Høgskulen på Vestlandet

MMO5017 Master thesis

MMO5017-MOPPG-1-2022-VÅR-FLOWassign

Predefinert informasjon

Startdato: 22-04-2022 14:11
Sluttdato: 03-06-2022 14:00
Eksamensform: Master thesis
Flowkode: 203 MMO5017 1 MOPPG-1 2022 VÅR
Intern sensor: (Anonymisert)
Termin: 2022 VÅR
Vurderingsform: Norsk 6-trinns skala (A-F)

Deltaker

Navn:	Thomas Blomvågnes
Kandidatnr.:	411
HVL-id:	136773@hvl.no

Informasjon fra deltaker

Antall ord *:	14891

Sett hake dersom besvarelsen kan brukes som eksempel i undervisning?: Nei

Jeg bekrefter at jeg har registrert oppgavetittelen på norsk og engelsk i StudentWeb og vet at denne vil stå på vitnemålet mitt *: Ja

Egenerklæring *: Ja

Inneholder besvarelsen konfidensielt materiale?: Nei

Gruppe

Gruppenavn: Enmannsgruppe
Gruppenummer: 8
Andre medlemmer i gruppen: Deltakeren har innlevert i en enkeltmannsgruppe

Jeg godkjenner avtalen om publisering av masteroppgaven min *

Ja

Er masteroppgaven skrevet som del av et større forskningsprosjekt ved HVL? *

Nei

Er masteroppgaven skrevet ved bedrift/virksomhet i næringsliv eller offentlig sektor? *

Nei

Høgskulen på Vestlandet

MASTER'S THESIS

How to ensure well control when performing permanent plug and abandonment operations

Thomas Blomvågnes

Master of Maritime Operations

Faculty of Engineering and Science

Submission Date: 03.06.2022

I confirm that the work is self-prepared and that references/source references to all sources used in the work are provided, cf. Regulation relating to academic studies and examinations at the Western Norway University of Applied Sciences (HVL), § 12-1.

Acknowledgment

This thesis is the concluding part of my Master degree in Maritime operations. The program is a joint master between University of Applied Sciences Hochschule Emden-Leer and the Western Norway University of Applied Sciences, where I have studied the profile *"Maritime Technology and Management"*.

I would like to share my gratitude to the companies and people who got involved during this thesis. My deep gratitude goes first to the informants that have been willing to participate in interviews for this research project. The information collected, the thoughts confirmed and refused, and the ideas discussed with all of you, have created a solid base of knowledge that lifts the validity of this research project to a higher level.

Secondly, I would like to express my deep gratitude to my supervisor and professor at the Western Norway University of Applied Sciences, Runald Walter Meyer, who has been very helpful with his thorough feedback, sharing of knowledge, and good discussions.

Lastly, I would like to express my sincere gratitude to everybody at PSW Technology for supporting me with valuable information and technical support. I would like to give a special thanks to my dear colleague Tor Fjelltveit for sharing his valuable knowledge, participating in good discussions, and helping me with a second opinion on my thoughts and ideas. I would also give a special thanks to everybody working the night shift in PSW Technology facilities at Mongstad. To have the opportunity of tanking my coffee breaks with you, throughout the work with this Master thesis, and this Master's program has been extremely valuable to me.

Abstract

On the Norwegian Continental Shelf there are over 5 000 well paths drilled for the extraction of oil and gas. Before the Norwegian oil and gas adventure could be brought to an end, all of these well paths would need to be permanently plugged and abandoned. With a typical time estimate for PP&A from 2015, it would take 15 semisubmersibles approximately 20-years to perform the operation on the established wells, not including any wells drilled after 2015 (Energi24, 2022). There are also technical difficulties involved with PP&A on the NCS. The wells waiting for PP&A have been drilled over a long period of time, and the development of the BOPs used today, has been a constant ongoing process. Therefore, it is natural that there are wellheads that will not sustain the forces applied from connecting a typical BOP used in 2022. The dimensional forces are the weight of the BOP, acting downwards on the wellhead, and the bending moment, caused by drag forces, or misalignment between the wellhead centre axis and the rig/vessels centre axis.

This gives the background for the research question for this thesis: "*How to ensure satisfying well control, at a low cost when performing permanent plug and abandonment operations on subsea controlled oil and gas wells, located on the Norwegian continental shelf, where the wellhead is not designed to withstand the forces applied by connecting a typical blow out preventer used today?"*

To investigate this issue it has been performed a literature study, to determine the laws and regulations surrounding well control during PP&A operations, and it has been performed interviews of different informants with key information from different backgrounds. The data collected through these methods has been used to evaluate several difference ideas, these are presented in Chapter 5, and the evaluation is presented in chapter 7.

From the evaluation of ideas, the idea of using existing components to create a smaller blow out preventer (BOP), also called a Subsea Shut of Devise (SSD) is concluded to be the most favourable method included in this research project. For the remaining part of this report, it is looked into optimising the SSD in regard to weight. It is concluded that the SSD should be designed after the ISO 13628-7 standard. This standard requires one bi-directional isolation valve, also known as an Annular BOP, and doble shearing valve or ram BOP. Based on this it is concluded that the main components from the bottom should be: a wellhead connector, one

shear ram, one shear seal ram, one annular, and one mandrel or customer specific component as a top connection.

With regards to the comparison of components it is concluded that the following components would be the most weight efficient for the main components, for the wellhead connector Oilstates Lynxgrip 15/30 connector is preferred, for the BOP a Hydril 15k double ram BOP with one 15” and one 22” bonnet is preferred, for the annular BOP a Cameron 18-3/4” 10k DL is preferred. This report does not conclude on which components that are optimal for top connection, and fail-safe valves. Some of these will be depending on customer specifications or the components that should be connected with the SSD. For the framework of the SSD, it will not be given a conclusion of the design, as this is too early in the design process.

Through this report, it has been discussed if the pressure rating of the ram BOP needs to be 15k, or if it could be changed to 10 or 5k. The possibility of using a BOP with a pressure rating lower than 15k should diffidently be present, as the numbers of wells, where the well pressure exceeds 15k are considered to be in the minority of wells on the NCS. It has also been discussed if it is possible to class up a 10k BOP to be used on a 15k well, by implementing measurements for improved inspection and surveillance. In this report, it is concluded that a solution like this would work, as long as the developer finds a manufacturer who is willing to agree. The fact that the OEM most likely must be included in the process, makes this the most important argument for which BOP that should be used. Therefore, it is not performed a thorough comparison of the weight of different 10k ram BOPs

It is concluded that there is a large possibility to offer a more cost-efficient method for PP&A operations, by using an SSD and an LWI vessel instead of a semisubmersible. It has also been discussed how the business module should be for a company developing an SSD. But it has not been performed a thorough enough consideration in this report to have a valid conclusion on this question. From a simple CO2 calculation presented in chapter 9.5, it can be concluded that it gives the indication that performing the PP&A operation with an SSD and LWI vessel should lead to lower emissions that performing the operation with a semisubmersible.

Table of content

List of Figures

List of tables

Figure 1: Two-barrier philosophy show using the “hat-over-hat” representation (Khalifeh & Saasen, 2020) 5
Figure 2: casing program typical deepwater wells (Yang Jin, 2022) 9
Figure 3: Vertical xmas tree (Crumpton, 2022) 11
Figure 4: Horizontal xmas tree (Subseapedia, 2022) 12

List of abbreviations

PP&A	Permanent Plug and Abandonment
P&A	Plug and abandonment
NCS	Norwegian Continental Shelf
SSD	Subsea Shutoff Device
PSV	Platform Supply vessel
MODU	Mobile offshore drilling unit
PGB	Permanent guide base
TGB	Temporary guide base
HFO	Heavy Fuel Oil
LWI	Light well intervention
OEM	Original Equipment Manufacture

1 Introduction

1.1 Background

Since oil was discovered on the NCS (Norwegian Continental Shelf) in December 1969, it has been found oil and gas in many different locations. The NCS has been equipped with permanent installations both subsea and above the waterline. In addition, numerous mobile installations like semisubmersible and vessels, have been operating on the NCS.

The oil and gas production from the NCS has without questing been an adventure. In total over 16 000 million NOK has been brought into the Norwegian gross national product, measured with the NOK value in October 2021 (Norsk-petroleum, 2022). Up to 2015, a total of 2 134 wells were drilled on the NCS. There were 451 wells with the status plugged or closed. 188 of these wells had a plan of re-usage, and 263 had the status: no plan, or unclear (Energi24, 2022). Going into 2022, fresh numbers show that 5292 well paths are drilled for the extraction of oil and gas (NPD, 2022). Some of these good paths are distributed from the same wellhead; hence the numbers can not be directly compared.

In 1996, the Norwegian government issued a White Paper requiring the Norwegian oil industry to reach the goal of ‘‘zero discharge’’ for the marine environment by 2005. To achieve this goal, the Norwegian oil and gas industry initiated the Zero Discharge Programme for discharges of produced formation water from the hydrocarbon-containing reservoir, in close communication with regulators. The purpose of this regime is to have zero environmental harmful discharges on the marine environment (Mathijs G D Smit, 2011).

With the technology available and frequently used in 2015, the total cost of a Permanent Plug and Abandonment (PP&A) operation was estimated to around 410 million NOK. The available methods for performing PP&A were pr 2015 limited to the usage of a semisubmersible, jack-up or drilling vessel, as the removal of production tubing requires the usage of a BOP to ensure the possibility to seal off the well. With a typical time estimate of a PP&A operation at this time, it would take 15 semisubmersibles approximately 20-years to perform the operation on the established wells, not including any wells drilled after 2015 (Energi24, 2022).

In addition to the ground basis presented above, there are also technical difficulties involved with PP&A on the NCS. The wells waiting for PP&A have been drilled over a long period of time, and the development of the BOPs used today, has been a constant ongoing process. Therefore, it is natural that there are wellheads that will not sustain the forces applied from connecting a typical BOP used in 2022. The dimensional forces are the weight of the BOP, acting downwards on the wellhead, and the bending moment, caused by drag forces, or misalignment between the wellhead centre axis and the rig/vessels centre axis.

The cost and time needed for performing PP&A on the entire NCS, provide the basis for this research project. It is without a doubt a large possibility to have an enormous benefit of providing a cheaper and less time-consuming way to perform the PP&A. The PP&A operation is today limited to the usage of a BOP, which means a semisubmersible, jack-up, or drilling vessel must be used in the operation. The usage of a Subsea Shut-off Device (SSD) could potentially provide an opportunity to move the operation from a drilling vessel to a smaller vessel, such as a customized Platform Supply Vessel (PSV), or a light well intervention vessel. This represents the background for this research project.

1.2 Objectives

The research question defined for the research leading up to this report is defined as follows: How to ensure satisfying well control, at a low cost when performing permanent plug and abandonment operations on subsea controlled oil and gas wells, located on the Norwegian continental shelf, where the wellhead is not designed to withstand the forces applied by connecting a typical blow out preventer used today?

1.3 Limitations

The theories presented in this report are collected from public documents, or internal documents provided through PSW Technology. PSW Technology is a service company for the energy market. With modern facilities located at Mongstad, western Norway, they offer re-certification, yearly service, and other services to the subsea industry. In addition, they supply the market with several new designs, and products used for both subsea and top sites.

Therefore, this research project is limited to available material. Hence the large potential for an economical benefit, for the company presenting the optimal solution for PP&A. Therefore, other companies may have research that are not accessible to the researcher. Onwards the research is limited to wells located on the NCS and to subsea controlled oil and gas wells

1.4 Expectations to reader

The langue used in this report will be subsea orientated. Therefore, it is expected that the reader has some knowledge of the subsea industry. It is also expected that the reader has a basic knowledge and technical understanding, through education or working experience.

1.5 Methods

To collect data for this research project, two methods have been used: qualitative interviews and literature study. The literature study is performed with the traditional method, which means the literature is chosen from a purposeful selection and considered by the researchers overall judgment, and the data is compared and discussed (Øveren, 2022).

The structure of the interviews was relatively unformal, some key questions must be asked, but the interview could change direction after what the object highlights as important. The interviews are performed face to face with the following structure: short presentation of the theme, general questions, and specific questions. A minute of meeting was written from each interview, this can be found in Attachment B to Attachment D. The interview guide can be found in Attachment A. The reasons to perform interviews for this research project are to get the interview object to deliver relevant information, learn something new, and confirm or refute what the researcher is unsure of. In this report, the collected data will be presented and used.

2 Theoretical background of PP&A

Permanent plug and abandonment are the name of the operation performed when an oil or gas well is at the end of its lifetime. The reason for doing the operations is that the environment shall never be negatively impacted by the extraction of oil and gas, avoiding any leakages of hydrocarbons, or other environmental harmful debris into the marine environment has an extremely high focus.

Plug and abandonment (P&A) operations can be temporary or permanent. Temporarily is used when the intention is to return and re-enter the well at a later stage. In this report, the focus will be on permanent P&A operations. Permanent P&A is defined as a well status where the intent is to never use or re-enter the well again. Due to this, it is crucial to have a long-term perspective when choosing the equipment and barrier used for the operation. There are mainly two reasons for plugging a well. One is that the section of a reservoir is no longer productive, but the main wellbore is to be re-used by drilling a side-track. The other reason for plugging is that the entire well, including all side-tracks, is no longer deemed to be economically feasible and needs to be shut-in.

2.1 Definitions

In this subchapter some definitions of concepts used for plug and abandonment will be presented.

