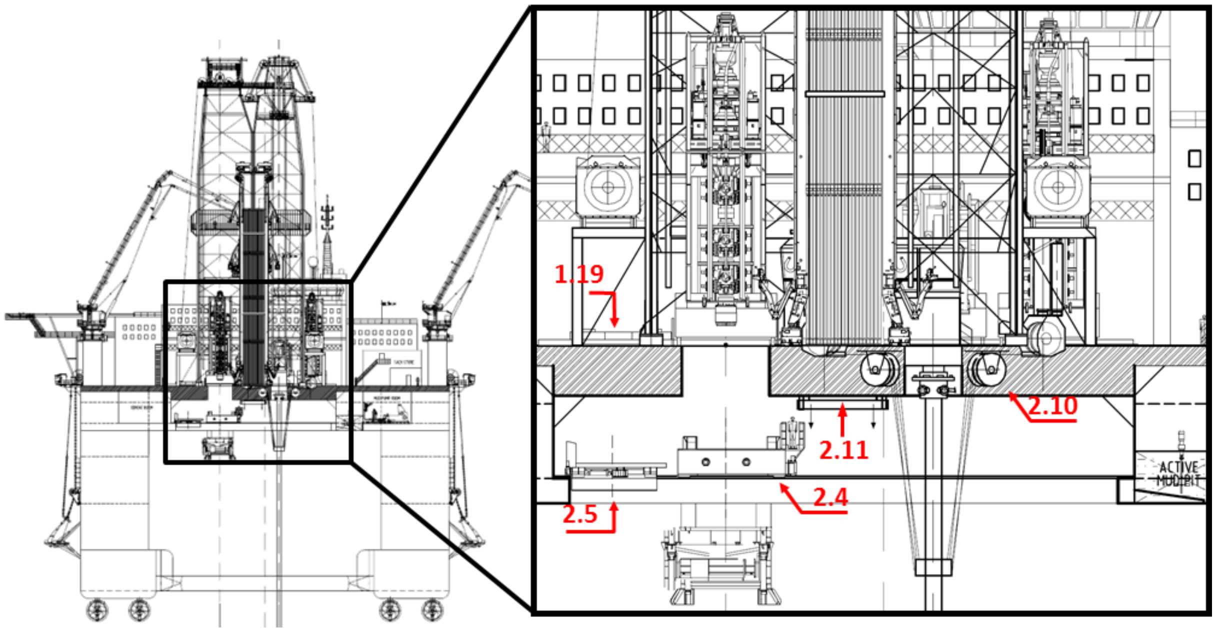

FIGURE 5-6 - SIDE VIEW WITH A ZOOMED IN SECTION VIEW OF THE AREA AROUND THE MOON POOL.

The mud return system is shown in two section views in Figure 5-7 and Figure 5-8 below. The shale shakers [3.1] (6x) are connected to the diverter [3.2] by the flow lines [3.3] and flow divider. When the mud return has passed through the shale shakers [3.1], it enters the process pits [3.4] (sand trap, degasser and desilter). After the process pits, the mud flows to the return tank and eventually from an overflow line [3.5] in the return tank into the active mud pits [3.6]. To accomplish a fully gravity driven mud return system, the active mud pits [3.6] had to be made shallower than the reserve mud pits [3.7]. However, as can be seen in Figure 5-5 above, the active mud pits are wider in order to keep their volume the same as on the GVA 7500 semi-sub. To transport mud between the active mud pits and the passive mud pits, a standard pumping system needs to be used.

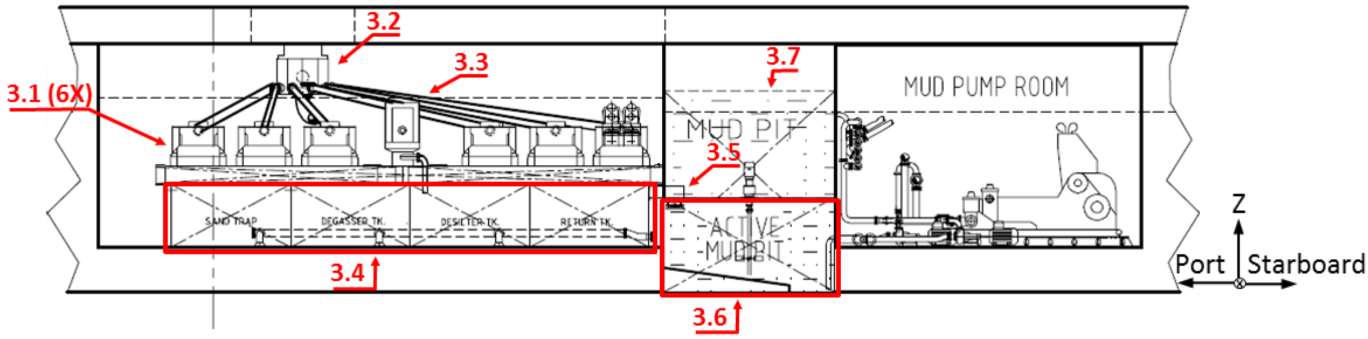

FIGURE 5-7 - SECTION VIEW OF THE MUD RETURN SYSTEM, SEEN FROM THE AFT SIDE.

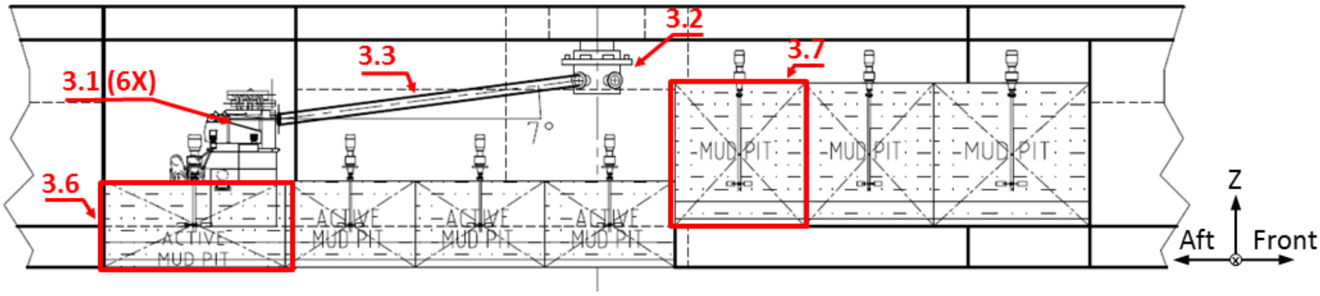

FIGURE 5-8 - SECTION VIEW OF THE MUD RETURN SYSTEM, SEEN FROM THE STARBOARD SIDE.

5.2.3 BOP DEPLOYMENT

In this chapter, the BOP deployment procedure will be presented in a step by step manner while the different operations will be shown in two parallel time series sequences illustrating the process both from a top view and from a side view (Figure 5-9 to Figure 5-15).

The BOP lower stack and the LMRP are tested on separate skid-trolleys in the BOP/X-mas tree handling area. Simultaneously, the pedestal crane lifts the spider adapter onto either of the universal skid-trolleys (a spider is used to hold the weight of the riser/BOP package, see chapter 2.5.1).

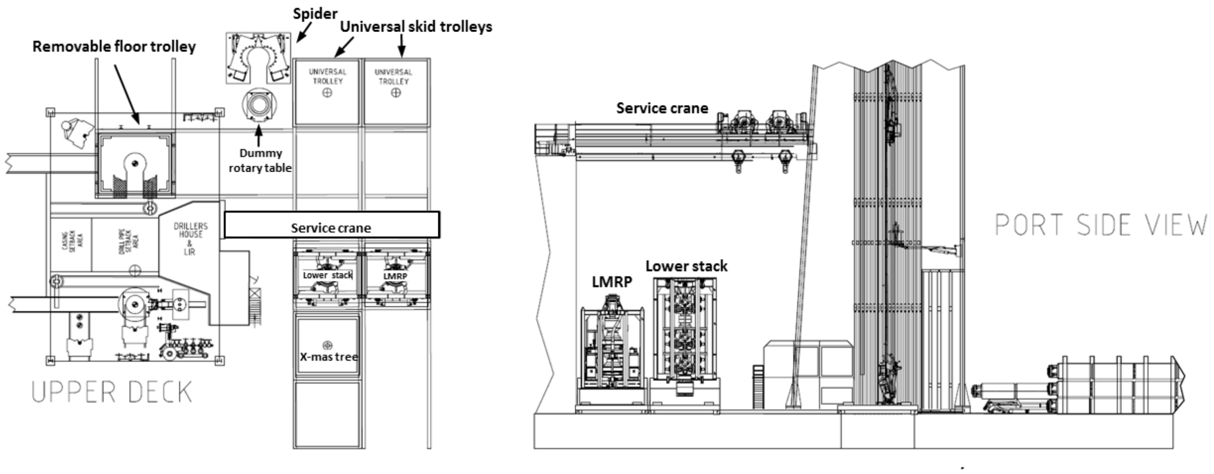

FIGURE 5-9 - SEQUENCE 1 OF THE BOP DEPLOYMENT PROCESS.

The universal trolley is thereafter moved into the derrick and the spider adapter is installed on the removable floor trolley. The BOP lower stack and the LMRP are connected to each other by using the crane in the BOP/X-mas tree handling area.

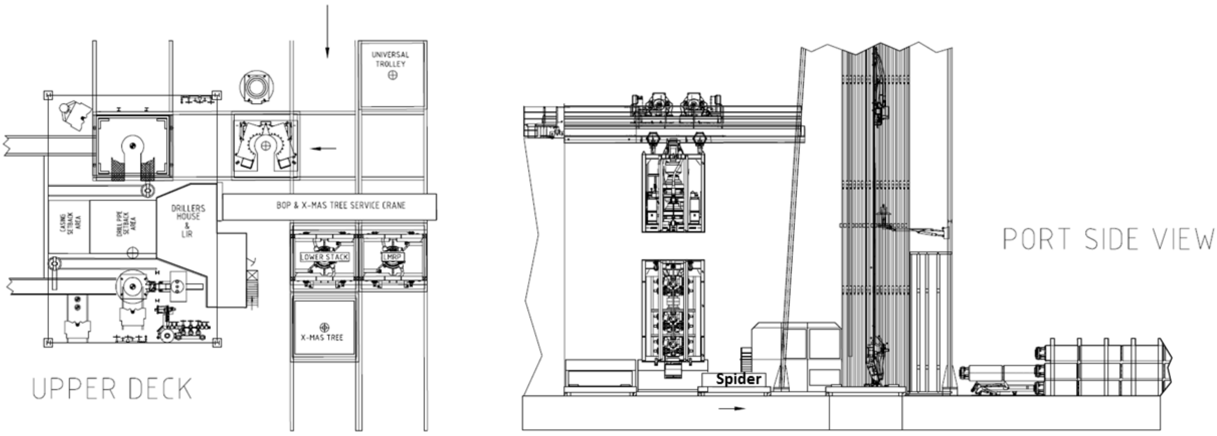

FIGURE 5-10 - SEQUENCE 2 OF THE BOP DEPLOYMENT PROCESS.

The entire BOP is then skidded to the auxiliary well center. Immediately prior to when the BOP reaches the well center, the removable floor trolley (with the spider adapter installed) is moved to its retracted position.