2.1.1.1 Temporary plug and abandonment

Well status, where the well is abandoned and/or the well control equipment is removed, with the intention that the operation will be resumed within a specified time frame (from days up to several years) (NORSOK-D-010, 2004).

2.1.1.2 Permanent plug and abandonment

Well status, where the well or part of the well, will be plugged and abandoned permanently, and with the intention of never being used or re-entered again. (NORSOK-D-010, 2004)

2.1.1.3 Well control

Collective expression for all measures that can be applied to prevent uncontrolled release of well bore effluents to the external environment or uncontrolled underground flow (NORSOK-D-010, 2004).

2.1.1.4 Well barrier

There is a generally accepted philosophy for well barriers that the well should be equipped with sufficient well barriers to prevent uncontrolled flow from the potential sources of flow. In addition, it is generally accepted that no single failure of a well barrier component should lead to unacceptable consequences. This means that, in practical terms, the well should be equipped with two independent well barriers: a primary and a secondary barrier. This is also known as the "hat-over-hat" principle whereas the secondary barrier acts as a back up to primary well barrier, see Figure 1, (Khalifeh & Saasen, 2020).

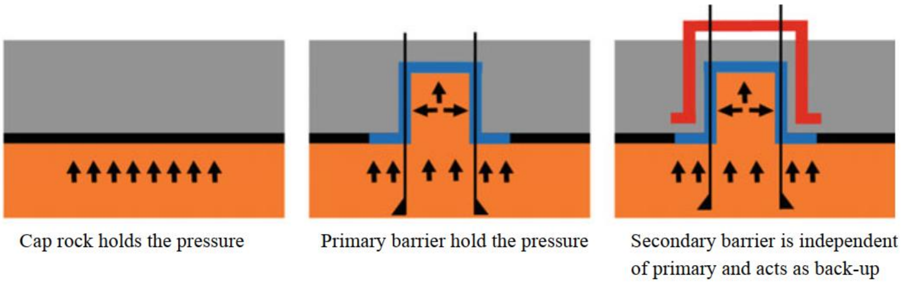

Figure 1: Two-barrier philosophy show using the "hat-over-hat" representation (Khalifeh & Saasen, 2020)

2.2 Plug and abandonment

PP&A of oil and gas well on the Norwegian continental shelf (NCS) is an operation that has not come as far, as the number of wells at the end of their lifecycle would correspond. With several thousand wells to be permanently plugged and abandoned in the upcoming years, this indicates that making the preferred solution would lead to potential enormous, marked shares within this field.

In this chapter, the theoretical background for PP&A operations will be presented. It starts with an overall picture of the operation, and looks into some of the areas considered by the author to be of great interest for this research project. For a more specific introduction to the theme in general, Khalifeh and Saasen's book "Introduction to Permanent Plug and Abandonment of Wells" (Khalifeh & Saasen, 2020), can be recommended.

2.2.1 The operation

Every well is unique and the associated challenges with it are as well. The main challenges which have been reported associated with the plug and abandonment of wells can be categorized as high temperatures, unconsolidated formations, changes in formation strength, tectonic stresses, and lack of data from old wells. (Khalifeh & Saasen, 2020). In this chapter, a brief overview of the operation of permanent plug and abandonment of wells will be presented.

The procedure of a PP&A can be described as presented in Table 1. The procedure is thought for a vertical Xmas tree, for a horizontal Xmas tree the procedure would need some adjustments. The table is inspired by (Øksnes, 2017). For a more detailed description of the operation, The master thesis "Permanent plugging and abandonment" from 2017 (Øksnes, 2017), is recommended, together with Khalifeh and Saasen book "Introduction to Permanent Plug and Abandonment of Wells" (Khalifeh & Saasen, 2020).

Table 1: P&A step by step operation (Øksnes, 2017)

Number	Name
1	Mobilization
2	Connect to xmas three
3	Install tubing hanger plugs
4	Handling of subsea tree
5	Run BOP and marine riser joints
6	Pull tubing hanger and tubing
7	Run cement log
8	Plug and abandon well
9	Open hole to surface
10	Removal of subsea components

2.3 Well control

As the definition given in paragraph 2.1.1.3, well control is a collective expression for all measurements that can be applied to prevent an uncontrolled release of well bore effluents. The main functions of well control equipment are to; close the top hole, Control the release of fluids, permit plumping into the hole, and allow movement of the inner string of pipe. For this research project, the well control equipment will be limited to the blow-out preventer, and the components described in chapter 3.3.

3 Introduction to subsea wells

The purpose of this chapter is to create a common understanding of the main components inside a well and at the seabed. The different components of a blowout preventer will, as mentioned in the previous chapter, be the main part of this report. Therefore, the BOP description will be the most detailed part of this chapter.

The main difference between surface-orientated wells and subsea-orientated wells is that the Xmas tree is installed subsea at the seabed, and produced oil or gas is transported from the well to a subsea manifold. The Xmas tree is designed to be installed in a wet environment with pressure from the water on the outside. The Xmas trees are equipped with more valves than a surface tree, and the valves are normally operated with hydraulic pressure and can be operated by acoustic if the hydraulic pressure fails. More on subsea Xmas trees will be presented in chapter 3.2.2.

Subsea wells may be installed individually, in clusters, or on a template. If the well shall be connected to a template, the framework is installed on the seabed first. Normally the template has room for four wells, but they can have up to ten wells. The frame can be anchored to the seabed by the usage of suction anchors. The frame has a Permanent Guide Base (PGB) for each well, with four columns installed in the corners. From the vessel, a wire is transported down and connected to the columns. Equipment that should down to the frame, is guided by the wires. If the well is to be installed individually, there is no need for the framework. A Temporary Guide Base (TGB) is then installed on the seabed and used for BOP during the drilling operation (Lervik, 2022).

3.1 Inside well

There are several different components used inside a subsea oil well, in this chapter the main of these components will be presented.

3.1.1 Casing

Casing are strong steel pipes that are installed inside the well to support and secure the drilled hole. The casing is produced in different steel qualities, dimensions, and thicknesses. The dimension of a casing is given by the external diameter. The wall thickness determines the internal diameter, and the strength of the casing. The length of the casing typically varies between 10 to 13 meters.

The casing shall isolate the hole and support the walls of the well, in addition to being resistant to corrosion and erosion from fluids and equipment used inside the well. The casing must resist the pressure force inside the well during the drilling operations. It will also function as guidance for the drill pipe into the next section, reduce the friction on the drill pipe, and support equipment that shall be installed in the well (Lidal, 2017). The casing has different names, depending on the sizing. In Table 2 an overview of the sizes and names is presented.

Table 2: Casing sizes and names.

Section	Name	Preferred size	Alternative size
1	Conductor	30”	36”, 24”, 20”
2	Surface casing	20”	24”, 18-5/8”, 16”
3	Intermediate casing	13-3/8“	16”, 14”, 10-3/4”
4	Production casing	9-5/8”	10-3/4”, 7”
Reservoir section	Liner	7”	5-1/2”

When the casing is installed in the well it will be distributed as shown in the figure below.

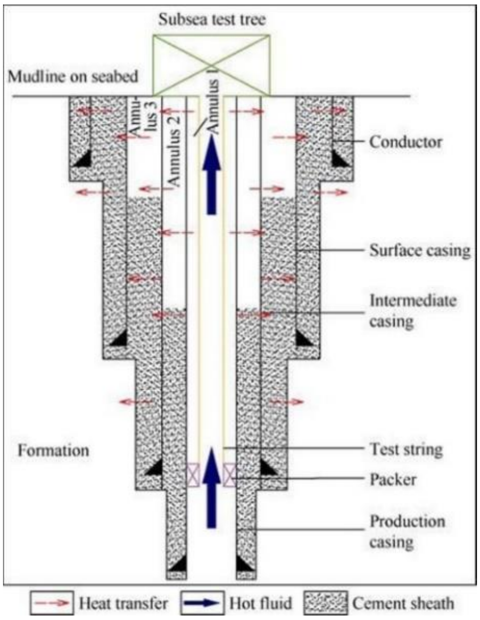

Figure 2: casing program typical deepwater wells (Yang Jin, 2022)

3.1.2 Production tubing

Production tubing is a wellbore tubular used to produce reservoir fluids. Production tubing is assembled with other completion components to make up the production string (Schlumberger, Production tubing, 2022). The production string is the primary conduit through which reservoir fluids are produced to the surface. The production string is assembled with production tubing and completion components in a configuration that suits the wellbore conditions and the production method. An important function of the production string is to protect the primary wellbore tubular, including the casing and liner, from corrosion or erosion by the reservoir fluid (Schlumberger, Production string , 2022)

3.1.3 Drill pipe

Drill pipe is a tubular steel conduit fitted with special threaded ends called tool joints. The drill pipe connects the rig surface equipment with the bottom hole assembly and the bit, both to pump drilling fluid to the bit and to be able to raise, lower, and rotate the bottom hole assembly and bit (Schlumberger, Drillpipe, 2022).

3.2 Subsea installation

In this chapter, the main components installed on the seabed will be presented.

3.2.1 Subsea wellhead

The subsea wellhead system is a pressure-containing component that provides a means to hang off and seal off the casing used in drilling the well. The wellhead also provides a profile to latch the subsea BOP-stack and drilling risers back to the floating vessel. In this way, access to the wellbore is secured in a pressure-controlled environment. The subsea wellhead system is located on the ocean floor and must be installed remotely with running tools and drill pipe (PetroWiki, 2022).

3.2.2 Xmas three

A subsea Xmas tree and subsea wellhead are separate components, which should not be mistaken as the same equipment. The Xmas tree is installed on top of the wellhead. A subsea Xmas tree is a stack of valves installed on a subsea wellhead to provide a controllable interface between the well and production facilities. It is composed of a variety of valves, which are used for testing, servicing, regulating, or choking the stream of produced oil, gas, and liquids coming up from the well below. Different types of subsea Xmas trees may be used for either production or water/gas injection (Tawekal, 2022). Well intervention or drilling operations can be performed without a Xmas tree.

There are different types of Xmas trees with variations depending on the design pressure and design temperature. Independent of this, there are two main categories of Xmas trees, vertical and horizontal Xmas trees. In the following sections, the difference between these categories will be presented.

3.2.2.1 Vertical xmas tree

Vertical Xmas trees have the master valves located above the tubing hanger and all the valves are stacked vertically. The production and annulus bore lays vertically on the body of the tree. Since the tubing hangar rests on the wellhead, the Xmas tree can be recovered without having to recover the downhole completion. This type is generally applied in subsea fields due to its flexibility of installation and operation (Crumpton, 2022). In Figure 3 a cross section of a vertical Xmas tree is presented.

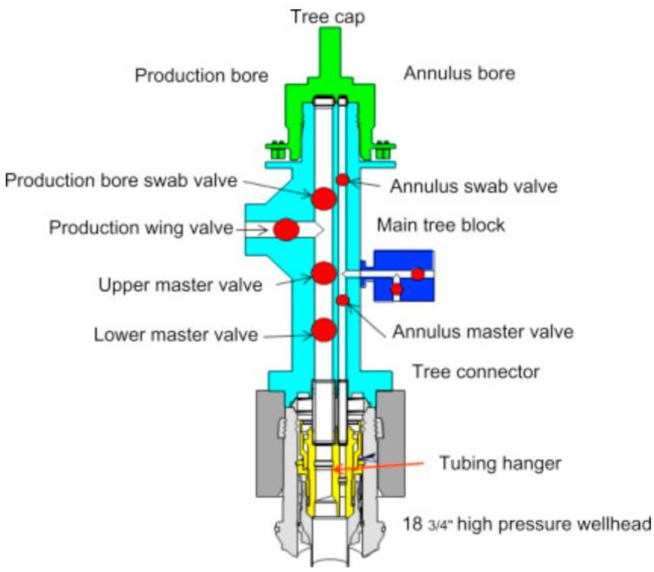

Figure 3: Vertical xmas tree (Crumpton, 2022)

3.2.2.2 Horizontal xmas tree

In contrast to a vertical Xmas tree, the valves of a horizontal Xmas tree are located on the lateral sides of the horizontal Xmas tree. This allows for easy well intervention and tubing recovery. Therefore, this type of subsea Xmas tree is very feasible for the wells that need many interventions, in Figure 4 a cross section of a horizontal Xmas tree is presented. The tubing hanger is installed in the tree body instead of the wellhead. Consequently, the tree is installed onto the wellhead before completion of the well (Tawekal, 2022).

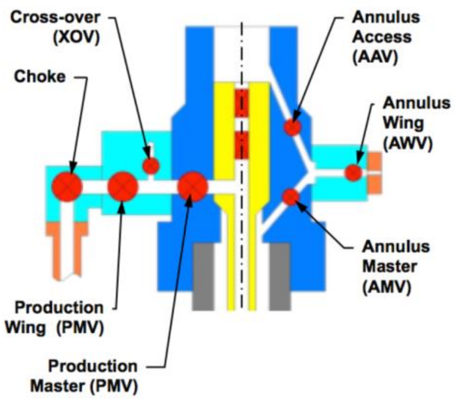

Figure 4: Horizontal xmas tree (Subseapedia, 2022)

3.2.3 Template

Subsea wells may be installed individually, in clusters, or on a template where the reservoir fluids from all the wells are channelled to a manifold that is tied back to a host platform. Often wellheads and wet tress are designed as “diver-less” and more recently “guideline-less” because they can be installed, maintained, and repaired either by remote control using equipment that does not need guidelines or tools that are wire guided from a vessel. A multi-well template offers several cost saving measurements compared with individually installed subsea wells. One example of this can be less sailing time for vessels since it is possible to work in several wells at the same location. (PetroWiki, 2022).

3.3 Blow out preventer

A BOP (Blow Out Preventer) is a large, specialised unit used to prevent an oil spill from occurring. It works like a valve to close an oil well, similar to a plumber closing a valve in a pipe. The BOP is located at the top of the well near the seabed and surrounds the pipe or drill string, which passes through it. The fact that the BOP surrounds the pipe and stays in place throughout the drilling operation means that it can be used at any time to shut in or seal off the well.

The BOP is deployed from the rig and installed on the well during the early stages of well construction. It remains in place during exploration activities, serving as a mechanical barrier that can be activated to seal off the well and isolate it from the rig or sea. Once activities on the well are complete, the BOP is retrieved back to the rig to be used for the next well. The BOP can shut in the well in minutes. If activated, the blowout preventer will automatically close hydraulic rams and activate specialised seals against the drill string to seal the bore. If this does not work properly, there are other rams which can completely cut through the drill string to seal the hole. Blowout preventers are proven to be highly effective in ensuring well safety (Equinor, 2022).

The BOP typical involves the components: Wellhead connector, BOP-body including share and casing ram, annular BOP, flex-joint, and riser adapter. In the following subchapters, a brief introduction to the main components will be presented. It will only be presented a summarised version in this report, for more detailed information it is recommended to look into the manufactures information sides. In Table 3: Overview of BOP components, and functions is presented.

Table 3: Overview of BOP components, and functions

Name	Function
Wellhead connector	Remotely connect the BOP stack onto the wellhead and to connect the LMRP onto the BOP stack. The wellhead can be located directly on the seabed or on top of an xmas three.
Casing ram	Will close around the drill pipe or production tubing and provide a seal between the outside of the drill pipe and wellbore. Does not restrict flow inside the drill pipe or production tubing.
Sealing ram	Does not have an opening for pipe or tubing, can close off the well when the bore is empty.
Blind shear ram	Will cut drill pipe or production tubing to close off well
Annular BOP	A large valve used to control wellbore fluids. Involves a sealing element that is mechanically squeezed inward to seal wellbore. Can seal different diameters and equipment like drill pipe, drill collar, drill pipe, casing or tubing. (Schlumberger, Oildield Glossary, 2022)
Flex-joint/Ball-joint	As the rig or vessel to some extant moves around on the surface, the marine risers will move around. To compensate for this motion a flex-joint or ball-joint is included in the BOP. Can also be included on the top end of the marine risers to allow for more movements.
Riser adapter	Is a cross-over between the interface of the BOP-stack (most commonly API-flanges or clamps) onto the interface of the marine riser joints.
Failsafe valves	Are connected to the kill and choke lines of the marine risers. Used to transport slam or mud in and out of well.

3.3.1 Wellhead connector

The design of a subsea wellhead connector is different depending on the different manufacturers. However, the most common connectors have a few design features in common. They all have hydraulic actuation with close and open chambers, the area difference areal difference between close and open is exposed to seawater, and the connector is self-locking by internal friction (Simulationx.com , 2022).

In Figure 5 an illustration of a wellhead connector can be found. When the connector is pressurized through the close port, the segment is moved downwards, and creating a seal around the wellhead. When pressurized through the open port, the areal around the segment increases, the segment is moved upwards, loosening the connector from the wellhead.

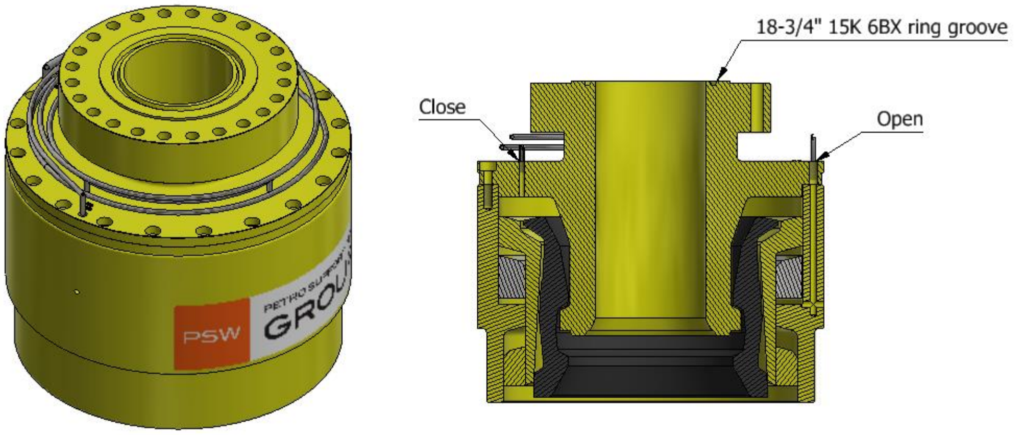

Figure 5: Illustration of H4 wellhead connector. (PSW Technology)

3.3.2 Ram BOP

There are several different versions of a ram BOP, the most common design includes a body, hinges, side outlets, hydraulic connections, and bonnets in different configurations. The bonnets are connected to the main body through the hinges.

The hinges have the function that the bonnets also called doors can be opened. This is typically performed with periodic maintenance or inspecting, in addition to changing the ram block depending on the dimensions of the equipment inside the BOP. There are several different variations of hinges, depending on the manufacturer. One of the designs is that the hinges rotate around the vertical axis, as shown in Figure 6, there are also designs where the hinges are moved parallel with the BOP body.

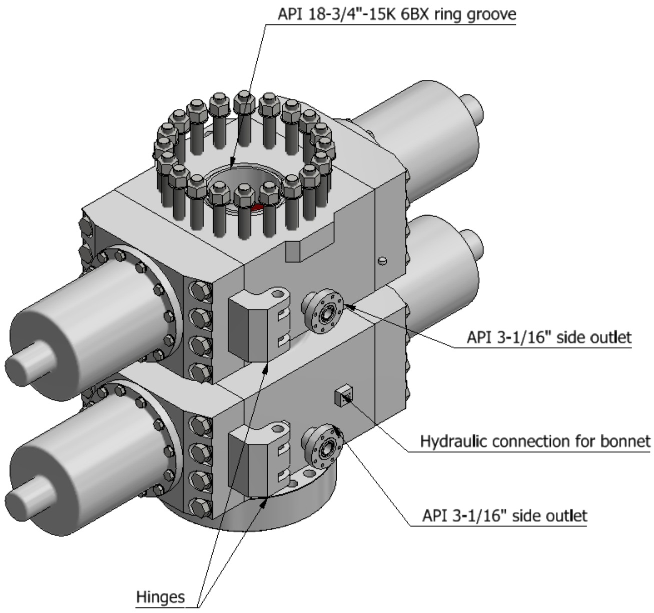

Figure 6: Illustration of typical ram BOP (PSW Technology)

There are two different categories of ram blocks used in a BOP, casing rams, and shearing rams. As the names indicate, the casing rams have the function of sealing the main bore of the BOP around a drill pipe, or production tubing. The shearing rams have the function to cut off the object inside the ram BOP, to seal off the well.

The ram blocks are operated with hydraulic inside the bonnets. Traditionally threaded connections have been used to move the blocks towards the center of the main bore. With subsea, and more modern BOP it is more common that the blocks are moved with hydraulic pressure. As shown in Figure 7, there is a piston that could be moved, depending on which side of the piston is pressurized. During normal operation, the piston would be fully extracted, and the main bore will be completely free. If there is a need for sealing of the well, it will be applied pressure on the outside of the piston, and the ram block is moved into the center.

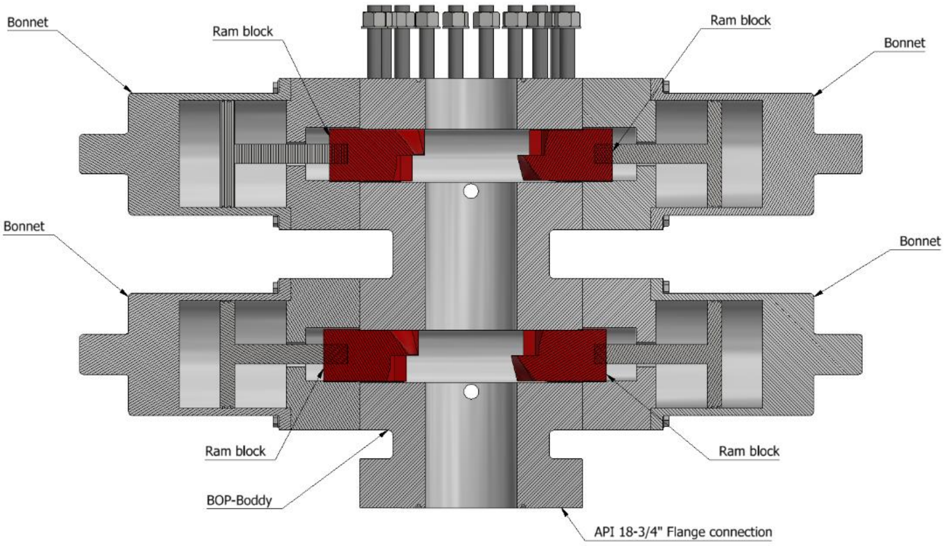

Figure 7: Illustration cross-section of typical BOP. (PSW Technology)

3.3.3 Annular BOP

An annular BOP shall be able to create a seal around all pipe dimensions (casing, drill pipe, production tubing) that could be found in the well. The annular is operated by a pressurizing the segment, leading the segment to deform around the current object inside the main bore. By regulating the pressure applied, the force from the segment on the object can be adjusted. If necessary, the object can be moved while the segment is activated, hence the annular can be used as a working tool during well interventions. If a kick from the well should occur, the annular is normally closed first, if the annular starts leaking the ram BOP is activated (Paaske, 2022).

Annular BOP consists of two main components, the body, and the segment. When the annular is pressurized through the primary lock port in the body, the segment is compressed by interfering with the oval face on the inside of the body, the segment then creates a seal around the object in the main bore. When the annular is pressurized through the primary release port, the segment is moved away from the oval face, releasing the seal around the object in the main bore. The annular BOP is placed between the ram BOP and flex-joint with the API flange connections. A simplified illustration of an annular BOP can be found in Figure 8.

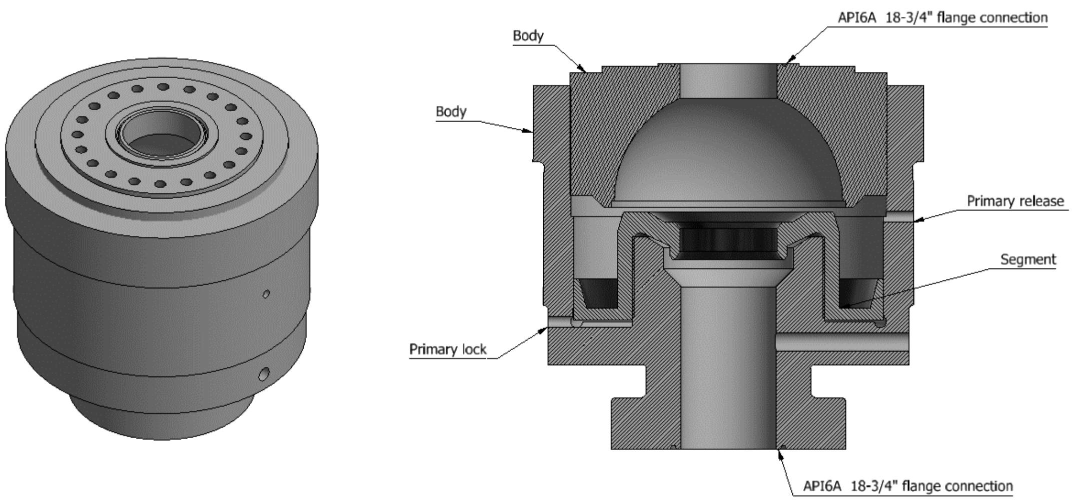

Figure 8: Illustration of annular BOP (PSW Technology)

3.3.4 Flex joint

The rig or vessel performing an operation inside a well needs to stay stable over the wellhead, commonly by the usage of a dynamic position system. Anyhow, deviations of the centre line between the two facilities can occur. To counteract this deviation, a flex joint is installed in the BOP. A flex joint shall compensate for the horizontal movement, so the marine riser is not damaged.

Normally one flex joint is installed in the BOP, and one right under the drill floor on the semisubmersible. In areas with strong underwater currents, it is normal to have an intermediate flex joint in addition to these. A flex joint is designed so it can cooperate a deviation of 10deg on the centre line, and it has an internal seal ensuring no well fluid is released into the ocean. In Figure 9 an illustration of a flex joint is presented.