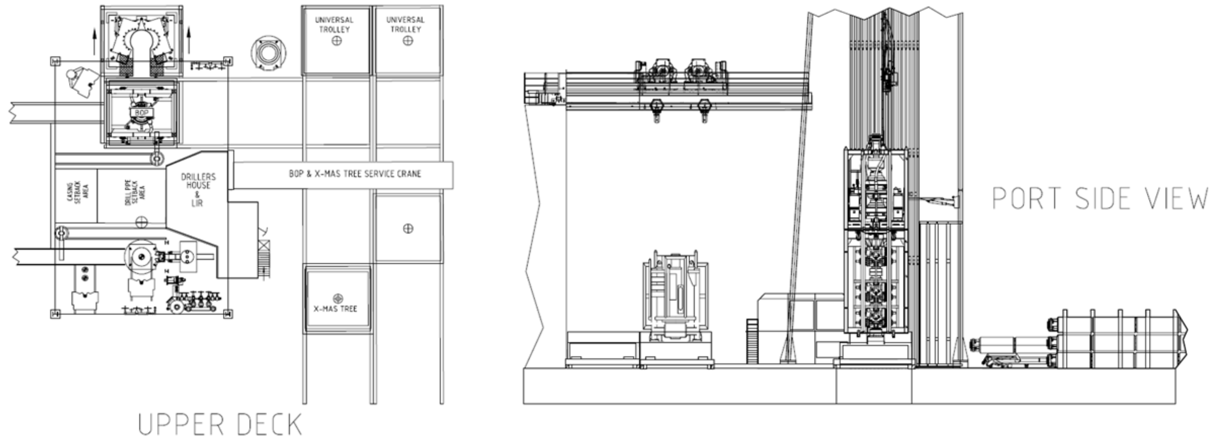

FIGURE 5-11 - SEQUENCE 3 OF THE BOP DEPLOYMENT PROCESS.

When the BOP is at the auxiliary well center, it is lifted from its trolley by the hoisting system, while being guided by guide arms in the derrick. As soon as the BOP is clear of its skid-trolley, the skid-trolley is moved outside the derrick. The BOP is lowered until a couple of meters of the BOP extend from the hole in drill floor (by not lowering it any lower, it is ensured to be clear of the splash zone). The BOP is then hung off on its trolley in the moon pool. In this position, the first riser joint is installed on the BOP by manually working from the service baskets in the derrick.

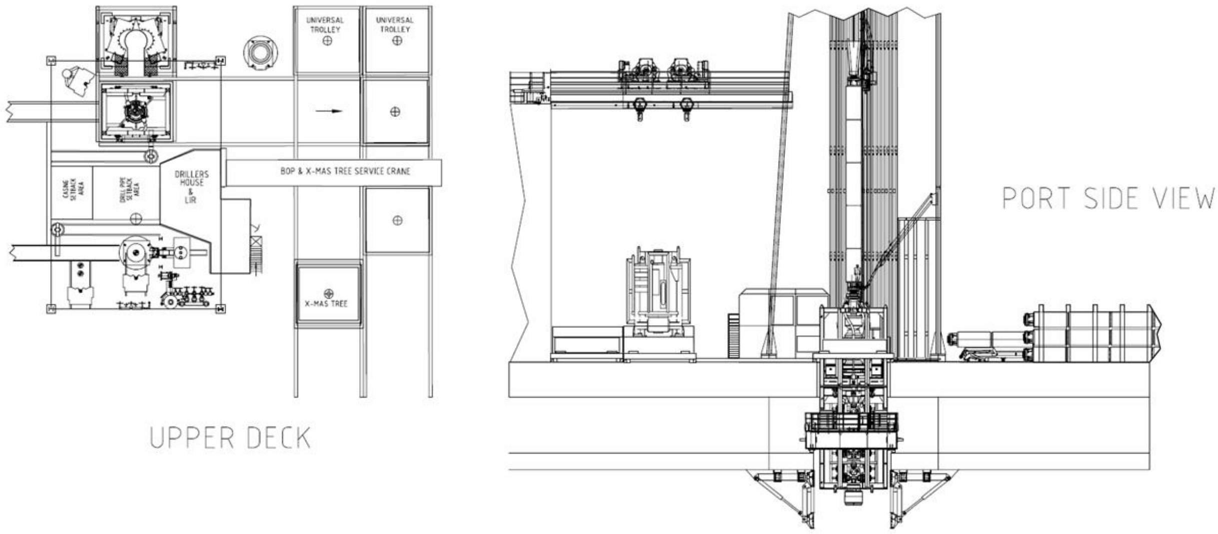

FIGURE 5-12 - SEQUENCE 4 OF THE BOP DEPLOYMENT PROCESS.

When the first riser joint is installed, the BOP is lowered until it is completely clear of the drill floor. The removable table trolley is then immediately returned to its closed position (due to its U-shaped groove it is not restricted by the riser joint). The BOP is then lowered through the waterline while being supported by the guide base (splash zone protection) and hung off on the spider adapter. Riser joints are then continuously installed in the auxiliary well center until one or two riser joint remains (the last riser joint must be installed in the main well center in order to be connected to the diverter). When building riser, work is performed in the cellar deck to ensure correct installation of the BOP POD-lines. While the BOP is lowered to the seabed, the BOP trolley in the moon pool is moved towards the center of the rig, below the parking position of the trip saver adapter. The trip saver adapter is then lowered and installed on the BOP trolley. When only one or two riser joints remain to be installed, the riser/BOP package is lowered below the drill floor and hung off on the trip saver adapter on the BOP trolley.

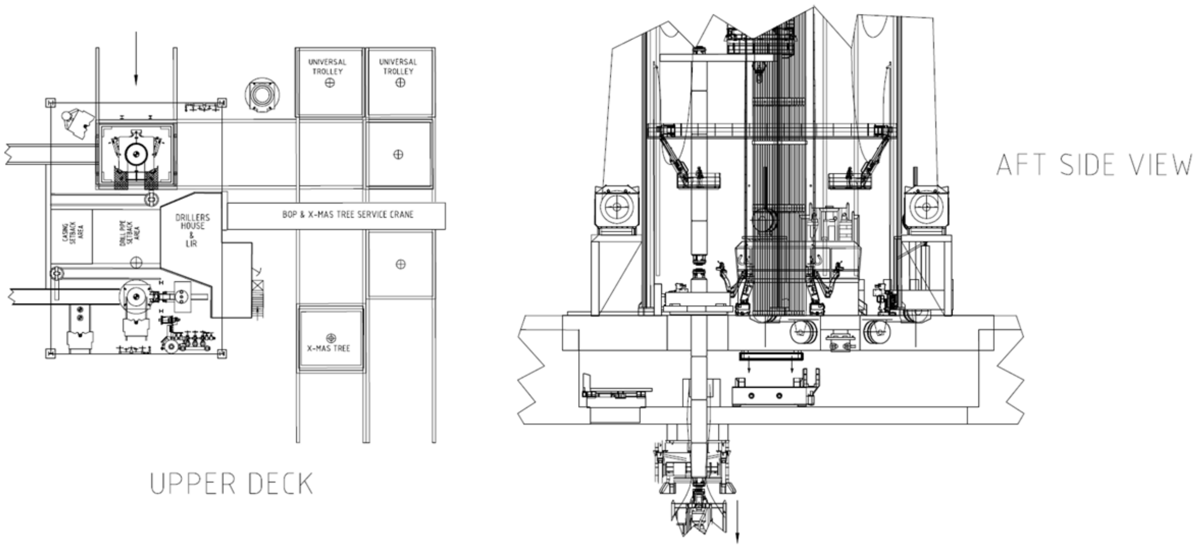

FIGURE 5-13 - SEQUENCE 5 OF THE BOP DEPLOYMENT PROCESS.

The BOP/riser package is then skidded on the BOP trolley in the moon pool to the main well center, where it is picked up and hung off on a spider in the main well center. The BOP trolley is moved to its most starboard position in order to not to interfere with the riser pipe and riser tensioners.

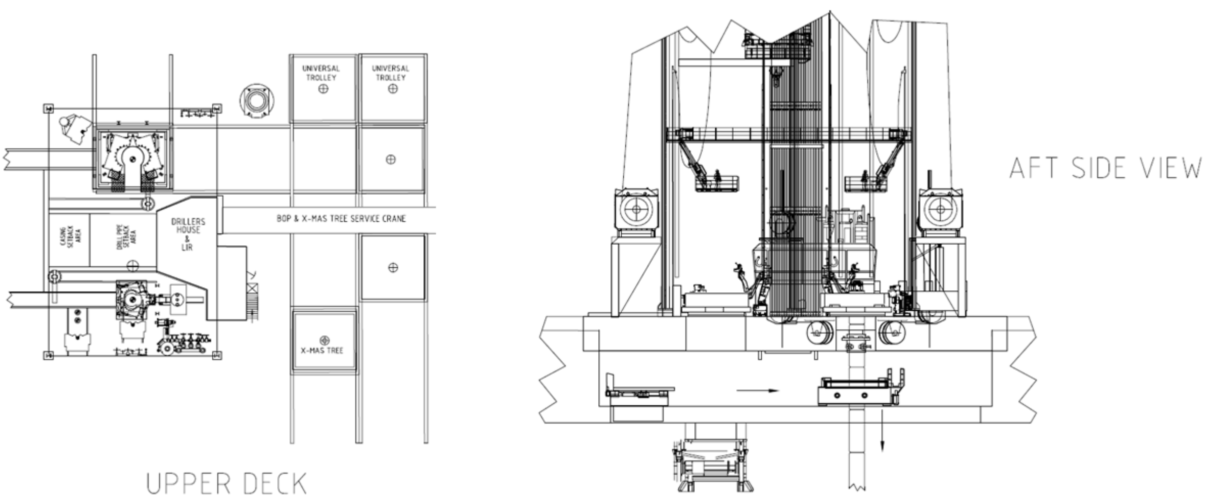

FIGURE 5-14 - SEQUENCE 6 OF THE BOP DEPLOYMENT PROCESS.

The last riser joint(s) are installed in the main well center while the BOP is lowered to the wellhead, the diverter is connected to the uppermost part of the riser tube and the riser tensioner support ring is installed on the riser. The riser installation is complete.

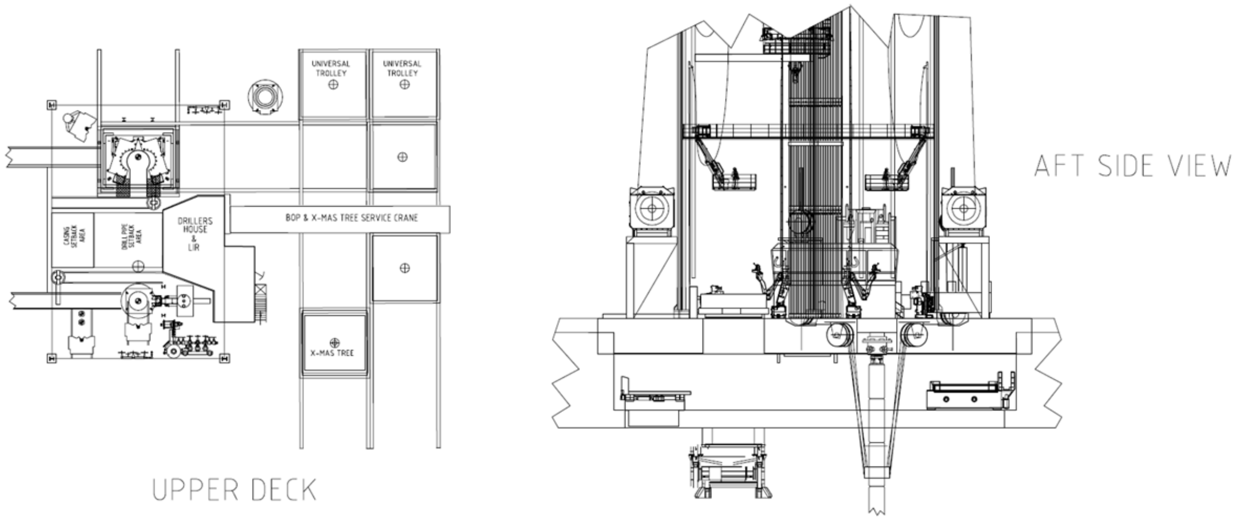

FIGURE 5-15 - SEQUENCE 7 OF THE BOP DEPLOYMENT PROCESS.