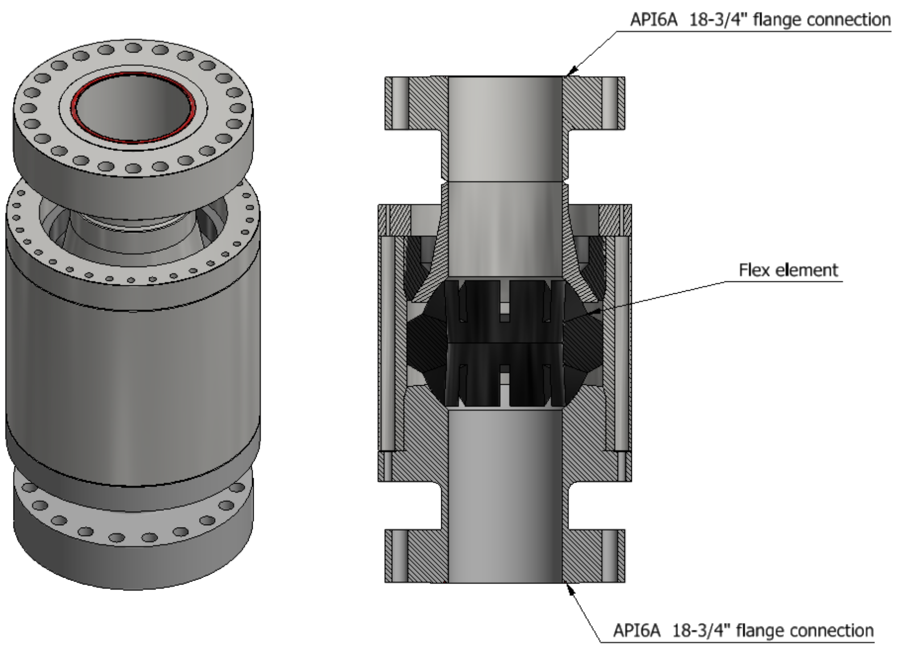

Figure 9: Illustration of flex joint. (PSW Technology)

3.3.5 Riser adapter

A riser adapter is the component placed at the top of a BOP-stack and has the purpose to connect the BOP with the marine riser joints. The design of a riser adapter is depending on the design of the BOP and the design of the marine riser joints. In Figure 10 a riser adapter with a transition between a typical riser flange and an API 6A flange.

From Figure 10 it can be seen three different connections marked with “kick-out”. The kick-out subs connect the kill and choke lines from the marine risers to the BOP, from this point it continues in flexible hoses to the fail-safe valves and pipes, and into the ram BOP. The reason for using flexible hoses is so the flex-joint can move freely around the vertical axis. The booster kick-out is where the booster line from the marine riser is connected to the main bore. Between the marine riser and riser adapter, there will be attached a booster valve, this is not illustrated in this figure.

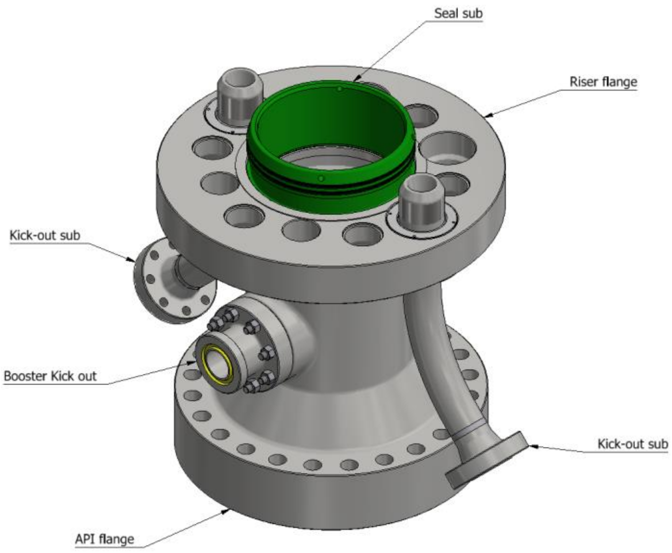

Figure 10: Illustration of riser adapter (PSW Technology)

3.3.6 Fail safe valves

The hoses from the riser adapter, described in chapter 3.3.5 are connected to hard piping on the BOP. The lines are used to circulate slam in and out of the well. The slam is transported from the rig down to the BOP through the kill line and transported from the well to the rig through the choke line (Yuldashev, 2022). In Figure 11 a typical fail-safe valve setup are illustrated. In Figure 12 it is illustrated how the fail-safe valves is connected to the ram BOP.

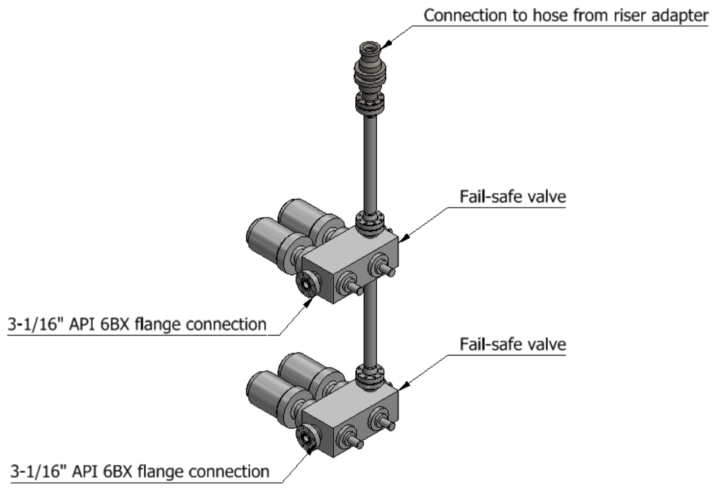

Figure 11: Illustration of fail-safe valve (PSW Technology)

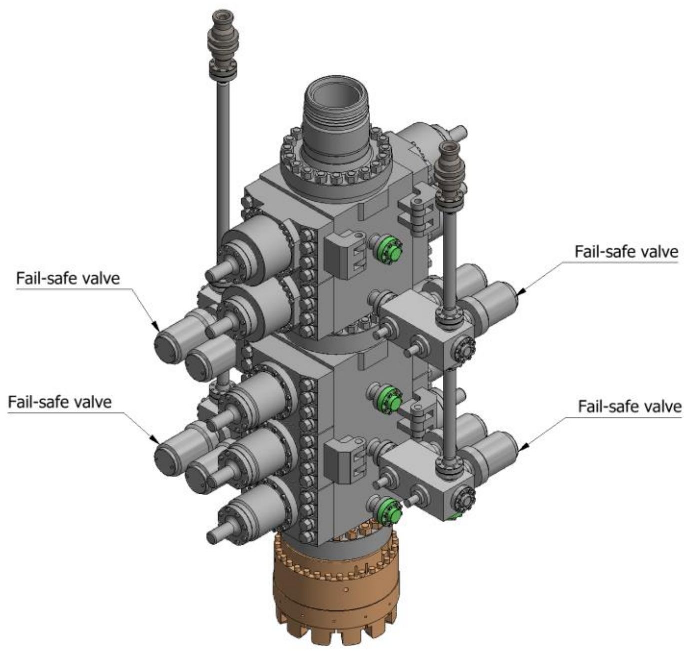

Figure 12: Illustration of BOP stack with fail safe valves. (PSW Technology)

4 Regulations and laws

In this chapter, the core of laws and regulations impacting the theme of PP&A, and the designing of a BOP will be presented. The information is collected from different standards, and only the information found as key requirements are included in this chapter. Therefore, the PP&A operation and designing of BOP is depending on but are not limited to the information presented in this chapter.

This research project origins from the requirement set in NORSOK D-010, which states that permanently abandoned wells shall be plugged with an eternal perspective taking into account the effects of any foreseeable injection, drainage, chemical, and geological processes. The eternal perspective with regards to the re-charge of formation pressure shall be verified and documented extending until formation pressure flattens and covers foreseeable uncertainties (NORSOK-D-010, 2004).

For designing a well control system, there are several standards that could be followed, deepening on the specification and usage. If the equipment shall be a drill through equipment or a part of a production barrier. The different standards that could be used for designing a BOP are DNV-OS-E101, ISO 13628-7, and NORSOK D-010.

From DNV-OS-E101 it is defined that a BOP subsea stack shall as a minimum consist of the following:

- One bag-type annular preventer
- Two shear rams, where at least one is a blind shear ram
- Two pipe rams
- Choke/kill line valves
- Wellhead connector
- Riser connector for Mobile Offshore Drilling Units (MODUs)

The arrangement of pipe rams should allow two rams to close around the drill pipe and not be hindered by the tool joint (DNV-GL, 2018).

In ISO 13628-7 it is defined that the number of BOP rams or shearing valves used in a WCT-BOP may vary depending on the design of the closure device and purchaser requirements. The TCT-BOP shall as a minimum include the following valves:

- An upper bi-directional isolation valve in every through-bore
- A shearing valve or ram in any bore that will have coiled tubing or wireline equipment (or any other tool/device) in the bore that can not be withdrawn from the bore during an emergency shutdown

Shearing/cutting devices may shear in either a single shear or double shear manner. A double shear device will leave a slug of coiled tubing or wireline behind when activated. In such cases, the system shall be designed to accommodate the spent slug. (ISO13628-7, 2006)

In NORSOK D-001 it is defined that a BOP subsea stack shall as a minimum consist of the following (NORSOK-D-001, 1998):

- One annular preventer
- One shear ram preventer
- Two pipe ram preventers
- Minimum of one choke like outlet
- Minimum one kill line outlet
- One wellhead connector
- Minimum two manual gate valves
- Minimum two remote hydraulic operated valves

For this research project, it is worth notating the difference ram requirements set from the different standards. This will be a key parameter for the discussion presented later in this report.

API 16D gives the basis for several operational requirements for a BOP, such as the main accumulator system shall be designed such that the loss of an individual accumulator or bank, or both, does not result in more than 25% loss of the total accumulator system capacity. Bladder and float type accumulators shall be mounted in a vertical position. The pre-charge pressure for bladder type accumulators should be greater than 25% of the system hydraulic pressure.

API 16D also determine the subsea control system shall be capable of meeting the following response times:

- Close each ram BOP in 45 seconds or less
- Close each shear ram in 45 seconds or less
- Close each annular BOP in 60 seconds or less
- Unlatch the riser (LMRP) connector in 45 seconds or less
- Choke and kill valves shall not exceed the minimum observed ram close response time

If multiple circuits are provided for operations of the above functions each circuit shall be capable of meeting the response time.

5 Initial ideas

In this chapter, there will be presented some different ideas for how the permanent plug and abandonments operation can be performed. The ideas presented here are initial, and there can be aspects of the ideas not covered by this presentation. It will only be presented with a brief description of the idea. Later in this report, the different ideas will be discussed, and the ideas will be considered both from the aspect of written literature and the interviews performed.

5.1 Using existing BOP

When looking into a problem, the easiest solution will always be to use an existing component. Hence the idea to use a BOP that already is in use on the NCS. The concept of using an existing solution removes the need for new designs and solutions.

5.2 Using existing components to create a lighter BOP

Another version of using existing components is to investigate on a component level what are the components that are nice to have, and must have, to ensure the well integrity. If several of the components on a traditional BOP could be removed, this gives the possibility to reduce the weight significantly. If the assembly of components is designed light enough, a possibility to move the operation from a semisubmersible rig, over to an offshore supply vessel could occur, this gives a possible enormous economic benefit compared with traditional PP&A operation. These issues will be discussed later in this report.

5.3 Transport underwater

If the wanted outcome is to have a solution that could move the operation from a rig over to a vessel, it is important to identify the reasons why this is not already done. One of the main reasons is that the lifting capacity onboard a typical vessel does not have the lifting capacity to handle the BOP. As an example, DOF Geoholm has a lifting capacity of 100t (Dof.no, 2022) and will not come close to lifting a BOP with a weight of 200-400 metric tons. As an initial idea, this could be handled with the BOP not being handled by the vessels crane capacity. To perform this, the BOP could be transported from shore to the offshore location, underwater, removing the need for airlifting operation.

5.4 Buoyance

To reduce the weight working on the wellhead, a buoyance element could be installed either on the BOP itself or above. Adding a 100t buoyance would require some volume, but would reduce the weight on the wellhead. As an initial idea, it is possible to think of four buoyance buoys being attached in the corners of the BOP frame.

5.5 Jacks on guideposts

As interview object 1 introduced: One method that has been used for wellheads not capable to withstand the forces applied to form a typical BOP, is to install jacks on the four guideposts on interfering between the BOP and the template (Object-1, 2022). As an example, if the BOP is connected to the wellhead, and the jacks combined lift force is 100t, the weight on the wellhead is reduced by 100t.

5.6 Suction anchors around the wellhead

To increase the area impacted by the bending moment caused by horizontal forces on BOP and marine risers, there has been testing of suction anchors being installed over and single standing wellhead (Neodrill, 2022). The bending moment and weight of BOP are then impaction on the total volume of the suction anchor, and not the wellhead itself. This method is limited to single standing wellheads.

5.7 Wire from BOP to template

Another method used to reduce the bending moment working on the wellhead is to install tensioned vires from the corner of the BOP down to the template (Object-1, 2022). This leads to the bending moment working on the total volume of the template, and its anchors, and not only the wellhead. This method is limited to wellheads mounted on a template.

6 Data from interviews

As described in the introduction of this report, there has been used two methods for collecting data for this research project. The first method was a literature study, the outcome of this could be found in the chapters 2 to 4. The other method used is a qualitative interview, and in this chapter, some of the data collected from the interviews will be presented. In chapter 7 the authors thoughts and considerations will be included in the evaluation. This evaluation will create the basis for further work in this research project.

6.1 History and Criticality

To start the interview it was asked a question, with the purpose to expose what the interviewee would describe as the most critical part of a typical operation from a rig is in its location above a wellhead and until the BOP is connected to the wellhead. The first question asked was: What do you think of as the most critical part of the operation from the rig is in position over the wellhead, until the BOP is connected to the wellhead?