5.2.4 X-MAS TREE DEPLOYMENT

In this chapter, the X-mas tree deployment procedure will be presented in a step by step manner while the different operations will be shown in two parallel time series sequences illustrating the process both from a top view and from a side view (Figure 5-16 to Figure 5-20).

The X-mas tree is tested and prepared for deployment in the BOP/X-mas tree handling area. A pedestal crane is used to lift the dummy rotary table and slip onto any of the universal skid-trolleys in the BOP/X-mas tree area. The dummy rotary table and slip is moved to the auxiliary well center and installed on the removable floor trolley.

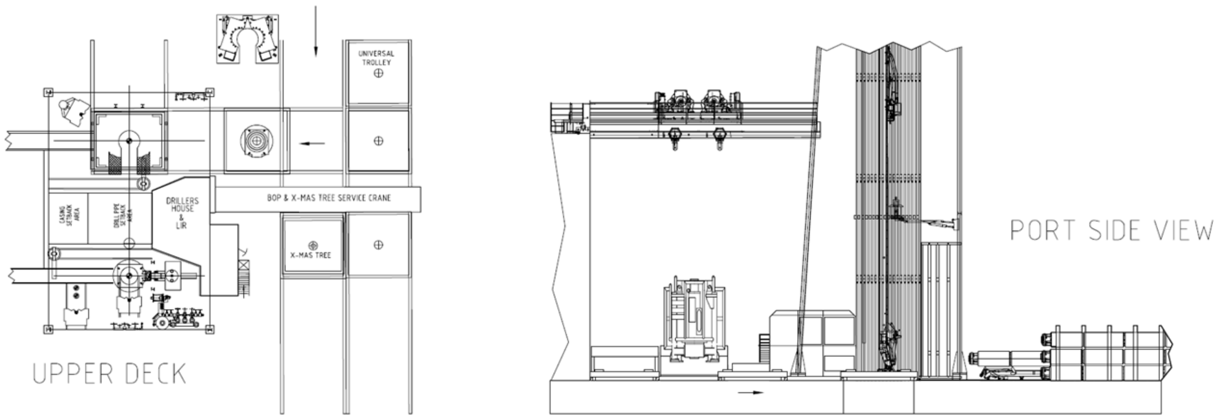

FIGURE 5-16 - SEQUENCE 1 OF THE X-MAS TREE DEPLOYMENT PROCESS.

The X-mas tree is skidded to the auxiliary well center, the removable floor trolley is moved to its retracted position just before the X-mas tree skid-trolley is in place.

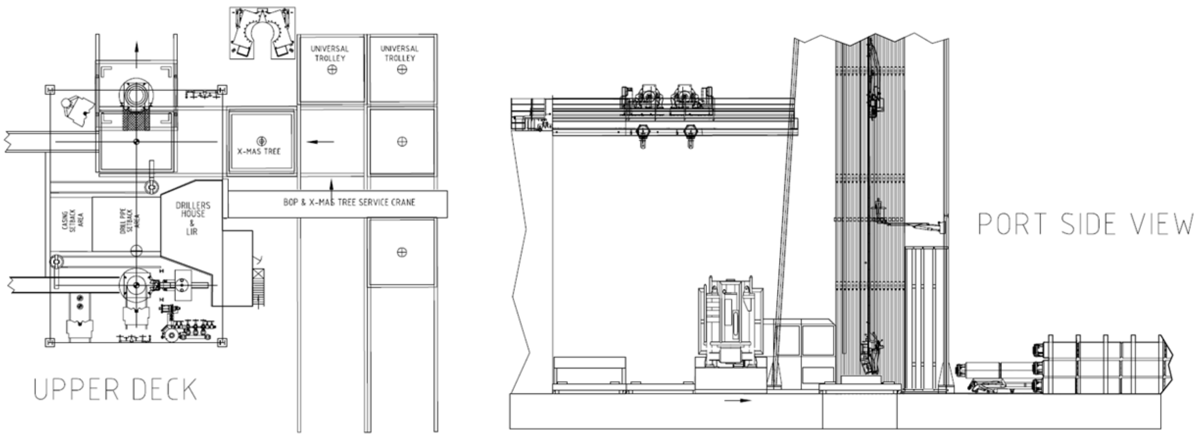

FIGURE 5-17 - SEQUENCE 2 OF THE X-MAS TREE DEPLOYMENT PROCESS.

The X-mas tree is lifted from its skid-trolley while being guided by guide clamps in the derrick. The X-mas tree skid-trolley is moved out of the derrick and the X-mas tree is lowered onto the X-mas tree trolley in the moon pool.

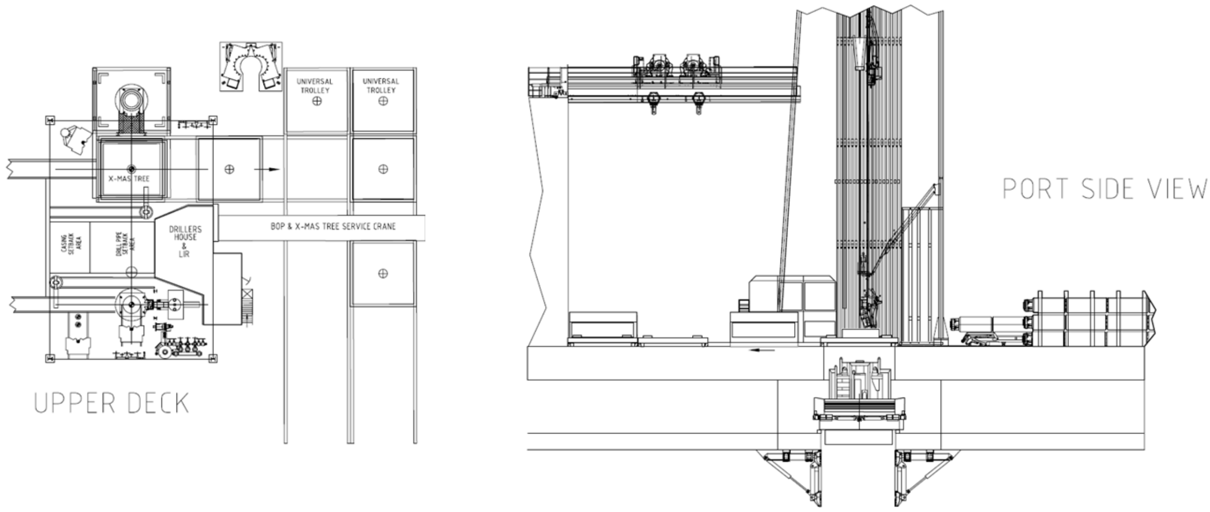

FIGURE 5-18 - SEQUENCE 3 OF THE X-MAS TREE DEPLOYMENT PROCESS.

The removable floor trolley is closed. The first stand of drill pipe is installed and the X-mas tree is lowered to the seabed by continuously adding drill pipe.

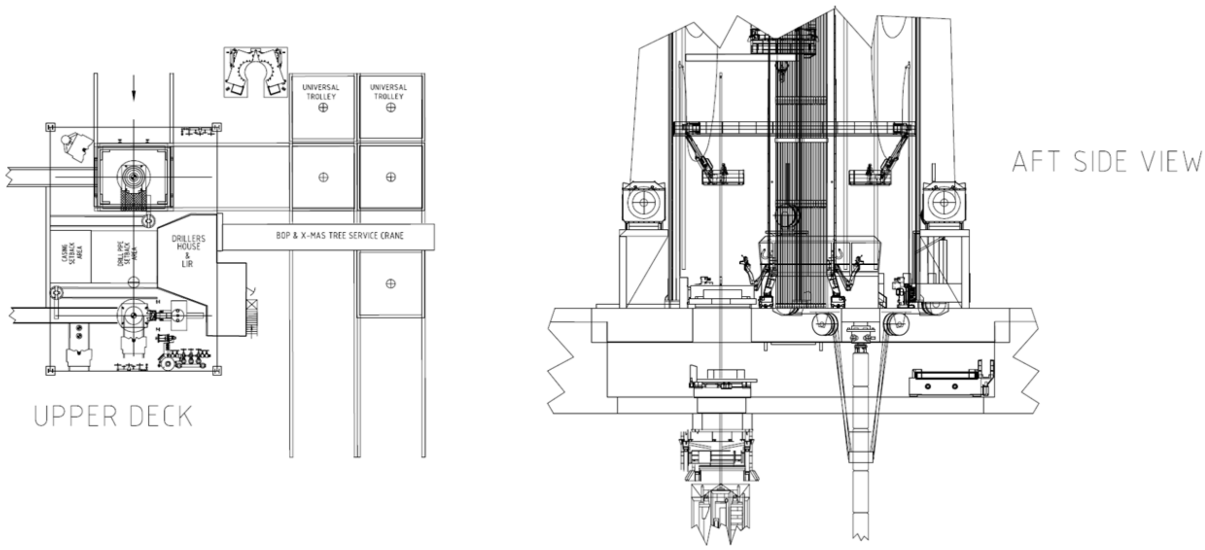

FIGURE 5-19 - SEQUENCE 4 OF THE X-MAS TREE DEPLOYMENT PROCESS.

When only one or two stands remain to be connected, the X-mas tree/drill pipe package is hung off on the X-mas tree trolley, which is then skidded to the main well center. The last stands are installed in the main well center and the X-mas tree is set down on the wellhead, while the BOP/Riser package is trip saved.

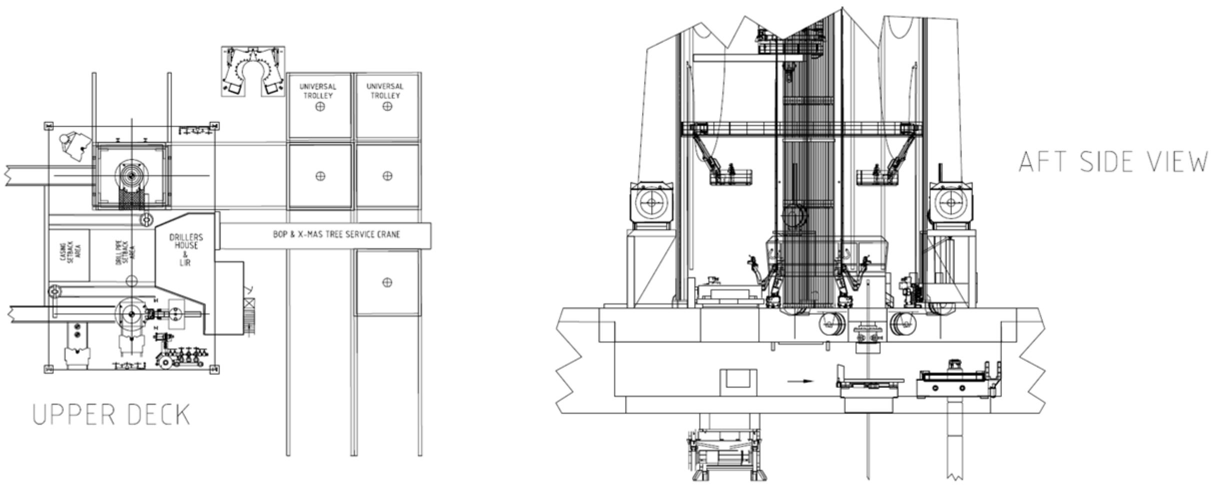

FIGURE 5-20 - SEQUENCE 5 OF THE X-MAS TREE DEPLOYMENT PROCESS.

If the auxiliary hoisting system is equipped with a heave compensator, the X-mas tree does not have to be transported to the main well center. Instead, the entire X-mas tree deployment process can be performed in the auxiliary well center.

5.2.5 CONFIGURATION ALTERNATIVES

The resulting design is rather flexible in terms of configuration alternatives. The only true constraint is that the semi-sub must be equipped with a double derrick and a deck box of at least 9.5 meters, where the active mud pits can be integrated in the box bottom. The most significant configuration alternatives relate to the hoisting systems and to the riser tensioner/trip saver systems.

As has already been mentioned, it is possible to use either draw-work compensation or top mounted compensators or a combination of the two, although draw-work compensation is favorable from a VCG perspective since it does not require as heavy equipment in the top of the derrick. In fact, the auxiliary hoisting system must not be equipped with a compensator at all if one does not have a need for being able to install X-mas trees or drill top hole sections in the auxiliary well center. If the auxiliary well center will not be used for drilling, the auxiliary hoisting system need not be specified with a top drive, since it will only be needed for upwards/downwards movement.

In the conceptual design drawings in this report, wire-line tensioners has been used in collaboration with a trip saver adapter placed on the BOP trolley to accommodate riser tensioning and trip saving. There are no restrictions for using an N-line type riser tensioning system and integrated trip saving system. Actually, if N-lines are used instead of wire-lines, the cellar deck area can be made slightly more slender, which would put the shale shakers closer to the diverter Thereby, the height loss due to the inclination of the diverter flow line would be smaller, which would reduce the challenge of fitting the mud return system to the flush drill floor design. A principal schematic of the flush drill floor design with N-line riser tensioners and integrated trip saving function is seen in Appendix D.

5.2.6 COMPARISON TO THE GVA 7500

The most significant differences between the flush drill floor conceptual design and the GVA 7500 semi-sub can be seen in the side view in Figure 5-21. The most notable difference is of course that the drill floor and everything attached to it has been lowered by ten meters, so that it is completely flush to the main deck. Further, while the BOP is stored on the cellar deck on the GVA 7500, it is stored behind the derrick on the main deck in the new design. As a result of no longer having to fit the BOPs, the cellar deck has been made smaller on the new design. The X-mas trees and the BOPs are stored on different sides of the derrick on the old design, with separate lifting equipment. The new design uses an integrated BOP/X-mas tree handling area, and both are deployed through the auxiliary well, which is equipped with a removable floor trolley. Although the mud return system on the new design is more compact in the vertical direction than on the GVA 7500, the deck box had to be made one meter taller on the new design than on the GVA 7500 to accomplish a fully gravity driven mud return system.

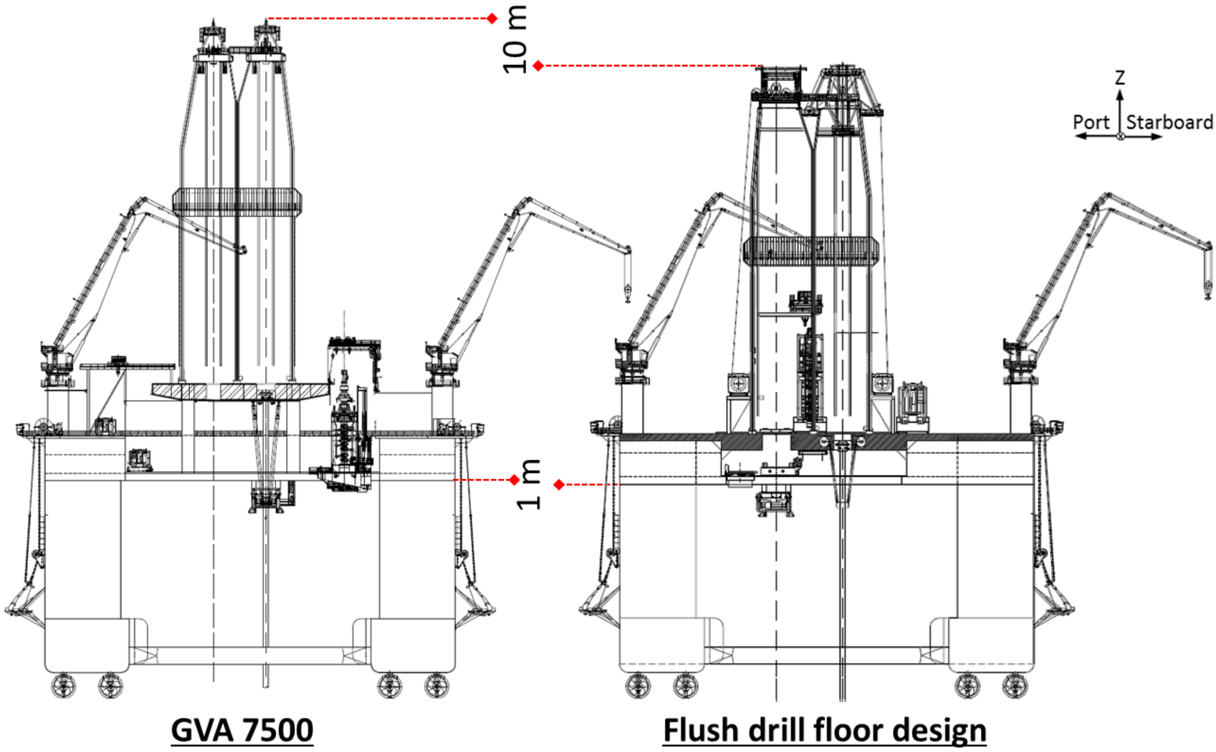

FIGURE 5-21 - COMPARISON OF THE FLUSH DRILL FLOOR DESIGN TO THE GVA 7500 SEMI-SUB.

6 ASSESSMENT

The feasibility of the conceptual design with regards to drilling operations was assessed throughout the system level design phase by design meetings with GVA engineers. In the final design meeting, no immediate weaknesses of the conceptual flush drill floor design were found compared to the conventional design. Additionally, by carefully considering the affected operational procedures (presented in chapter 5.2.3 and chapter 5.2.4) and comparing to how they are performed on a conventional semi-sub, the functionality of the concept was assured to an as large degree as possible. Ideally, testing or simulation of the operations would have been desirable, but unfortunately there were no such possibilities during the course of the project.

To assess the significance of the VCG reduction, Equation 2-4 in chapter 2.7 was used extensively. Since the project only included conceptual design, and no detailed design, exact dimensions and weights for the necessary components were not determined. Therefore, the VCG assessment needed to be performed by an approximation. The most straightforward approximation method was to use the benchmark rig, the GVA 7500, and move the location of the relevant components according to the new design.

The VCG of the LUW of the benchmark rig was calculated in Microsoft Excel, by using a spreadsheet of the weight and the location of the center of gravity for all components on the rig provided by GVA. The results are presented in Table 6-1 below.

TABLE 6-1 - VCG SUMMARY FOR THE GVA 7500 SEMI-SUB (SAME AS TABLE 2-1).

Discipline	Weight [tonnes]	VCG [m]
Structural	18 782.0	24.25
HVAC	519.8	46.03
Mechanical	1 742.3	27.44
Drilling	3 464.0	57.42
Piping	1 877.7	34.19
Electrical	1 749.0	33.83
Steel Outfitting	2 429.7	39.68
Architectural	993.3	46.33
Paint	197.5	23.01
Subtotal	**31 755.3**	**31.38**
Fluid	532.5	32.94
Mill & Weld	93.9	24.25
Correction For Inclination	-170.4	-19.35
LUW	**32 211.4**	**31.65**

In addition to the LUW, one must also consider particular load conditions when calculating the VCG. It was decided to use the “pre spud” load condition, in which the rig is in operational draught, with all equipment onboard and no riser or drill string attached. This load condition is conservative since it penalizes the new concept as much as possible by having both BOPs on board, with their VCG significantly higher than on the reference rig. Additionally, by adding a hook load (weight of the drill string) and a load on the riser tensioners, the new design would benefit compared to the reference design due to both a lower position for the hook load and for the riser tensioners. The load condition summary for the GVA 7500 can be seen in Table 6-2 below.

TABLE 6-2 – "PRE SPUD" LOAD CONDITION SUMMARY FOR THE GVA 7500.

Item	Capacity [tonnes]	Percent full	Weight [tonnes]	VCG [m]
Crew provision and store			150	45,00
Service and settling tank			150	41,50
Stores, workshops			100	41,00
Well-testing equipment			150	47,00
Electric logging unit			35	52,50
Mud logging unit			20	52,50
ROV unit			32	46,00
Casing and tubulars			400	46,20
Riser (7,500ft) incl. slip-joint			2 460	48,90
Riser tension			0	49,00
Set back			600	73,50
Hook load			0	116,00
Drill tools			60	52,50
B.O.P stack			1 000	47,00
X-mas tree			100	47,00
Liquid mud (active)			600	40,50
Misc. Drilling liquids			60	43,50
Sack material & mud containers			250	46,50
Bulk mud & cement in deck tanks			300	48,00
Remaining available			284	46,00
SUBTOTAL DECK PAYLOAD			**6 751**	**49,21**
Bulk mud & cement			1 050	25,00
SUBTOTAL COLUMN PAYLOAD			**1 050**	**25,00**
SUBTOTAL DECK & COLUMN			**7 801**	**45,95**
Fuel oil	2 770	87	2 410	4,48
Potable water	426	59	250	3,67
Drill water	2 608	38	1 000	2,05
Brine	1 196	67	800	3,92
Liquid mud	3 692	27	1 000	3,51
Base oil	598	79	471	4,88
SUBTOTAL PONTOON			**5 931**	**3,83**
Mooring line vertical tension			0	0,00
Mooring line onboard			2 101	17,20
Anchors			126	12,50
Marine growth			0	0,00
WB in pontoons	12 453	53	6 564	4,60
WB in columns	11 486	0	0	10,26
WB in wing pontoon	3370	64	2 157	3,17
LUW			32 211	31,65
Displacement			56 891	**25,934**

As can be seen in the bottom row of Table 6-2, the overall VCG of the benchmark design in the "pre spud" load condition is 25.934 meters, note also that the total weight is almost 57'000 metric tons, compared to 32'000 metric tons for the LUW.

When the relevant components had been relocated according to the conceptual flush drill floor design, the VCG of the LUW was decreased with 0.81 meters compared to the original GVA 7500 semi-sub, as can be seen in Table 6-3 below. The underlined values are the ones affected by the flush drill floor design.

TABLE 6-3 - VCG SUMMARY FOR THE CONCEPTUAL FLUSH DRILL FLOOR SEMI-SUB.

Discipline	**Weight [tonnes]**	**Old VCG [m]**	**New VCG [m]**
Structural	18 782.0	24.25	**23.85**
HVAC	519.8	46.03	46.03
Mechanical	1 742.3	27.44	27.44
Drilling	3 464.0	57.42	**52.67**
Piping	1 877.7	34.19	**33.83**
Electrical	1 749.0	33.83	**33.66**
Steel Outfitting	2 429.7	39.68	**39.24**
Architectural	993.3	46.33	46.33
Paint	197.5	23.01	23.01
Subtotal	**31 755.3**	**31.38**	**30.56**
Fluid	532.5	32.94	32.94
Mill & Weld	93.9	24.25	23.85
Correction For Inclination	-170.4	-19.35	-19.35
LUW	**32 211.4**	**31.65**	**30.84**

As can be seen in the two rightmost columns of Table 6-3, the most significant VCG reduction has been achieved in the drilling discipline. This is a natural result of having lowered the drill floor structure, including the derrick, approximately ten meters, while holding more or less all else constant. The VCG of the structural discipline, which constitutes the largest fraction of the rig weight, has been lowered 0.4 meters since the supporting drill floor structure has been lowered. The VCG changes of the piping, electrical and steel outfitting disciplines is a result of having some parts located on the drill floor, i.e. the changes are indirect effects of lowering the drill floor.

In the "pre spud" load condition, the total VCG reduction is slightly reduced due to the higher vertical position of the BOPs on the flush drill floor design. The load condition summary for the new design is shown in Table 6-4 below, the changes relative to the benchmark design are underlined.