One of the answers given to this question is: "*The most critical parts of the operation are the running of BOP and marine riser, as there are forces being moved between the running tool and the spider. That the BOP is set to the correct running procedure. This to ensure that there are no pressurized systems on the BOP, that could lead to and disconnect of the lower BOP stack*" (Object-1, 2022).

Another participant answered: *"The most critical part of the operation is when the crown plug is pulled, then the operators need to have trust in the valves installed in the tubing, since there is no backup before the BOP is connected"* (Object-2, 2022).

The last participant answered: *"The most critical part of the operation is running the BOP, as there is a possibility for an unplanned release of the lower stack from LRMP. Can occur if pressure is allowed to build up in the control system."*

Another question from this section chosen to highlight is: Historical the weight of a typical BOP was 100 tons, now it is 300 – 400 tons, what is the reason for the increased weight?

One of the participants answered: *"The requirements for cutting capacity have been increased over the years. The required working pressure have been increased, leading to larger and* *heavier components. The required redundancy has been increased, today it is normal with the yellow and blue pod, acoustic supply and ROV supply leading to four separate control systems."* (Object-1, 2022).

Another answer given is: *"There are several reasons for the increased weight, the number of ram blocks has been increased, the area of use has increased, and the requirements have become stricter. There are several new control systems. Where it previously was common to send the return fluid from the BOP directly to sea, there are requirements to send it back to the tank, this would of course also increase the weight with more piping, and room for the return liquid."* (Object-2, 2022)

6.2 Forces, geometry, and signals

Onwards in the interview, it was asked more specific questions about the limitations to a BOP, in regard to sizing, which forces acting on a BOP, and how the signal is transmitted between the vessel and BOP. The questions were chosen to either confirm or refute the authors understanding of the phenomenon. The answers were fairly similar, so only one of the answers will be presented in this chapter. To see the complete answers, see Attachment B to Attachment D - Minutes of meeting-Object 3.

The first question is: Which limitations surrounding the geometry of a BOP can you think of? *"The footprint of the BOP has geometrical limitations depending on the template. There are limitations in regard to the dimensions of the BOP, so it fits inside the pocket on the template. Large and heavy BOPs can damage the wellhead. If the BOP is too high, it can lead to an increased bending moment on the wellhead"* (Object-3, 2022).

The second question is: How would you describe the forces impacting a BOP when it is connected to the wellhead? One participant answered: *"There is a formidable bending moment applied to the wellhead. Studies have shown that the buoyance element on the marine riser joints creates a larger drag force than expected, increasing the bending moment additionally to the forces that occur from misalignment of the vertical axes"* (Object-1, 2022).

The last question included on this topic is: How would you describe the signals between the rig and the BOP? One of the participants answered: *"Emergency communication is performed* *with acoustic, or by hot stabs and ROV. Normal communication is performed with either MUX-cables and pods, or by a hydraulic umbilical. The hydraulic umbilical is often used in shallow waters, in deep waters the response time is too long"* (Object-3, 2022)

6.3 Other ideas, and comments

The next question presented in this chapter is: Do you have any other ideas than what has been discussed here in this session, or any other questions or comments? The following three answers were given:

"Save weight by placing accumulators on a separate unit.
If the operation is performed with risers, the different flex-joints can give a different magnitude of bending moment on the wellhead. Move the weight from the wellhead to the guidepost, by using jacks. Electrical BOP" (Object-1, 2022).

"One possibility can be to use banding, with wires connected to the top of a BOP down to the template, moving the bending moment from the wellhead to the template. The large disadvantages are time and cost, since it is a complex operation, and requires a rebuild of a BOP. The horizontal forces on the BOP, and marine riser system or similar must be the dimensional limitation for an SSD" (Object-2, 2022).

"Is it possible to reduce the main bore of components? The wellhead connector must be 18-3/4", since most of the wellheads are of this dimension. Anyhow, it could be possible to reduce the main bore diameter for other BOP components. This would reduce the total weight of the design" (Object-3, 2022).

6.4 SSD

A thought experience was performed during the interview, were the participants where asked: Let us assume that an SSD should be built, what would you point out as the most important thing to consider?

The following three answers were given: *"Low weight. Components adjusted to the well pressure. Investigate the possible clients requiring a 15k BOP. It can be stated that this is a* *so small market share, that the design for an SSD should be limited to 5 or 10k BOP. The standard lifetime of BOP components is 20years, with increased maintenance and reduced lifetime, it could be possible to increase the pressure rating for components. One example could be to increase a 5k BOP to a working pressure of 7,5k, to be able to perform PP&A on wells just over 5k well pressure."* (Object-1, 2022).

"Reliability in the control system, and that there is enough cutting capacity" (Object-2, 2022).

"Needs to be designed after established laws and regulations. Should be easy to perform maintenance. Investigate the possibility to build an electrical BOP. With an electrical BOP the maintenance will be very simple, and the possibilities for control increase. The company Electric Drilling Solutions has a solution where the bonnets of a traditional BOP are changed with electrical bonnets, that closes mechanical." (Object-3, 2022).

6.5 Ideas

In this chapter, it will be given a summary of the comments the participants had on the different ideas presented during the interview, the summary is presented in Table 4. The complete answer of each participant will not be presented here, only a summarized version of the combined answers. To see the complete answers, see Attachment B to Attachment D. In chapter 6.5, an evaluation of the different ideas will be presented.

Table 4: Summary of comments on ideas.

Idea	Comment
Using of existing BOP (5.1)	There is a possibility that some rig owners have access to a BOP light enough to perform the operations on wellheads struggling with fatigue.
Using existing components to create a lighter BOP (5.2)	From all the interviewee this is pointed out as a good idea, that there is a marked for on the NCS and by some international
Transport under water (5.3)	To many disadvantages, low sailing speed, no access for maintenance, high risk.
Buoyance (5.4)	Can in a worst case scenario lead to increased bending moment on the wellhead.
Existing solutions (5.5,5.6, 5.7)	None of the existing solutions gives room for the total PP&A operation to be performed with a vessel, costly operations.

7 Evaluation of ideas for further work

In this chapter, it will be evaluated the different ideas presented so far in this report. The evaluation is based on the laws and regulations, data collected from the interviews, and the writers own perspective. The chapter starts with a discussion surrounding each of the different ideas, with advantages and disadvantages discovered through the work with this research project. The chapter rounds up with a conclusion of which of the ideas that will be further investigated in this project.

7.1 Using existing BOP

It is possible to assume that there is a BOP, somewhere in the world, which could be light enough to be used on wellheads struggling with fatigue, and would not withstand the weight of a typical BOP used today. If the solution could be presented where it only is to use a component already existing, this would be an advantage.

As interview object 1 answered the question about why the weight of a BOP has increased through the years: *"The requirements for cutting capacity have been increased over the years. The required working pressure has been increased, leading to larger and heavier components. Their required redundancy have been increased over the last years, today it is normal with the yellow and blue pod, acoustic supply and ROV supply leading to four separate control systems."* Based on this, it will be difficult to find a BOP which still is usable, but not rebuilt to meet todays requirements.

Another aspect is that a BOP used on NCS, will in most cases be designed after NORSOK-D-001 or DNV-OS-E101 which requires: one annular preventer, and two share rams, two pipe rams, giving a total of four bonnets. If a special component is designed for PP&A operations, or other operations not involving drilling of new wells, it can be designed after ISO13628-7, which requires one annular and two share rams. It can be asserted that this reduction will be a significant weight reduction. In addition, the accumulator bottles will most likely be placed on the BOP stack for a typical BOP, for a special design component the accumulator bottles could be placed on a separate structure, removing weight from the wellhead.

It can also be argued that using an existing BOP would not give the possibility to perform the PP&A operation from a vessel, and the total cost would remain the same as with todays methods. This could be a negative parameter to the economical aspect.

7.2 Using existing components to create a lighter BOP

From all the interviews the usage of components from an existing BOP to create an SSD is pointed out to be a good idea, especial for performing PP&A operations. There is also pointed out that the SSD could be used in other well intervention operations, where the requirement from NORSOK-D010, not are needed. For this idea, there are some areas of concern in regard to which laws and regulations should be followed. Normally, when drilling through a BOP, the NORSOK-D010 is the dimensional regulation. As described in the last chapter, the number of rams and bonnets are higher for NORSOK D-010 than for ISO13628-7.

Since there is no drilling operation involved with a PP&A operation, it can be asserted that the operation could be performed with a component that meets the requirements of ISO13628-7. In addition to this, it can be argued that the accumulators installed on a BOP could be moved to a separate component, reducing the weight significantly on the wellhead.

At this stage of the research, the SSD solution gives a clear advantage with the possibility to move the operation from a rig, over to a smaller vessel. It can be challenged that this alone gives the solution a clear advantage compared with the other solutions.

7.3 Transport underwater

The solution with transporting the BOP underwater will lead to significantly operation limitations. This idea has some initial problems, one of these is that the maintenance on the BOP would require the BOP to be transported back to shore. From the authors perspective, it is assumed that there will be some difficulties conserving the insurance of the BOP when it is transported underwater. Another possibility could be to have a rig place the BOP on the wellhead, and then a vessel could connect and perform the PP&A operation.

An operation with the same principle is when a rig jumps between wells, without pulling the BOP to the top site. The BOP is then lifted from the wellhead to a safe height, and the rig moves to a nearby location. This operation has strict limitations in regard to sailing speed and weather. One of the reasons for this is that when the BOP is hanging many meters below the rig, it will be a delay in the movement between rig and the BOP, causing the BOP to be dragging behind the rig. If the speed of the rig is increased, the distance will increase.

Another aspect is that it will not be possible to perform maintenance on the BOP offshore, like an in-between well. If the BOP constantly is underwater, this would mean that the vessel must go back to shore to perform the maintenance. It can be questioned if the savings for moving the operation from a rig to a vessel will be smaller than the extra cost of sailing to shore for every maintenance stop.

7.4 Buoyance

If buoyance were to be placed on the BOP itself, to reduce the weight on the wellhead, it will be several areas of concern. Firstly, it is limited space inside the templates, making it difficult to install an extra volume with buoyance on the BOP. If the buoyance volume is placed above the BOP, it gives in a worst-case scenario, the possibility for an increased bending moment on the wellhead. Since the bending moment is one of the dimensional forces, it can be argued that the solution will not be a satisfying solution.

7.5 Existing solutions

There are several existing solutions that already have been used, both for reducing the weight and bending moment on the wellhead. Common for all the solutions is the fact that they require a complex operation either before, or under the running for the BOP. From the authors perspective, none of the solutions gives the possibility to move the operation over to a vessel. Therefore, it can be argued that none of the solutions presented in chapters 5.5-5.7 is the optimal solution.

7.6 Conclusion of evaluation of ideas for further work

In Table 5 the conclusion from the evaluation of ideas is presented.

Table 5: Conclusion of evaluation of ideas for further work

Idea	Conclusion
Using of existing BOP (5.1)	The solution is not investigated further in this report
Using existing components to create a lighter BOP (5.2)	The solution is investigated further in this report
Transport under water (5.3)	The solution is not investigated further in this report
Buoyance (5.4)	The solution is not investigated further in this report
Existing solutions (5.5,5.6, 5.7)	The solutions are not included further in this report

Based on the evaluation presented in this chapter, with the comments from the interview objects, it is concluded that from this point of the report, the research will go into detail on the idea of building an SSD, designed after the requirements of ISO13628-7. The other ideas presented so far in this report, will not be investigated further in this project. In the following chapters, it will be presented a comparison of different manufacturers BOP components.

8 Comparison of components

In this chapter, it will be presented a comparison of the different components that must be included in an SSD. The main focus of this comparison is the weight of the components. The comparison is performed based on the hypothesis that there is a large difference between the manufacturers, in regard to the weight of the components. The components included in this comparison are wellhead connector, ram BOP, annular BOP, top connection, and fail-safe valves. In this chapter, it will only be presented data and information about the components. In chapter 8.6 the data will be discussed, and other aspects like data from interviews will be implemented.

8.1 Wellhead connector

As described in chapter 3.3 the wellhead connector is used to connect a BOP to the well, making it possible to perform well intervention operations. The standard size of the high-pressure wellhead being used all over the world is 18-3/4". The exemption to this is Brazil where there is a tradition of using 16-3/4" wellheads. The interface profile used for locking the subsea tree or the drilling BOP to the wellhead is today dominated by the standard H4 wellhead profile. (Gundersen, 2022). In the table below, some commonly known wellhead connectors are compared in regard to weight.

Table 6: Dimensional data for wellhead connectors. (GE-Oil&Gas, MRB SHD H4 Connector, 2015) , (Dril-Quip, 2014) , (Cameron, slb.com, 2022) , (OilStates, 2022)

Manufacture	Main Bore	Pressure rating	Component	Weight
GE Oil & Gas	18-3/4"	15K	Shd. Wellhead connector	34 034 lbs
Dril-Quip	18-3/4"	15K	DX-DW Wellhead connector	39 500 lbs
Shaffer	18-3/4"	15K	DX-DW Wellhead connector	36 000 lbs
Cameron	18-3/4"	15K	HCH4 Wellhead connector	25 350 lbs
Cameron	18-3/4"	15K	EVO Collet Wellhead connector	44 902 bs
OilStates	18-3/4"	15K	LynxGrip Wellhead connector	13 900 lbs

8.2 BOP

In this chapter it is presented different types of BOPs from several well recognized manufactures. The main focus of this comparison is to reduce the weight of an SSD. Therefore, the weight and dimensions of the components are the key variables for this comparison. This chapter is limited to presenting the data of each component, the discussion and conclusion of which components to be used will be presented in the following chapters.