TABLE 6-4 – "PRE SPUD" LOAD CONDITION SUMMARY AT FOR THE FLUSH DRILL FLOOR DESIGN.

Item	Capacity [tonnes]	Percent full	Weight [tonnes]	Old VCG [m]	New VCG [m]
Crew provision and store			150	45,00	45,00
Service and settling tank			150	41,50	41,50
Stores, w orkshops			100	41,00	41,00
Well-testing equipment			150	47,00	47,00
Electric logging unit			35	52,50	52,50
Mud logging unit			20	52,50	52,50
ROV unit			32	46,00	46,00
Casing and tubulars			400	46,20	46,20
Riser (7,500ft) incl. slip-joint			2 460	48,90	48,90
Riser tension			0	49,00	**39,00**
Set back			600	73,50	**63,50**
Hook load			0	116,00	**106,00**
Drill tools			60	52,50	**42,50**
B.O.P stack			1 000	47,00	**51,00**
X-mas tree			100	47,00	47,00
Liquid mud (active)			600	40,50	40,50
Misc. Drilling liquids			60	43,50	43,50
Sack material & mud containers			250	46,50	46,50
Bulk mud & cement in deck tanks			300	48,00	48,00
Remaining available			284	46,00	46,00
SUBTOTAL DECK PAYLOAD			**6 751**	**49,21**	**48,82**
Bulk mud & cement			1 050	25,00	25,00
SUBTOTAL COLUMN PAYLOAD			**1 050**	**25,00**	**25,00**
SUBTOTAL DECK & COLUMN			**7 801**	**45,95**	**45,62**
Fuel oil	2 770	87	2 410	4,48	4,48
Potable w ater	426	59	250	3,67	3,67
Drill w ater	2 608	38	1 000	2,05	2,05
Brine	1 196	67	800	3,92	3,92
Liquid mud	3 692	27	1 000	3,51	3,51
Base oil	598	79	471	4,88	4,88
SUBTOTAL PONTOON PAYLOAD			**5 931**	3,83	**3,83**
Mooring line vertical tension			0	0,00	0,00
Mooring line onboard			2 101	17,20	17,20
Anchors			126	12,50	12,50
Marine grow th			0	0,00	0,00
WB in pontoons	12 453	53	6 564	4,60	4,60
WB in columns	11 486	0	0	10,26	10,26
WB in w ing pontoon	3370	64	2 157	3,17	3,17
LUW			32 211	31,65	**30,84**
Displacement			56 891	**25,934**	**25,429**

By comparing Table 6-2 and Table 6-4, one sees that the riser tension, set back, hook load and drill tools items have been lowered ten meters compared to the benchmark design, which is a direct effect of these items being attached to the drill floor. Since there is no riser tension or hook load in the "pre spud" locations, the lowered VCG for these two items had no effect on the total VCG in the bottom row. The BOP stacks, which are located on the main deck on the new design compared to being partly stored on the cellar deck on the benchmark design has a four meter higher VCG in the new design. Which offsets some of the VCG reduction of the LUW. As can be seen by comparing the numbers in the bottom rows of Table 6-2 and Table 6-4, the total VCG reduction in the "pre spud" load condition is:

$$25.934 - 25.429 = 0.505\ m$$

7 DISCUSSION

From the conservative approximation of the VCG reduction in chapter 6, it was estimated that the VCG in the "pre spud" load condition is approximately 0.5 meters lower for the conceptual flush drill floor design than for the conventional GVA 7500 semi-sub. From equation 2-3, where KG has been lowered by the same distance as the VCG, it follows that if KB, I and V are kept constant, the GM is 0.5 meters larger on the new design than on the GVA 7500.

$$GM = KB + \frac{I}{V} - KG \qquad \textbf{7-1}$$

When designing a semi-sub, a typical GVA design target for the GM is 1-2 meters, thus 0.5 meters is a significant increase. The potential to reduce I and KB in order to get the same GM as the GVA 7500 due to the lower KG/VCG of the flush drill floor design can therefore significantly reduce the rig weight.

The feasibility/universality of the proposed concept has been ensured by consequently using as strict design requirements as possible. By designing the rig for the largest possible BOPs/X-mas trees, the concept can be used on both shallow waters, with lower pore pressure, and on deeper waters where pore pressure is higher and safety concerns are large. Additionally, the concept has been designed with wire-line riser tensioners and conventional trip saving on the BOP trolley. There are no constraints for instead using N-line type riser tensioners and integrated trip saver, which enables the conceptual design to handle both so that the semi-sub can be tailored according to customer preferences. Similarly, several different specification alternatives with regards to hoisting systems are possible. For customers who see limited use of the auxiliary well, and mainly plan to use it for offline casing building, offline riser building and lowering of the X-mas tree, the concept can be specified without a top drive and without a heave compensator in the auxiliary hoisting system. In the opposite, if the customer plans to use the auxiliary well for complete installation of the X-mas tree and for drilling the top hole section (where a riser is not used, and there is therefore no need for a diverter), the concept can be specified with heave compensation and a top drive in both of the hoisting systems. With regards to heave compensation, the concept works with both traditional top mounted compensators and with active heave compensation integrated in the draw-works on the main deck/drill floor level. Obviously, the latter option would be the best from a VCG perspective, since it allows for less weight to be placed in the top of the derrick.

The mud return system has been designed to be functional with fully standardized components, which resulted in a functional system, although it required the mud pits to be placed in the box bottom. However, since the problem of finding vertical room for a gravity fed mud return system is non-existent in a conventional semi-sub, the components has thus probably not been designed with vertical compactness as a primary design objective. It is therefore likely that several components in the mud return system, perhaps most notably the diverter, can be designed with a shallower footprint than on the current design, which would allow the mud return system to be even less specialized in the flush drill floor design concept.

The concept is not infinitely flexible however, most importantly it is constrained to a double derrick with sufficient well center spacing to allow for BOP deployment through the auxiliary well center. Additionally, although the mud return system probably can be improved by purpose built components as discussed above, the mud return system on the conceptual design cannot handle too short deck boxes. Therefore, the conceptual design is not suitable for very small rigs, and is best used on larger rigs designed to operate on deeper waters (where the double derrick design is put to most use due to its capability of offline riser building). However, as was described in chapter 2.2, the exploitation of oil fields on shallow waters are nearing completion, and it is therefore likely that deep water operational capability will become increasingly important for semi-subs in the future. The restriction of only being applicable to larger rigs with double derricks is therefore not a major discouragement.

As was found out during the course of the project, the strengths of the conceptual design is not limited to the lower VCG. Some other improvements are:

- Less climbing in stairs when going to and from the drill floor, this reduces falling hazards, especially in arctic climates where there is a risk for ice and snow on the rig.
- The BOP/X-mas tree service area is concentrated to one specific area on the rig, where the derrick and the deckhouse structures can be used as natural support for access floors for working on the upper parts of the BOPs and X-mas trees.
- Space on the main deck is freed up by placing for example the cement unit in the deck box, which can be made larger since the size of the cellar deck can be decreased when it does not have to fit any parked BOPs.
- The universal trolleys in the BOP/X-mas tree handling areas can be used to transport heavy equipment that otherwise would have to be transported on the catwalks to and from the auxiliary well center.
- Although not investigated in this report, it should be possible to increase the height of the derrick by the distance that its base has been lowered, i.e. ten meters, and thereby allow for every stand to consist of one extra drill pipe single, which would increase operational efficiency.

8 CONCLUSION

This thesis project has studied the feasibility of a flush drill floor semi-sub design by designing a flush drill floor semi-sub with the same drilling capabilities as the benchmark GVA 7500 semi-sub. The results have shown that a flush drill floor design capable of the same drilling operations as the GVA 7500 semi-sub can indeed be designed by partly novel solutions and partly modifying existing solutions. The project has resulted in a completely novel BOP/X-mas tree handling system, which solves the main challenge of a flush drill floor, i.e. storing and deploying the large and heavy BOP. Further, the project has shown that the concept can accommodate both wire-line as well as N-line type riser tensioners and that a gravity based mud return system is applicable after slight modifications.

The estimated VCG reduction of the conceptual design in the project is 0.5 meters, which implies that the GM of the rig is automatically increased by the same amount. 0.5 meters is a significant increase of the GM, for which GVA uses a design target of 1-2 meters. Thus due to the significant reduction in VCG, the flush drill floor design can potentially lead to large weight savings.

The first step for future research is to perform a structural assessment of the conceptual flush drill floor design. A structural assessment would provide a detailed estimate of the weight savings of the flush drill floor design. If the structural assessment provides promising results, further development can be performed on a more detailed level in order to transform the conceptual design to a production ready design.

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APPENDICES

APPENDIX A – SPECIFICATION OF THE GVA 7500 SEMI-SUB

GVA
A KBR Company

Master of the Oceans

GVA 7500 – SEMI-SUBMERSIBLE DRILLING RIG

Operation area	Worldwide use including North Sea. From mild to harsh environmental conditions
Operation water depth	70 – 3,000 m (230 –10,000 ft)
Drilling depth	Up to 12,000 m (40,000 ft)
Regulations	Norwegian NMD & PSA, UK HSE, US Coast Guard, Norsk Technical Safety
Classification	DNV
Accommodation	156 persons
Features	Designed to be operational year round in ultra deep water. Favourable motion characteristics for efficient and reliable operation in harsh environmental conditions. Suitable for both exploration and development drilling. Variable deck load capacity 7500 mt in operational and survival conditions. Low operation and maintenance costs. Large deck area for storage and handling of equipment. GVA 7500 series can be delivered with different equipment.

MAIN PARTICULARS

Length over all	118.6 m	389.1 ft
Width over all	96.7 m	317.3 ft
Width outside pontoons	78.1 m	256.2 ft
Length of pontoons	108.8 m	357.0 ft
Height of pontoons	10.2 m	33.6 ft
Height to Main Deck	45.0 m	147.6 ft
Height of deck box	8.5 m	27.9 ft
Four columns	18.4 x 14.4 m	60.4 x 47.2 ft
Transit draught	9.9 m	32.3 ft
Transit displacement	41,300 mt	45,522 st
Transit deck & column payload	6,500 mt	6,393 st
Operation draught	23.0 m	7,165 ft
Operation displacement	56,150 mt	61,890 st
Operation deck & column payload	7,500 mt	8,267 st
Survival draught	19.0 m	62.3 ft
Air gap in survival	17.5 m	57.4 ft

MAIN MARINE SYSTEMS / EQUIPMENT

Power generation	8 x 5500 kW	8 x 7400 HP
Thrusters	8 x 4000 kW	8 x 5,400 HP
Thruster control	DP 3	
Mooring system	8 point mooring, 84 mm chain	
Main deck cranes	1 x 100,1 x 85 mf	2 x 93 st
		1 x 110 st, 1,94 st

MAIN DRILLING SYSTEMS / EQUIPMENT

Derrick for up to 135 ft stands	908 mt	1,000 st
Top drive	908 mt	1,000 st
Drawworks Aux	450 mt	500 st
Drawworks Main	908 mt	1,000 st
Drilling riser, 75 ft joints	3,500 kips flange rating	
Mud pumps	4 x 1,700 kW	4 x 2,200 hp
BOP Stack	15,000 psi, 6 rams	
Riser tensioners, N-line type	1,450 mt	1,598 st

TANK / STORAGE CAPACITIES

Fuel oil	3,500 m³	22,014 bbls
Drill water	2,600 m³	16,350 bbls
Potable water	500 m³	3,145 bbls
Mud storage, col+pont	800 m³	5,032 bbls
Mud pits	900 m³	5,660 bbls
Brine	1100 m³	6,919 bbls
Base oil	700 m³	4,403 bbls
Complation fluid	920 m³	5,787 bbls
Bulk mud	620 m³	22,000 cbft
Bulk cement	280 m³	10,000 cbft
Sack storage	7,500 pce	
Clean Drain	460 m³	2,893 bbls
Riser storage 21 riser	3000 meter	

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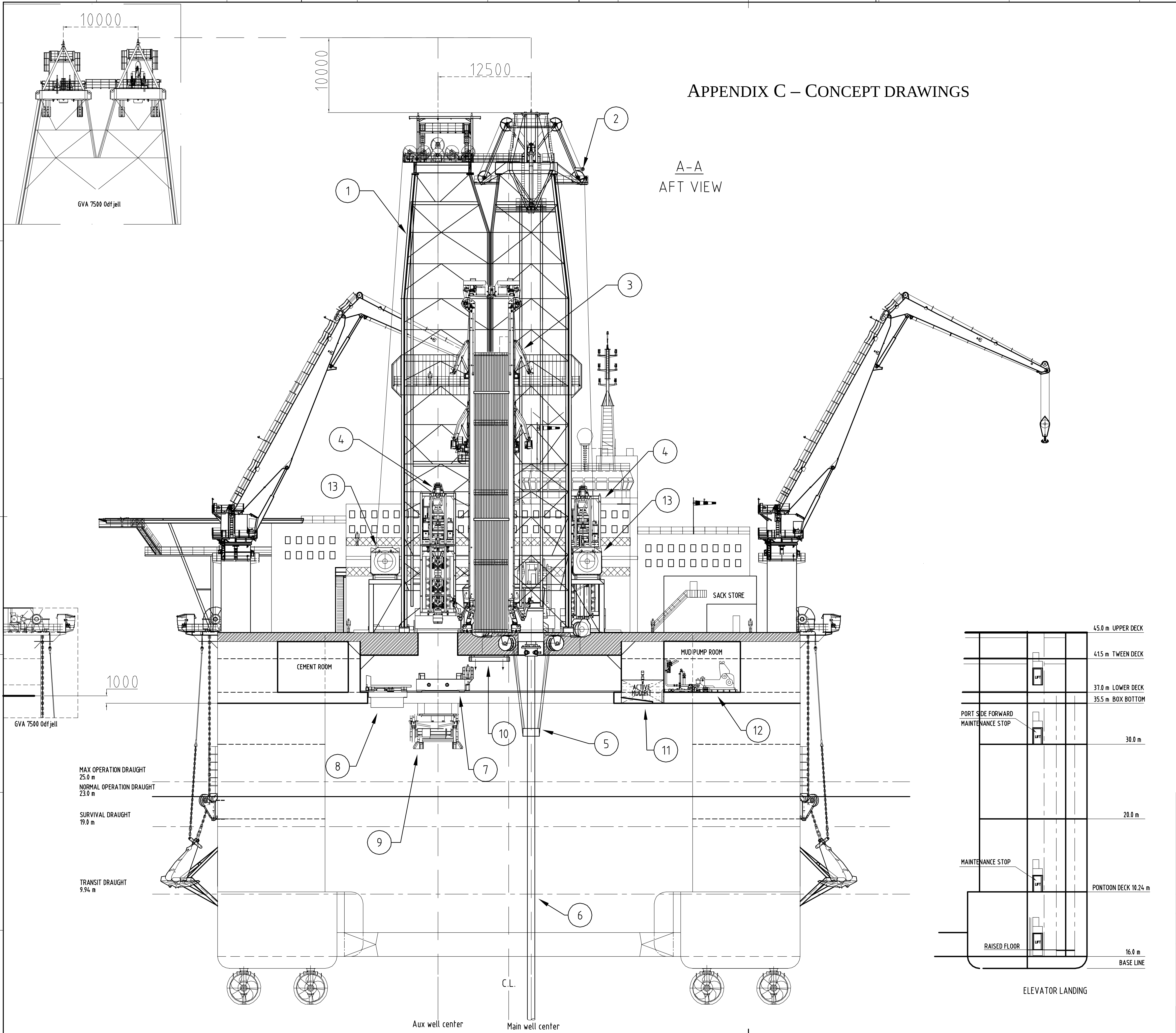
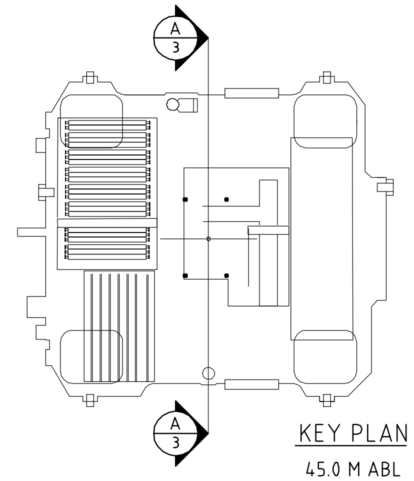
APPENDIX B – LIST OF REQUIREMENTS

Project: Flush Drill Floor - GVA		**Created:** 14 feb 2014 **Last revised:** 31 Mars 2014	**Issuer:** Mikael Ahlstedt Joakim Andersson		
Design space/requirements	**Target value**	**Justification**	**Evaluation/Verification**	**R/D**	**Fulfilled**
1 General					
1.1 Minimum load capacity	7500 mT (current design)	GVA	Estimation/Engineering judgement	R	Yes
1.2 Marine riser capacity	10,000 ft (75 segments)	GVA	AutoCad	R	Yes
2 Drill floor layout					
2.1 Offline stand building	Yes	GVA	AutoCad/GVA engineers	R	Yes
2.2 Offline casing biulding	Yes	GVA	AutoCad/GVA engineers	D	Yes
2.3 Offline riser biulding	Yes	GVA	AutoCad/GVA engineers	D	Yes
2.4 Minimum set back area	41 m2 (current design)	GVA	AutoCad	R	Yes (45.5 m2)
3 Bop/X-mas tree handling system					
3.1 Number of BOPs to handle	2	GVA	AutoCad/GVA engineers	R	Yes
3.2 Number of X-mas trees to handle	2	GVA	AutoCad/GVA engineers	R	Yes
3.3 Guided lifts of BOP/X-mas tree	Yes	GVA	AutoCad/GVA engineers	R	Yes
3.4 Dimensions of BOP (HxLxW)	6096x4872x1885 0 mm	GVA	AutoCad/GVA engineers	R	Yes
3.5 Dimensions of X-mas tree (HxLxW)	5740x5200x8000 mm	GVA	AutoCad/GVA engineers	R	Yes
3.6 Weigth of one BOP	500 mT	GVA	AutoCad/GVA engineers	R	Yes
3.7 Weigth of one X-mas tree	50 mT	GVA	AutoCad/GVA engineers	R	Yes
3.8 X-mas tree storage within reach of pedestal cranes	Yes	GVA	AutoCad	R	Yes
4 Trip saver system					
4.1 N-line trip saver compatibility	Yes	GVA	Engineering judgement	R	Yes
4.2 Trip saver trolley compatibility	Yes	GVA	AutoCad	R	Yes
5 Riser tensioner system					
5.1 Wire line riser tensioning copatiblity	Yes	GVA	AutoCad	R	Yes
5.2 N-line riser tensioner compatibility	Yes	GVA	Engineering judgement	R	Yes
6 Mud system					
6.1 Gravity driven mud return (> 6 degrees inclination in return lines)	Yes	GVA / Norsok standard	AutoCad	R	Yes
6.2 Standard mud return components compatibility	100% standard	GVA	AutoCad	D	Yes
7 Safety					
7.1 Minimize number of operations with open hole in drill floor	0 operations	GVA	Operation procedure description	D	Yes (0)
7.2 Minimize work in moon pool area	Only POD lines	GVA	Operation procedure description	D	No (trip saver adapter and pod lines)
8 Time constraints					
8.1 Final presentation	17th of May	Chalmers university of technology & GVA		R	
8.2 Final report	4th of June	Chalmers university of technology & GVA		R	

Appendix C – Concept drawings





ITEM	DESCRIPTION	ITEM	DESCRIPTION
1	DERRICK	17	AUXILIARY CATWALK
2	TOP HEAVE COMPENSATION	18	PIPE/CASING STORAGE
3	PIPE RACKING SYSTEM	19	MAIN CATWALK
4	BOP	20	DIVERTER
5	RISER TENSIONING SYSTEM	21	PIPE STAND
6	RISER	22	SET BACK
7	BOP MOON POOL TROLLEY	23	CASING
8	X-MAS TREE MOON POOL TROLLEY	24	TOP DRIVE
9	BOP GUIDE STRUCTURE	25	SKID TROLLEY
10	TRIP SAVER ADAPTER	26	REMOVABLE FLOOR TROLLEY
11	ACTIVE MUD PIT	27	ROUGHNECK
12	MUD PUMP	28	DRILLERS HOUSE
13	DRAW-WORK	29	LIR
14	BOP/X-MAS TREE SERVICE CRANE	30	SERVICE BASKET
15	X-MAS TREE	31	CHOKE & KILL MANIFOLD
16	RISER STORAGE	32	UNIVERSAL SKID TROLLEY

Some labels may be referred to the drawing: FLUSH DRILL FLOOR-2

REFERENCE DRAWINGS

No	DRAWING No	TITLE
1	FLUSH DRILL FLOOR-1	GENERAL ARRANGEMENT - AFT SECTION VIEW
2	FLUSH DRILL FLOOR-2	DRILL FLOOR ARRANGEMENT - SECTION VIEWS
3	FLUSH DRILL FLOOR-3	GENERAL ARRANGEMENT - UPPER DECK
4	FLUSH DRILL FLOOR-4	GENERAL ARRANGEMENT - LOWER DECK
5	FLUSH DRILL FLOOR-5	PRINCIPLES OF MUD RETURN SYSTEM

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PROJ

PROJECT TITLE
FLUSH DRILL FLOOR
Master thesis - Concept for an integrated drill floor design

DRAWING TITLE
GENERAL ARRANGEMENT
AFT SECTION VIEW

Doc ID
Scale 250
Dwg format A1

GVAC DOC NO. FLUSH DRILL FLOOR-1
Drawn by JAN
Rev. 1
ALT DOC NO.
ALT. Rev.