8.2.1 Hydril BOP

The Hydril 18-3/4”-15K compact ram BOP is a hydraulically operated ram type BOP as defined in API Specification 16A entitled Specification for Drill Through equipment, third edition, June 2004. The top connection typically is an 18-3/4”-15K API type 6BX studded flange with a BX-164 Inconel ring groove. The bottom connection is an 18-3/4”-15K API type 6BX flange with a BX-164 Inconel ring groove.

The Hydril BOP can be manufactured with different configurations, with both single, double, and triple bonnet configurations. The BOP has two side outlets per ram cavity, one on each side, for connection of choke and kill valves. Each side outlet is a 3-1/16”-15K studded flange with a BX-154 Inconel ring groove. Side outlets not in use are fitted with blind flanges. All surfaces exposed to wellbore fluids meet the requirements of NACE Standard MR-01-75. Inconel weld overlays are applied on the following locations: Ring grooves, bonnet sealing area, seal connector ring and bonnet door, piston rod seal surface, upper seal seat, and ram seal seat. (Manual.no.3131615-04-OM,RevA1, 2007)

The BOP body is drilled to allow mounting of the manifold/hinges on either side, making it possible to install the bonnets so that they swing open in either direction. In addition, the seal seat and wear plate in each ram compartment are field replaceable without removal of the BOP from the stack.

The BOP can be equipped with 22” MPL operators, or 15,5” MPL operators in different configurations. In the tables below, the estimated weight for the different BOP configurations will be presented. The data is collected from GE Oil and Gas Operator’s Manual RAM-1505767-OM Rev A, (GE-Oil&Gas, Operator's Manual RAM-1505767-OM Rev A, 2010).

Table 7: Dimensional data for Compact Hydril BOP (GE-Oil&Gas, Operator's Manual RAM-1505767-OM Rev A, 2010)

Manufacture	Main Bore	Pressure rating	Component	Weight
Hydril	18-3/4”	15K	Triple ram BOP 3x15,5	72 400 lbs
			Double ram BOP 2x22	55 500 lbs
			Double ram BOP 22&15	53 016 lbs
			Double ram BOP 2x15,5	50 634 lbs
			Single ram BOP 15,5	28 159 lbs

8.2.2 NOV-Shaffer

Shaffer’s history in BOP technology began with a cellar gate mechanical BOP and moved into hydraulic operation in the 1950s. Shaffer has three different types of BOPs with a bore of 18-3/4” and a pressure rating of 15K Psi, the NXT, and SL/SLX that could be used for subsea operations. NXT version is the newest, in addition to smaller and lighter than the SL/SLX version. One of the reasons for this comparison is to find the most weight efficient components. Therefore, only the NXT model is presented in this chapter.

8.2.2.1 Shaffer NXT 18-3/4” 15K BOP Assembly

Shaffer NXT BOP systems are unique in providing a means of significantly improving safety and efficiency in the critical path of activity. With the replacement of the door bolts in ram BOPs, National Oilwell Varco has eliminated the time consuming manual practice of using brute force to torque up numerous large door bolts. This has also reduced the weight and height of the BOP to be potential the lightest, and smallest BOP system in the industry. In addition to the elimination of manual labour under time pressure (NOV, 2022).

The NOV 18-3/4 15K NXT BOP comes in three different variations, triple, double, and single BOP, depending on how many ram blocks are connected to the same body. A more detailed description of different types of BOPs can be found in chapter 3.3. In Table 8 the weight of each configuration is presented.

Table 8: Dimensional data for Shaffer NXT BOP (NOV, 2022)

Manufacture	Main Bore	Pressure rating	Component	Weight
NOV-Shaffer	18-3/4”	15K	Tiple ram BOP 3x14”	63 000 lbs
			Triple ram BOP 22”x22”x14”	101 700 lbs
			Tiple ram BOP 3x22”	121 650 lbs
			Double ram bop 14”x14”	46 700 lbs
			Double ram BOP 22”x14”	65 250 lbs
			Double ram BOP 22”x22”	85 100 lbs

8.2.3 Cameron

Cameron delivers complete systems for containing wellbore pressure and diverting formation fluids and gas from the wellhead connector to the manifold system. Cameron BOPs is the most widely used BOP system in the world, which can be applied onshore, offshore on a platform, or subsea. Camron BOP size range goes from 7-7/16” to 26-3/4”, work pressure from 5000 Psi to 15 000 Psi (Schlumberger, 2022).

Cameron has two types of BOP of the 18-3/4”-15K specification, that can be used for subsea operations, EVO compact BOP, and the TL-type BOP. In the following subchapters, some key information about these types will be presented.

8.2.3.1 EVO Compact Offshore BOP 18-3/4” 15K

Introduced in 2006, the EVO compact, ram-type BOP combines engineering simplicity, footprint, operational savings, and superior reliability for improved performance in a demanding drilling environment. The EVO BOP design achieves a shorter, lighter footprint than standard BOPs, requiring fewer accumulator bottles. The bonnets, pistons and seals are field proven. Al surfaces are according to NACE, and API Spec 16A. (Schlumberger, EVO RAM-Type BOP, 2022). In Table 9 the weight of the different EVO compact configurations is presented.

Table 9: Dimensional data EVO Compact BOP (Cameron, slb.com, 2022)

Manufacture	Main Bore	Pressure rating	Component	Weight
Cameron	18-3/4”	15K	Double without tandem boosters	58 200 lbs
			Double with tandem boosters	62 800 lbs
			Single without tandem boosters	32 900 lbs
			Single with tandem boosters	36 500 lbs

8.2.3.2 TL Offshore Ram-Type BOP 18-3/4” 15K

The TL type BOP integrated design characteristics of the most commonly used BOPs into a lighter product. The TL-type BOP side gate can be mobile, which is a breakthrough in constant drilling time and deduces the heigh requirements. In addition, using the bonnet seal reduces maintenance time and cut off the drill pipe (Cameron, TL-Offshore ram-type BOP, 2022) in Table 10 the dimensional data for this ram BOP is presented.

Table 10: Dimensional data TL-type BOP (Cameron, TL-Offshore ram-type BOP, 2022)

Manufacture	Main Bore	Pressure rating	Component	Weight
Cameron	18-3/4”	15K	Double with manual lock screws	55 440 lbs
			Double with ST locks	74 800 lbs
			Double with ram locks	68 400 lbs
			Double with tandem boosters and ST locks	70 025 lbs
			Single with ST locks	39 150 lbs
			Single with ram locks	35 950 lbs
			Single with tandem boosters	44 650 lbs
Cameron	18-3/4”	10K	Double with manual lock screws	42 000 lbs
			Double with ST locks	60 500 lbs
			Double with ram locks	49 750 lbs
			Single with ST locks	26 450 lbs
			Single with ram locks	25 750 lbs
Cameron	18-3/4”	5K	Double with manual lock screws	33 600 lbs
			Double with tandem boosters	39 300 lbs
			Double with ram locks	38 300 lbs
			Single with manual lock screws	17 500 lbs
			Single with ram locks	20 050 lbs
			Single with tandem boosters	20 500 lbs

8.3 Annular

It can be asserted that the most commonly manufactures of annular BOPs intended for subsea usage, are Hydril, Cameron, and Shaffer. In the table below it is shown the weight of tree typical annular BOP. The reason that the comparison is limited to these three, is that the working pressure is chosen to be 10k psi. If the pressure rating were set lower, several manufacturers could be included.

Table 11: (Cameron, DL High-pressure annular BOP, 2022) , (Hydril, 2003) (Drillingmanual.com, 2022)

Manufacture	Main Bore	Pressure rating	Component	Weight
Hydril	18-3/4”	10K	GX 18-3/4” 10K Annular BOP	38 580 lbs
Cameron	18-3/4”	10K	DL Annular BOP	29 500 lbs
Shaffer	18-3/4”	10K	Spherical BOP	57 050 lbs

8.4 Mandrel or Riser adapter

The transaction between annular BOP and the components over is not something that could be determined without further knowledge. If the operation is to be performed with marine risers, the transaction would need to involve a riser adapter. The design of the riser adapter would be relying on the risers that should be used since there is a large difference between the connections of the different riser joints.

For the sake of this research project, it is assumed that the operation is preferred performed riser-less, with an H4 mandrel as a top connection. If the operation is to be performed with marine risers, the riser adapter would need to be customer-specific.

In Figure 13 it is shown an illustration of a typical mandrel. The mandrel can have some variation in weight, due to the different lengths, this variation is evaluated to be relatively small. The mandrel shown in Figure 13 weighs approximately two metric tons, or 4409 lbs, this will be used for the discussion in the following chapters.

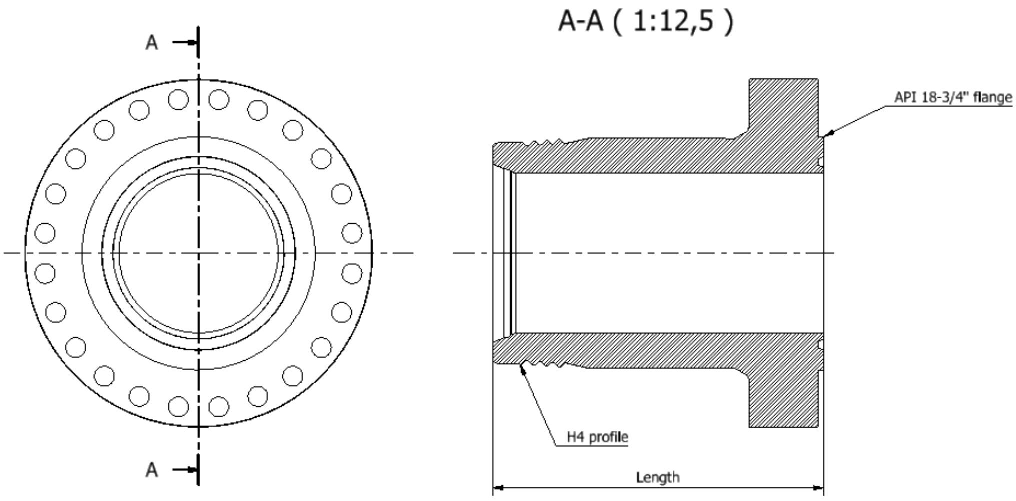

Figure 13: Illustration of mandrel

8.5 Fail safe valves (Kill/Choke)

There is a relatively small variation in the weight of fail-safe valves. With a large certainty, it can be argued that it is possible to design the fail-safe system with a weight between four-six metric tons, or 8818-2 13 227lbs. The potential weight saving is limited and could be considered to not have an impact on the overall result. Hence, it will not be performed a more thorough analysis of this system in this report.

8.6 Electrical Subsea & drilling

The company Electrical Subsea & Drilling are in the developing stages of a total electrical BOP. The information available for this product is limited. But they present on their web pages that the total weight saving on the BOP could be up to 493 834 lbs. To reduce this weight, the accumulator bottles are removed, as there is no need for the liquid in an electrical BOP, the control pods are removed, hydraulic distribution systems are removed, and the weight of the main components is reduced. The detailed information on this design is not available. Therefore, it is not compared directly with the other components in this chapter.

9 Discussion

In this chapter, it will be presented a discussion on surrounding the data presented in the previous chapters. The discussion starts with the basis for a design specification before the main components of the SSD are discussed, followed by a discussion on the economic and environmental aspects of the PP&A operation. The discussion will be the basis for a conclusion presented in the next chapter.

9.1 Design specification

One of the areas that must be discussed is the need for an 18-3/4" main bore. Through the interviews performed for this research, it has been suggested to use a ram BOP with a smaller main bore. Previously in this report, it has been presented that one of the reasons why modern BOPs are heavier than older ones are higher cutting requirements, and higher well pressures. It goes without saying that a BOP with a main bore of 10" will not weigh the same as a BOP with an 18-3/4" main bore. Therefore, it can be stated that using a BOP with a smaller main bore, would reduce the weight of an SSD. On the other hand, one of the reasons for an 18-3/4" main bore is that the equipment installed inside the well will require a main bore of these dimensions to be removed.

Another aspect that needs to be discussed is the need for a 15k BOP. It can be challenged if the pressure rating could be lowered to 10k or even 5k. At this stage of the discussion, it can be assumed that reducing the pressure rating, will reduce the weight of the ram BOP component. At a later stage of the discussion, this issue will be discussed more in detail. Interview object 1 stated, that one of the reasons many rig owners chose to have a 15k BOP are so the rig could be used for most of the jobs on the NCS. It can be stated that the number of wells with 15k well pressure is so low, that an SSD should be designed as a component for a lower pressure rating, and have a separate component for the 15k wells. Regardless of the pressure rating of the ram BOP, there will be components that must have a pressure rating of 15k. One of these components is the wellhead connector, which should be an H4-type because this is the most common wellhead on the NCS.

As a desktop study, it could be thought that a 10k SSD is sufficient to perform 70% of the PP&A operations on the NCS. The company building the SSD must then consider if designing the SSD to perform the last 30% is economically responsible, or if the company should not offer the well control equipment for these wells. Making a component that is an optimal solution for the 70%, and one for the remaining 30% could be beneficial, in regard to operation, weight, and loads on the wellhead. It is important to note that this is only a thought example, the numbers used for this example have not been verified.