ITEM	DESCRIPTION	ITEM	DESCRIPTION
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2	TOP HEAVE COMPENSATION	18	PIPE/CASING STORAGE
3	PIPE RACKING SYSTEM	19	MAIN CATWALK
4	BOP	20	DIVERTER
5	RISER TENSIONING SYSTEM	21	PIPE STAND
6	RISER	22	SET BACK
7	BOP MOON POOL TROLLEY	23	CASING
8	X-MAS TREE MOON POOL TROLLEY	24	TOP DRIVE
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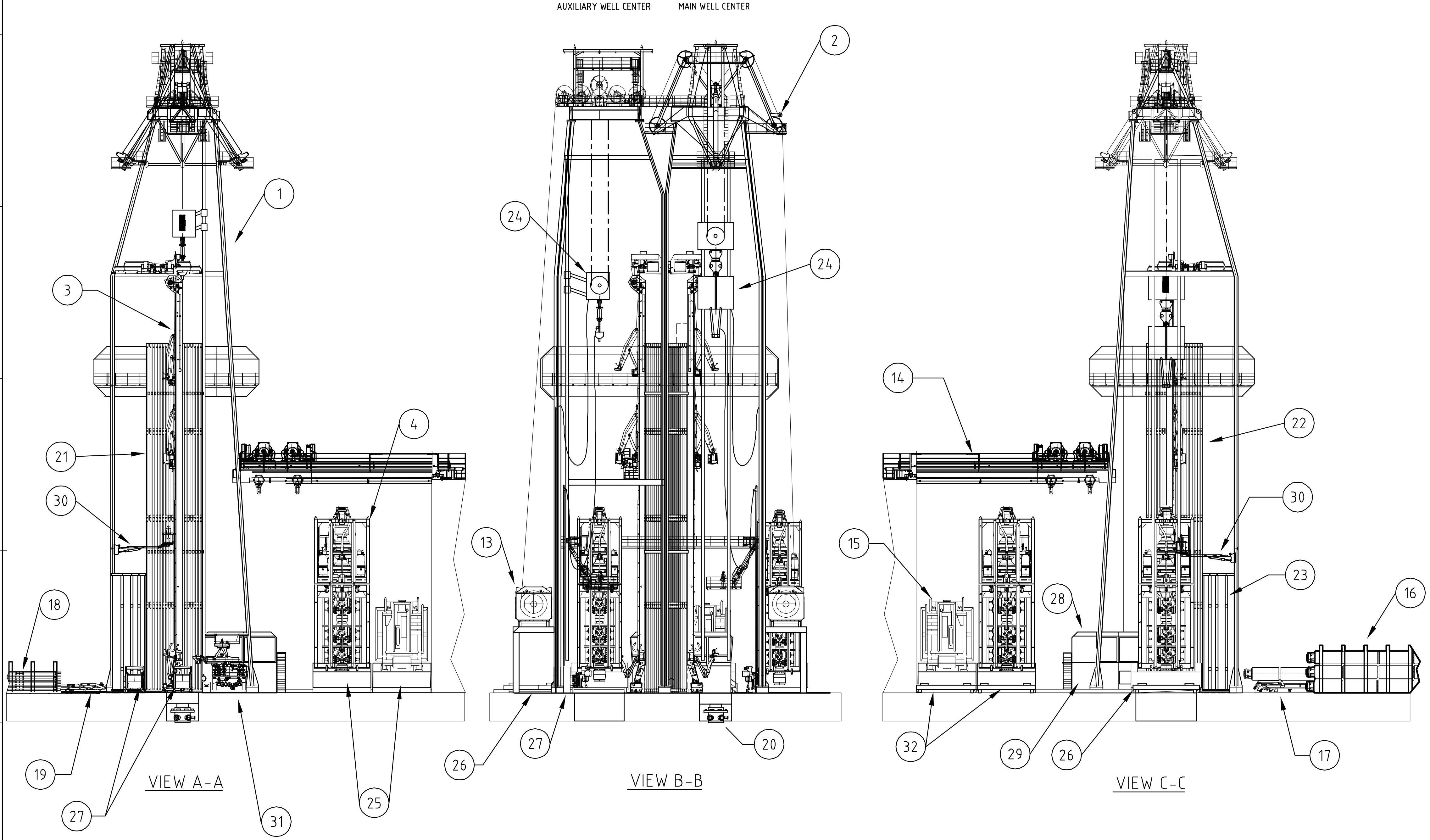
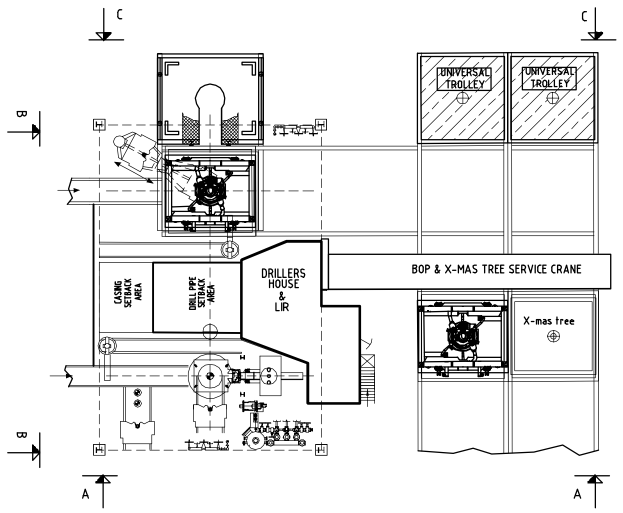
14	BOP/X-MAS TREE SERVICE CRANE	30	SERVICE BASKET
15	X-MAS TREE	31	CHOKE & KILL MANIFOLD
16	RISER STORAGE	32	UNIVERSAL SKID TROLLEY

Some labels may be referred to the drawing: FLUSH DRILL FLOOR-1



VIEW A-A   VIEW B-B   VIEW C-C



The drawing is simplified in order to illustrate the equipment

REFERENCE DRAWINGS

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2	FLUSH DRILL FLOOR-2	DRILL FLOOR ARRENGEMENT - SECTION VIEWS
3	FLUSH DRILL FLOOR-3	GENERAL ARRENGEMENT - UPPER DECK
4	FLUSH DRILL FLOOR-4	GENERAL ARRENGEMENT - LOWER DECK
5	FLUSH DRILL FLOOR-5	PRINCIPLES OF MUD RETURN SYSTEM

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DRAWING TITLE
DRILL FLOOR ARRANGEMENT
SECTION VIEWS

Scale 1:250
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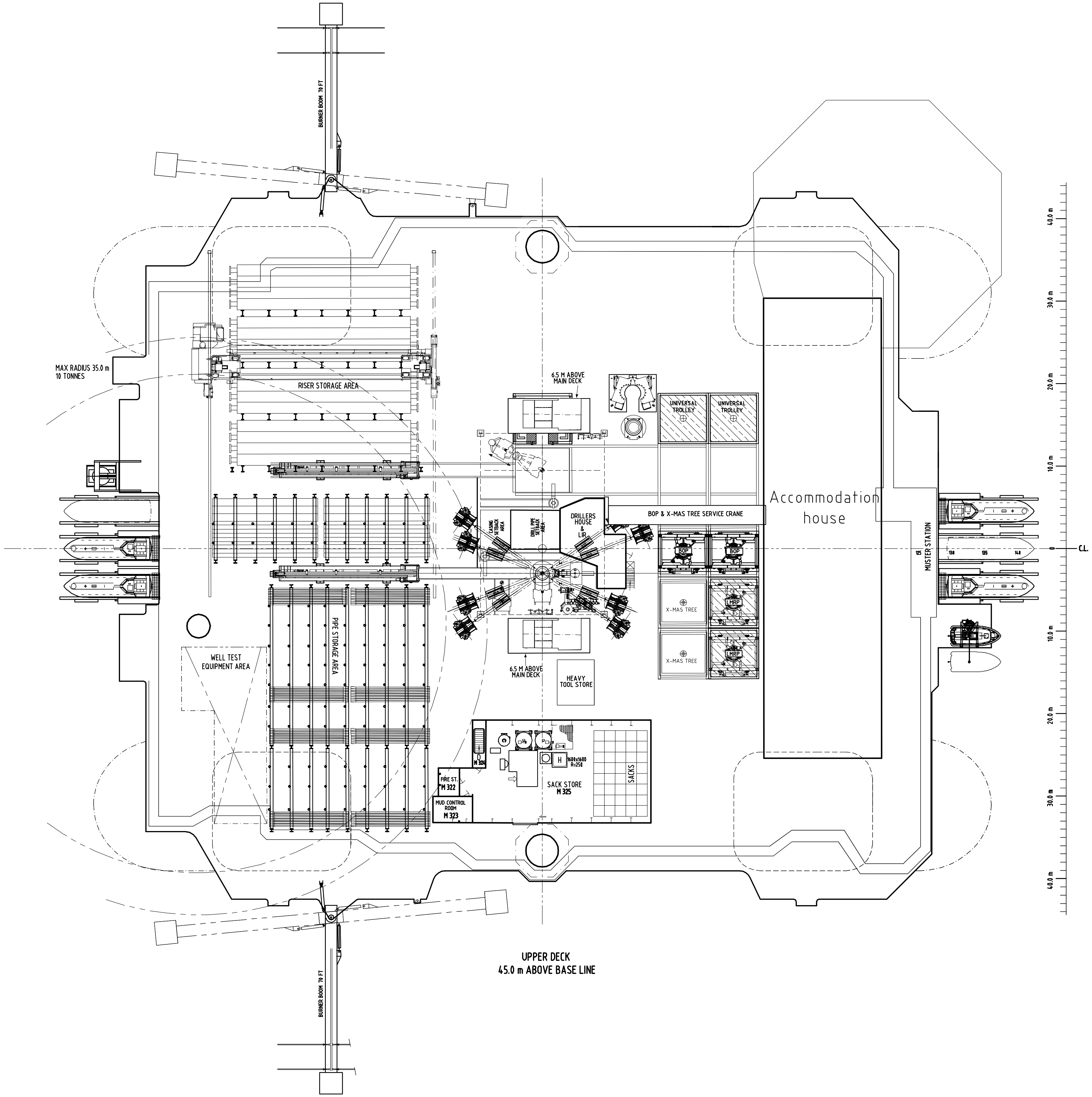

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DRAWING TITLE
GENERAL ARRANGEMENT
UPPER DECK

Doc ID

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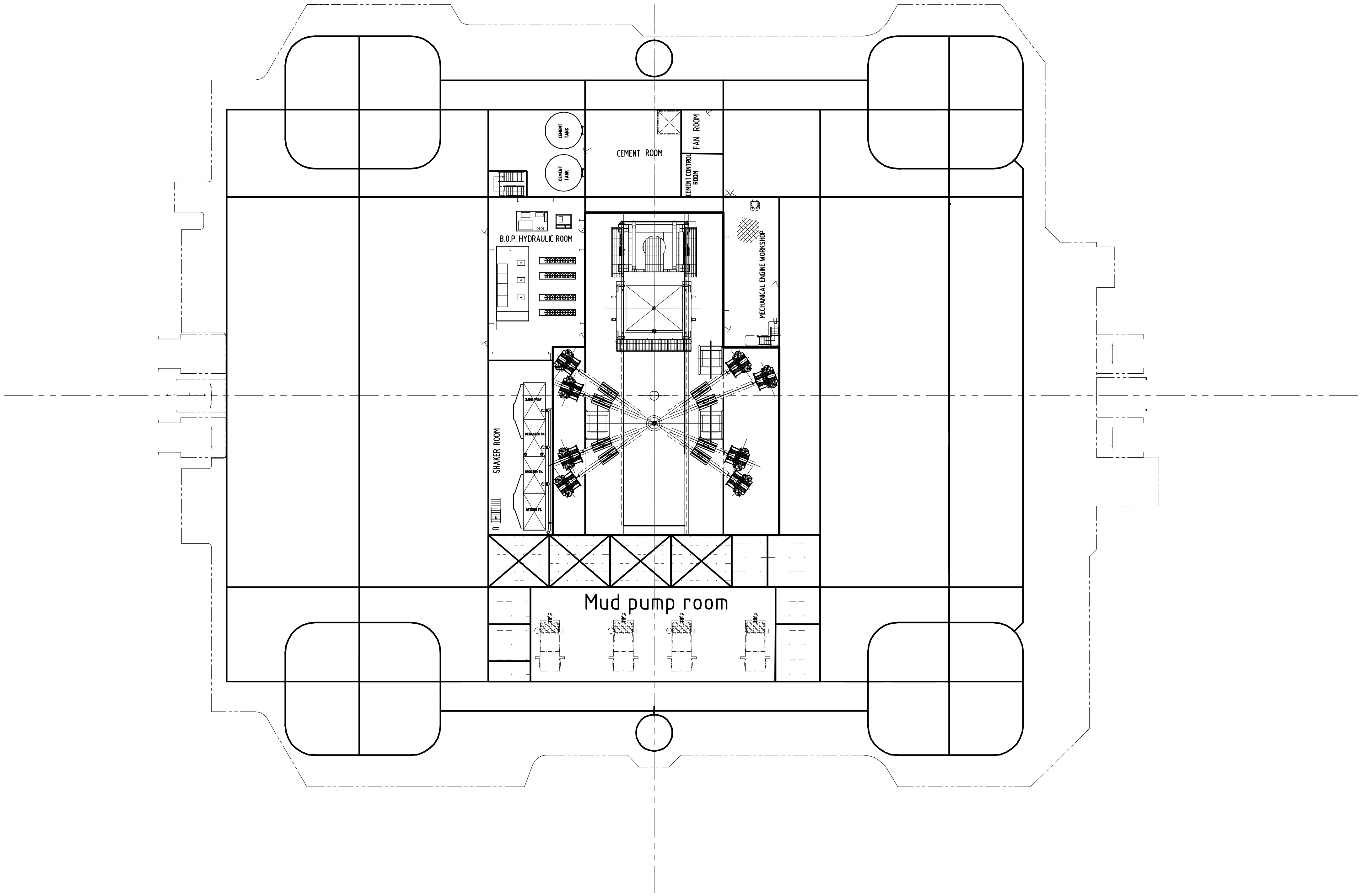
Rev.