9.2 Design specification main components

In this chapter, it will be presented a discussion surrounding the different components that must be included as main components in an SSD. The discussion with be based on data presented in the previous chapters of this report, data collected from the interviews, and the writers own perspective.

9.2.1 Wellhead connector

Based on the comparison presented in chapter 8.1 where OilStates LyncGrip wellhead connector and a standard HCH4 wellhead connector produced by Cameron, are the lightest components, whit the weights of 13 900 lbs and 25 350 lbs. The heaviest component included in this comparison is the EVO collet wellhead connector produced by Cameron, which weighs 44 902 lbs. The weight reduction by using a LynxGrip compared with an EVO is 70% or 31 020 lbs.

There are some uncertainties regarding the weight of the LynxGrip connector if it has a hub, flanged, or studded connections. This could possibly lead to some reduction or adding of weight. On the other side, it is clear that a potential addition of weight would not be in the range of getting close to the next connector in this comparison.

From the writers perspective, and data collected for this project there are no clear indicators as to why an OilStates components should not be used. Therefore, it can be argued that the OilState LyncGrip connector should be used. From the interviews Cameron is mentioned as a good product when it comes to maintenance, it can be stated that the maintenance of a wellhead connector is limited, and should not influence the final decision. On the other hand, it will always be some maintenance, and it can be challenged that it should always influence the final decision.

9.2.2 BOP

When it shall be discussed which ram BOP that should be used in an SSD, there are several questions that need answers before making a qualified conclusion. The first question is how many ram blocks shall be used. As mentioned, several times throughout this report, there are two different regulations that could be used for qualifying the SSD. If the SSD is qualified as a BOP after NORSOK regulations, it will require four ram blocks, meaning it requires four bonnets. To meet this requirement, it could be used one triple ram BOP and one single ram BOP, two double ram BOPs, or four single BOPs. Taking Hydril BOPs for comparison, the triple combined with one single will weigh 100 159 lbs, two double will weigh between 101 268-111 000 lbs depending on the bonnet configuration, and four singles will weigh 112 636 lbs.

The other regulation that could be used is ISO13628-7. The requirement using this standard will be two rams, hence two bonnets. Using the same weights as in the previous example with Hydril ram BOPs, it will weigh between 50 634 lbs-55 550 lbs for a double ram BOP, and 56 318 lbs for two single ram BOPs. Based on this it is clear that a double ram BOP weighs less than two single ram BOP. Hence, it could be argued that a double ram BOP should be used if the SSD is to be designed in accordance with ISO13628-7. Another argument for this is that the height of a double BOP will be lower than two single BOPs. For the sake of this discussion, it will from this point out be origin as if the SSD is to be designed after ISO13628-7. To compare the bonnets, it will be based on a minimum requirement of one super share bonnet. For Hydril and NOV this will be a 22” bonnet, and for Cameron, this will be a bonnet with tandem boosters.

When the origin of discussion is defined as above, it will be natural to think that a double ram BOP should be the most favorable. Looking into the different manufacturer ram BOPs presented in this report, with a pressure rating of 15k psi, and a main bore of 18-3/4”, Hydrils double ram BOP with one 15” and one 22” bonnets, weighs 53 016 lbs. NOV Shaffer double ram BOP with one 22” and one 14” bonnet weighs 62 250 lbs. Cameron has two different BOP types that meet the requirements set for this discussion. The lightest of these is the EVO compact BOP, and since this discussion is based on weight, only this type will be included. The EVO compact double ram BOP with tandem boosters weighs 62 800 lbs.

By using Hydril double ram BOP it will weigh 9784 lbs (15%) less than the Cameron BOP, and 12 234 lbs (18%) less than the NOV Shaffer double ram BOP. Hence it can be argued that the Hydril double ram BOP should be used.

It can be questioned if the comparison between Hydril and Cameron is not on even grounds, as the Cameron BOP includes two tandem boosters when the requirement set for this discussion was a minimum of one tandem booster. On another side it can be found that the Cameron BOP without tandem boosters weighs 58 200 lbs, this is still 9% more than the Hydril double ram BOP. Therefore, it can be asserted that this deviation from the discussion basis does not impact the overall result.

Another thing that could impact the decision of which ram BOP that should be used in an SSD is how cumbersome the maintenance of the different manufacturers is. From the data collected for this research project, Cameron is pointed out as a manufacturer of components easy to work on. On the other side, it can be argued that it is not collected enough data on this issue, to make a qualified decision.

As presented previously in this report, the development of an electrical BOP has begun. How far away we are from the first rig on the NCS, using an electrical BOP is difficult to determine. Looking at a traditional development phase, the developer and customer often have a different timeframe in regard to when the product is ready for usage. Where the developer often would say that the product is just around the corner from launching, the customer is more sceptical and would wait for the product to be fully launched. Based on this it could be argued that an electrical BOP should not be considered, since the technology is not ready at the time of this research project. On another note, it is clear that an electrical BOP offers an advantage in the main problem of PP&A operations, the loads applied to the wellhead by the BOP.

The needed pressure rating is also something that must be discussed when designing an SSD. Based on the data collected in this report, it is difficult to imagine that the 15k design pressure will be needed on most of the wells on NCS. To repeat the argument, if a 10k SSD could be used on 80% of the PP&A jobs, it could be economically beneficial to make an SSD for 10k, and not get involved in PP&A operations on wells with higher well pressures. If the Cameron ram BOP used in the previous example is changed with a 10k ram BOP, the weight will be reduced from 62 800 lbs to 42 000 lbs. Mark that this weight is without tandem boosters. If the tandem boosters weigh 5 000 lbs, this means the 10k ram BOP will be approximately 15 000 lbs lighter than the 15k ram BOP.

Another approach to this thought is that the 10k BOP is regularly tested to 15k. Therefore, it can be asserted that the components are capable to handle the pressure, at least a given number of times. An interesting idea could be to class up a 10k ram BOP to a 15k ram BOP, as this would give a significant weight reduction. Measurements for making it possible could be increased maintenance, shorter class periods, and logging of pressure. it could be possible to stay that the BOP could be used for a period of time, as long as the total number of times it sees pressures over design pressure is below a given number. This of course would be a concept that must involve the Original Equipment Manufacturer (OEM).

It is possible to take this idea one step further, if the SSD is designed for a maximum well pressure of 10k psi, this idea gives room for thinking of using a 5k ram BOP. Looking at Cameron ram BOP, it can be found that a double 5k ram BOP weigh 20 500 lbs. this is 50% of the 10k BOP, and 33% of the 15k BOP. This discussion is limited to one example for manufacture. Anyhow, based on this example it could be assumed that several of the other manufacturers BOPs would follow the same pattern, and argued that this would be an interesting topic to investigate further with the OEM.

9.2.3 Annular

Of the annular BOPs considered in this report, the Cameron DL annular BOP is the lightest component with 29 500 lbs. The heaviest component included in this report is Shaffer spherical BOP with 57 050 lbs. By using a Cameron annular BOP instead of a Shaffer BOP, it could be saved the weight of 27 550 lbs, or 52%. From the interviews, Cameron is mentioned as a good product when it comes to maintenance. This combined with the fact that this is the easiest component in this comparison gives the foundation for the argument that the Cameron DL annular BOP should be used further.

9.2.4 Top connection and fail safe valves

As discussed in the comparison of components in chapter 8, the weight contribution from the fail-safe valves, and top connection is relatively small assuming that the top connection is a standard HCH4 connector. Hence there can be argued that there is no need for a more detailed discussion on these components. On the other side, if the top connection is to be replaced with some other component, like a riser adapter, it will be necessary to investigate this more in detail. Changing the top connection could typically be a customer specific component. For the sake of this discussion, it will not be made further consideration to these components.

9.2.5 Summary

In the table below, some of the key parts of this discussion are visualised. The purpose of this table is to give a visualisation of the potential savings from choosing the lightest component, compared with the heaviest component included in this discussion. For more information on the component, see the references on each component. It is worth noticing that the framework is not included in this summary, it can be asserted that the framework design for lifting the heaviest setup, would have a higher weight than the frame for the lighter setup.

Table 12: Summary of discussion

Component	Weight of heaviest component	Weight of lightest component	Potential weight saving	More information on component
Wellhead connector	44 902 lbs	13 900 lbs	31 002 lbs	3.3.1
Ram BOP	85 100 lbs	53 016 lbs	32 084 lbs	3.3.2
Annular BOP	57 050 lbs	29 500 lbs	27 550 lbs	3.3.3
Top connection	4 409 lbs (1	4 409 lbs (1	-	3.3.4 3.3.5
Fail safe valves	8 818 lbs (1	8 818 lbs (1	-	3.3.6
Total	155 377 lbs	95 743 lbs	59 634 lbs	

1) The weight is assumed in this discussion. Deviations could occur.

9.3 Framework

The framework will be a particularly important topic in the development of an SSD. In addition to the obvious function that all the components must be connected, the framework has a function when moving the SSD both on land and subsea. Therefore, it will be important that the framework is designed in accordance with a recognized standard for the intended use. There are several standards that would fill this purpose, two of those are NORSOK-R002 and DNVGL-2.7.3. Both of these standards could be used to qualify the lifting arrangement for an SSD. It can be argued that the SSD should be designed in accordance with both, to ensure it meets possible customer requirements, special areas, and similar. This is especially important if the SSD is designed for rental, this will be elaborated on in a later part of the discussion.

At this stage of the research, it is too early to conclude on the weight of the framework, as this will be depending on several components, and areas that have not yet been discussed. One of the most important areas of concern when designing the framework is how the weight of the main components is transferred to the framework. If the main components are connected through one or more plates, out to lifting points far from the centre, this plate/plates must be strong enough to not deform when lifting the component. Naturally, this often leads to a thick steel plate, which increases the weight of the construction. It can be stated that the lifting plate must be as small as possible, and the lifting point to be kept as close to the vertical centre line as possible, to reduce the weight to a minimum.

9.4 Economical aspect

During a rig move with its own power, it is estimated to use approximately 40m^3 fuel per day, and by operation, it will be using approximately 25-50% of this fuel consumption to keep itself in the position, and by bad weather conditions the fuel consumption can be up to three times as high (approx. 120m3) (Vidvei, 2012). During the voyage, a Light Well Intervention vessel (LWI) could be assumed to use approximately the same fuel as a PSV. The PSV Enea, owned by Portasalvo Limited uses approximately 11m^3 when cursing at 11kt (Ship-Technology.com, 2022)

In the period from March 2019 to January 2022, the daily rig rates have varied between 125 000USD and 225 000USD (Ihsmarkit.com, 2022). From the writers perspective, it can be assumed that the daily rate for an LWI vessel could be between 30-50% of this. Using the median day rate for a semisubmersible at 175 000USD, this gives a day rate of 87 500USD for a LWI vessel.

Assuming a PP&A operation last for 15days, the saving just in the day rates be 1 750 000USD. If there are 5000 wells that must be PP&A on the NCS, it could be argued that this saving alone is a good reason to investigate the idea further. Onwards, it could be argued that using an LWI vessel instead of a rig would lead to a more flexible operation, which could be performed more efficiently, leading to shorter operation time, leading to fewer days on rate.

Another economical aspect that should be discussed is how a business module for a company putting an SSD out in the world, should be. There are two clear possibilities, either the SSD is built to sell it, or it is built to be used for rental. From the writers perspective, it is difficult to determine what an SSD could be sold for, and what the building cost would be. Therefore, it is difficult to have a relevant discussion on the topic. When a design is on a more detailed level than what is used in this report, it would be possible to make an estimate of the investing cost. On a general note, it can be assumed that there will be necessary for the SSD to interact with other involved parties for the control system, special equipment for a PP&A operation, and similar. Therefore, it can be asserted that a joined venture between different actors to offer a complete solution for the PP&A operation.

9.5 Environmental aspect

Heavy fuel oil (HFO) is known to have a CO2 emission of 3,11Kg CO2 for each Kg of burned fuel. Using the numbers from the previous chapter, assuming both vessels use HFO. The saving of CO2 each day will then be 27430,2Kg. This is based on the calculation: (20m3 – 11m3) = 9000litre, 9000litre = 8820kg, 8820kg*3,11 = 27430,2kg CO2. It can be stated that a saving of 50% of CO2 released into the atmosphere, will with todays environmental focus give a competitive advantage by offering a more environmentally friendly method for PP&A operations.

It can be assumed that a PP&A operation will be more efficient when performed with an LWI vessel, compared with a semisubmersible. From an environmental aspect, this would be a clear advantage, for each day saved the emission to the environment will be reduced. It can be challenged that the emission will not disappear the second the operation is completed but will continue as long as the vessel is burning fuel. On the other hand, if it is looked at from a bigger perspective like 20 wells combined, the environmental and economical savings of one or three days pr well start to be of notable size.

10 Conclusion

In chapter 6.5 it is discussed and concluded that out of the methods and ideas presented in this report, building a BOP consisting of existing components, with the main focus of keeping the weight as low as possible, is considered to be the best solution.

Based on data collected for this report, it is concluded that an SSD should be designed after ISO13628-7. This gives some requirements for the which components that should be included. Based on this it is concluded that the main components from the bottom should be; a wellhead connector, one shear ram, one shear seal ram, one annular, and one mandrel or customer specific component as a top connection. In addition to this, it must be some outlets from the stack, to make room for pressure transmitters.