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FLUSH DRILL FLOOR
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DRAWING TITLE
GENERAL ARRANGEMENT
LOWER DECK

Doc ID
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Drawn by JAN
Rev. 1
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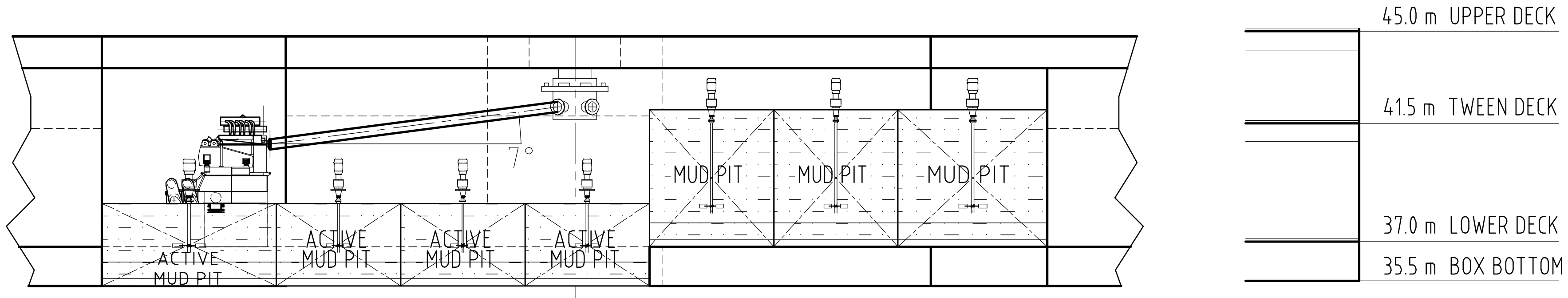
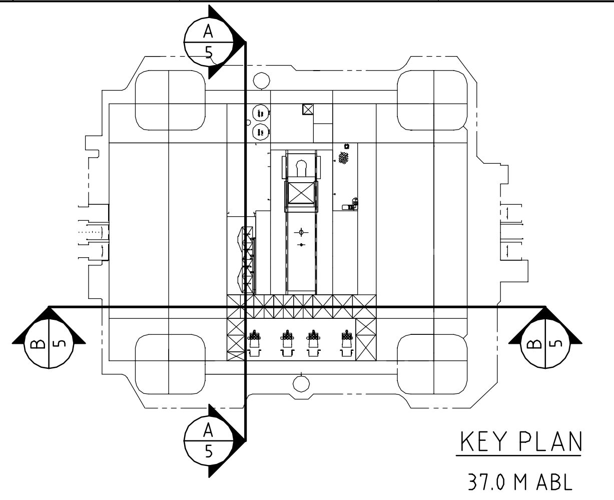


SECTION B-B
STARBOARD SIDE



REFERENCE DRAWINGS

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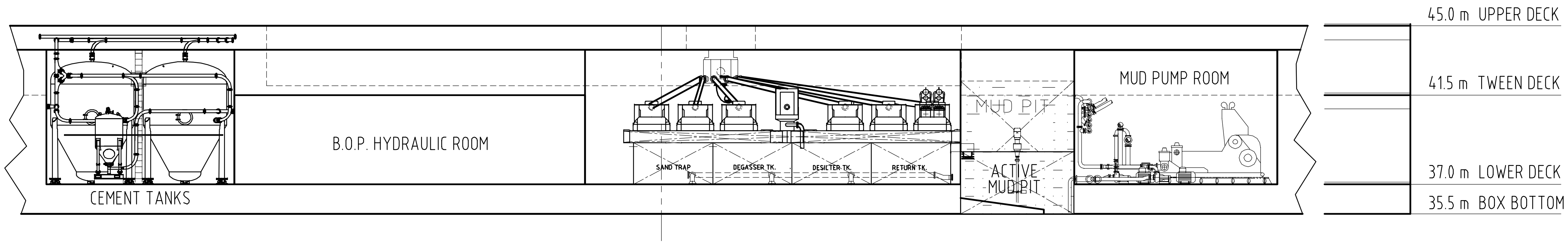

SECTION A-A
AFT VIEW

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DRAWING TITLE
PRINCIPLES OF MUD RETURN SYSTEM
SECTION VIEWS

Doc ID
Scale 125
Dwg format A3

GVAC DOC NO. FLUSH DRILL FLOOR-5
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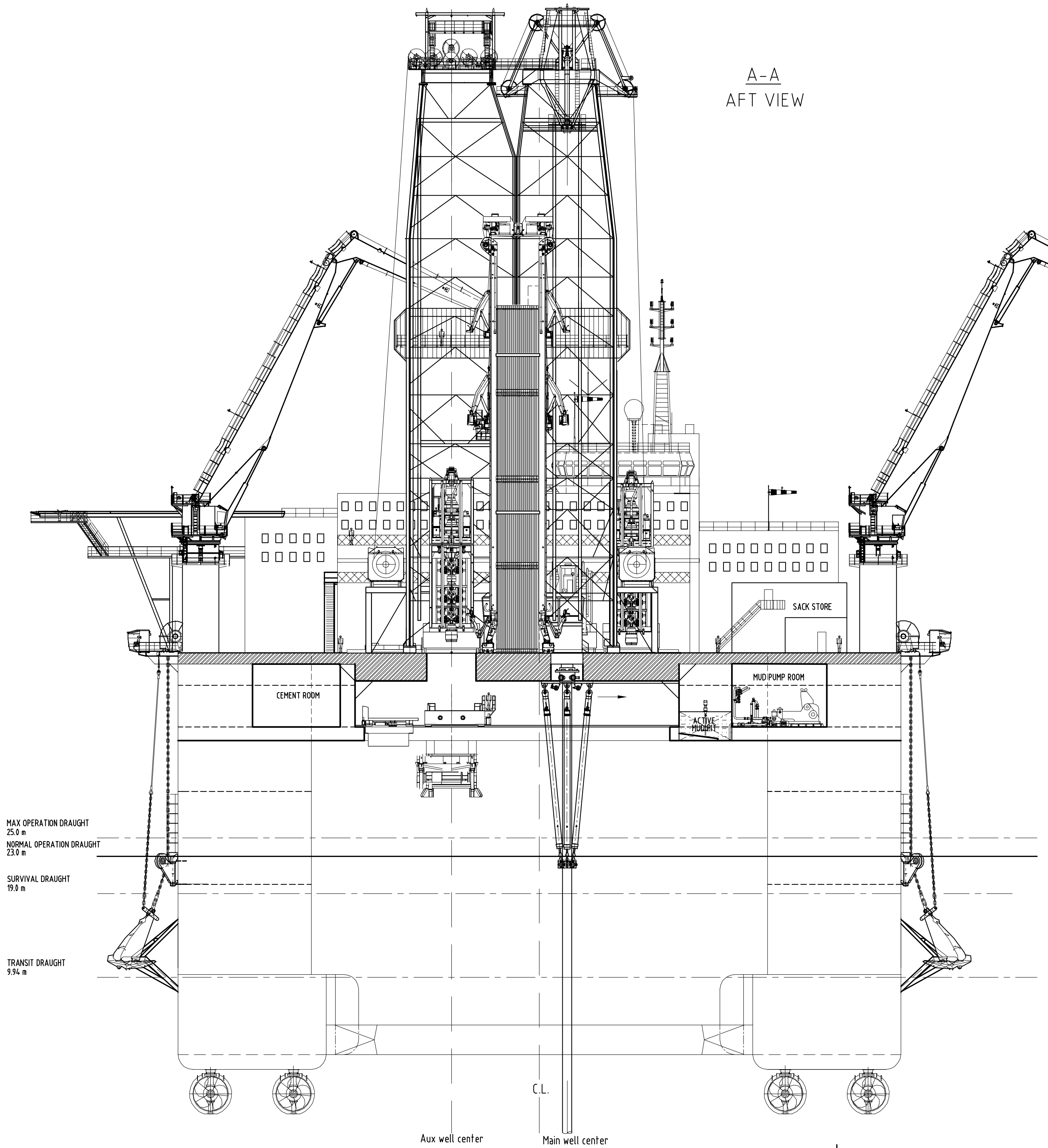
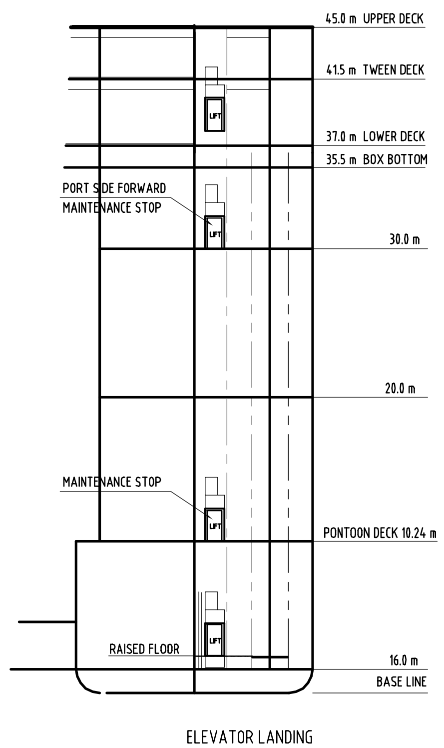
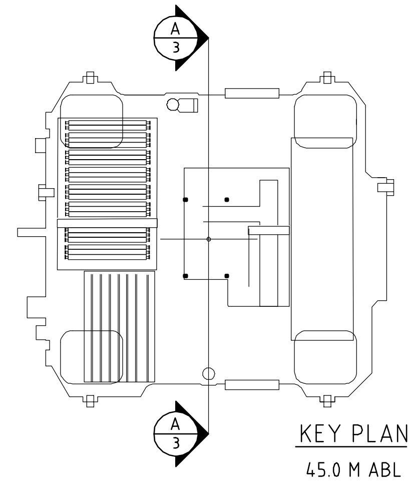
ALT Rev.
Drawn by JAN
Rev. 1

Appendix D – Flush drill floor with N-line tensioners

A-A
AFT VIEW







REFERENCE DRAWINGS

No	DRAWING No	TITLE
1	FLUSH DRILL FLOOR-1	GENERAL ARRANGEMENT - AFT SECTION VIEW
2	FLUSH DRILL FLOOR-3	DRILL FLOOR ARRANGEMENT - SECTION VIEWS
3	FLUSH DRILL FLOOR-3	GENERAL ARRANGEMENT - UPPER DECK
4	FLUSH DRILL FLOOR-4	GENERAL ARRANGEMENT - LOWER DECK
5	FLUSH DRILL FLOOR-5	PRINCIPLES OF MUD RETURN SYSTEM

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PROJ

PROJECT TITLE
FLUSH DRILL FLOOR
Master thesis - Concept for an integrated drill floor design

DRAWING TITLE
GENERAL ARRANGEMENT
AFT SECTION VIEW
N-LINE CONCEPT

Doc ID

Scale 250

Dwg format A1

GVAC DOC NO. FLUSH DRILL FLOOR-X

Drawn by JAN | Rev. 1

ALT DOC NO. | ALT. Rev.