After the conclusion that the SSD is the best solution included in this report, a comparison of different components that could be used is performed, this could be found in chapter 8. The first conclusion of the comparison is that the preferred wellhead connector is the Oilstates Lynxgrip 15/30 connector, with a weight of 13 900 lbs. Onwards it is concluded that if it should be used a 15k BOP, Hydrils double ram BOP with one 15" and one 22" bonnets will be the preferred option from the options included in this report, this ram BOP weighs 53 016 lbs. Through this report, it has been discussed if the pressure rating of the ram BOP needs to be 15k, or if it could be changed to 10 or 5k. The possibility of using a BOP with a pressure rating lower than 15k should diffidently be present, as the numbers of wells, where the well pressure exceeds 15k are considered to be in the minority of wells on the NCS. It has also been discussed if it is possible to class up a 10k BOP to be used on a 15k well, by implementing measurements for improved inspection and surveillance. In this report, it is concluded that a solution like this would work, as long as the developer finds a manufacturer who is willing to agree. The fact that the OEM most likely must be included in the process, makes this the most important argument for which BOP that should be used. Therefore, it is not performed a thorough comparison of the weight of different 10k ram BOPs. Regarding annular BOP, this report concludes that Cameron 18-3/4" 10k DL Annular BOP is the preferred option, this component has a weight of 29 500 lbs. In Figure 14 an illustration of the concluded components for the main stack of the SSD is presented. Some of the components are only illustrated as typical components, and not the accurate component, which is concluded most favorable in this report, all components are only an overview of the design, and not actual fabrication models. Therefore, deviations could occur.

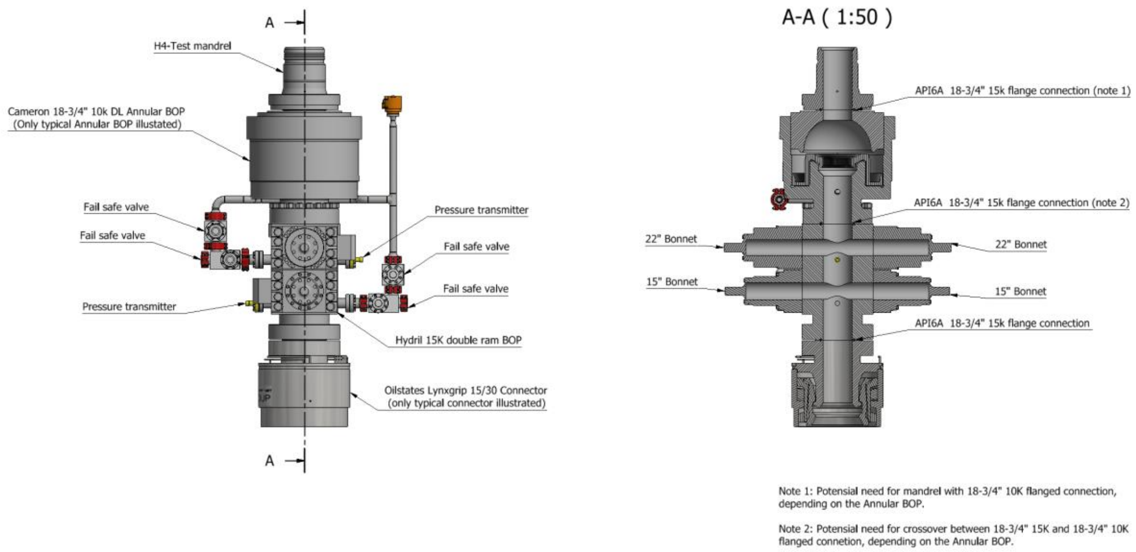

Figure 14: Concluded components for main stack. (PSW Technology)

As the discussion implies, it will not be made a conclusion on which components that are optimal for top connection, and fail-safe valves. Some of these will be depending on customer specifications or the components that should be connected with the SSD. For the framework of the SSD, it will not be given a conclusion of the design, as this is too early in the design process. This report concludes that the framework and lifting arrangement should be in agreement with both NORSOK-R002 and DNVGL-2.7.3.

On a different note, it has been discussed the economical aspect of using an SSD and an LWI vessel compared with a semisubmersible. Based on the brief discussion presented in this report it is concluded that there is a large possibility to offer a more cost-efficient method for PP&A operations, by using an SSD and an LWI vessel instead of a semisubmersible. It has also been discussed how the business module should be for a company developing an SSD. It has not been performed a thorough enough consideration in this report to have a valid conclusion on this question. From a simple CO2 calculation presented in chapter 9.5, it can be concluded that it gives the indication that performing the PP&A operation with an SSD and LWI vessel should lead to lower emissions that performing the operation with a semisubmersible.

11 References

PSW Technology. (n.d.).

Andersen, I. (2021, 11 13). *Teknisk ukenblad*. Retrieved from Mener verktøyet deres kan spare oljeselskapene for milliarder. Nå er alt de trenger en brønn å plugge: https://www.tu.no/artikler/mener-verktoyet-deres-kan-spare-oljeselskapene-for-milliarder-na-er-alt-de-trenger-en-bronn-a-plugge/513751?utm_source=newsletter-tudaily&utm_medium=email&utm_campaign=newsletter-2021-10-11

API. (2022, Januray 29). *API.org*. Retrieved from https://www.api.org/products-and-services/standards

API16A. (2004). *API spesification 16A forth edition* . ANSI/API.

Cameron. (2022, April 11). *DL High-pressure annular BOP*. Retrieved from slb.com: https://www.slb.com/-/media/files/cam-drlg-pc/brochure/dl-bop-br.ashx

Cameron. (2022, April 07). *slb.com.* Retrieved from Collet Connectors : https://www.slb.com/-/media/files/cam-drlg-pc/brochure/collet-connector-br.ashx

Cameron. (2022, 02 19). *slb.com.* Retrieved from EVO compact, offshore, ram-type BOP: https://www.slb.com/-/media/files/cam-drlg-pc/brochure/evo-br.ashx

Cameron. (2022, 02 19). *TL-Offshore ram-type BOP*. Retrieved from slb.com: https://www.slb.com/-/media/files/cam-drlg-pc/product-sheet/tl-ram-type-bop-ps.ashx

Crumpton, H. (2022, March 01). *Sciencedirect* . Retrieved from Subsea tree: https://www.sciencedirect.com/topics/engineering/subsea-tree

DNV. (2022, 01 29). *DNV*. Retrieved from About DNV-Maritime: https://www.dnv.com/about/maritime/index.html?_ga=2.166265854.174981722.1643461292-136882523.1643461292

DNV-GL. (2018). *DNVGL-OS-E101*. DNV-GL.

Dof.no. (2022, 14 may). Retrieved from DOF Fleet booklet : http://www.dof.no/Files/PDF/DOF%20Group/Media/DOF_fleet_booklet_web.pdf

Drillingmanual.com. (2022, April 11). Retrieved from Vcat.book: https://www.drillingmanual.com/wp-content/uploads/2021/08/documents.pub_shaffer-rambo-p-18-nov.pdf

Dril-Quip. (2014). *MRB DX-DW Wellhead connector* . Dril-quip.

Energi24. (2022, January 17). *Energi24.no*. Retrieved from https://energi24.no/featured/ny-pa-teknologi-kan-bli-milliardmarked

Equinor. (2022, May 05). *What is a blow out preventer.* Retrieved from www.scribd.com: https://www.scribd.com/document/512235886/Equinor-Fact-Sheet-Blowout-Preventer

Forskningsrådet. (2021, 11 13). *Forskningsrådet* . Retrieved from Prosjektbanken MTR: https://prosjektbanken.forskningsradet.no/project/FORISS/256341?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=score&sortOrder=desc&resultCount=30&offset=0&Fritekst=MTR

GE-Oil&Gas. (2010). Operator's Manual RAM-1505767-OM Rev A. GE Oil & Gas.

GE-Oil&Gas. (2015). *MRB SHD H4 Connector.* GE Oil & Gas.

Gundersen, S. (2022, April 11). *Ptil.no.* Retrieved from Subsea facilities : https://www.ptil.no/contentassets/112504561adf408aad95b8ebeb830a85/subsea-facilities---technology-development-incidents-and-future-trends_2014.pdf

Hydril. (2003). *Operator's Manual GX 18-3/4" 10K Annular BOP.* Hydril.

Ihsmarkit.com. (2022, April 28). Retrieved from Petrodata Offshore Rig Day Rate Trends : https://ihsmarkit.com/products/oil-gas-drilling-rigs-offshore-day-rates.html

ISO. (2022, January 29). *Iso.org*. Retrieved from about us: https://www.iso.org/about-us.html

ISO13628-7. (2006). *ISO13628-7.* Standard Norge.

Jacobsen, D. I. (2005). Hvordan gjennomføre undersøkelser . In D. I. Jacobsen, *Innføring i samfunnsvitenskaplig methode* (pp. 141-163). Oslo: Cappelen Damm .

Khalifeh, M., & Saasen, A. (2020). *Introduction to Permantet Plug and Abandonment of Wells.* Cham: Springer Nature Switzerland AG.

Lervik, O. (2022, March 19). *NDLA.* Retrieved from Komplementering på havbunnen: https://ndla.no/subject:1:6951e039-c23e-483f-94bf-2194a1fb197d/topic:d8b9525a-9310-4cb5-a08d-023e90ef0858/resource:1:173361

Lidal, L. V. (2017). Casing. *Cerpus AS*. Retrieved January 22, 2022, from https://ndla.no/subject:1:01c27030-e8f8-4a7c-a5b3-489fdb8fea30/topic:2:182849/topic:2:177989/resource:1:178058

Manual.no.3131615-04-OM,RevA1. (2007). In F. O. ASA, *18-3/4"-15K Compact ram BOP Operators manual* (pp. 2-1). Hydril Company LP.

Mathijs G D Smit, T. K. (2011). Achievements of Risk-Based Produced Water Management onthe Norwegian Continental Shelf (2002–2008). *Integrated Environmental Assessment and Management,* 668–677.

Neodrill. (2022, May 14). Retrieved from Neodrill.com : https://www.neodrill.com/solutions

Norsk-petroleum. (2022, January 17). *norsk petroleum* . Retrieved from Economy-The goverment's revenues : https://www.norskpetroleum.no/en/economy/governments-revenues/

NORSOK-D-001. (1998). *Drilling facilities.* Oslo,Norway: that a BOP subsea stack shall as a minimum consist of the following:.

NORSOK-D-010. (2004). *Norsk Standard.* Norsk Standard.

NOV. (2022, 02 19). *Technical Marketing Sheet* . Retrieved from Nov.com : https://www.nov.com/-/media/nov/files/products/rig/rig-equipment/pressure-control-systems/offshore-pressure-control-equipment-spec-sheet.pdf

NPD. (2022, January 18). *Factpage Norwegian Petroleum Directorate*. Retrieved from https://factpages.npd.no/en/wellbore/statistics/entryyear

Object-1. (2022, March 25). Attachment B. (T. Blomvågnes, Interviewer)

Object-2. (2022, March 29). Attachment C. (T. Blomvågnes, Interviewer)

Object-3. (2022, March 29). Attachment D. (T. Blomvågnes, Interviewer)

Oceaneering. (2022, March 24). *Oceaneering.com.* Retrieved from Brochures-Rig chase : https://www.oceaneering.com/brochures/rig-chase/

OilStates. (2022, April 07). *Oilstates.com.* Retrieved from OSUKFlysheetTemplate: http://oilstates.com/wp-content/uploads/LynxGrip-Wellhead-Connector.pdf

PetroWiki. (2022, March 19). Retrieved from Subsea wellhead system : https://petrowiki.spe.org/Subsea_wellhead_systems

PetroWiki. (2022, March 19). *Subsea system*. Retrieved from https://petrowiki.spe.org/Subsea_systems

Paaske, S. (2022, March 16). *NDLA.no*. Retrieved from Nasjonal digital læringsarena : https://ndla.no/nb/subject:1:01c27030-e8f8-4a7c-a5b3-489fdb8fea30/topic:2:182849/topic:2:163658/resource:1:162411

Schlumberger. (2022, 02 19). Retrieved from Cameron Pressure control equipment: https://www.slb.com/drilling/rigs-and-equipment/pressure-control-equipment

Schlumberger. (2022, March 19). *Drillpipe*. Retrieved from Oilfield glossary: https://glossary.oilfield.slb.com/en/terms/d/drillpipe

Schlumberger. (2022, 02 19). *EVO RAM-Type BOP.* Retrieved from SLB.com : https://www.slb.com/drilling/rigs-and-equipment/pressure-control-equipment/ram-type-bops/evo-ram-type-bop#related-information

Schlumberger. (2022, March 18). *Oildield Glossary*. Retrieved from https://glossary.oilfield.slb.com/en/terms/a/annular_bop

Schlumberger. (2022, March 19). *Production string* . Retrieved from Oilfield glossary: https://glossary.oilfield.slb.com/en/terms/p/production_string

Schlumberger. (2022, March 19). *Production tubing*. Retrieved from Oilfield glossary: https://glossary.oilfield.slb.com/en/terms/p/production_tubing

Ship-Technology.com. (2022, April 28). Retrieved from Enea Platform Supply Vessel: https://www.ship-technology.com/projects/enea-platform-supply-vessel/

Simulationx.com . (2022, March 18). Retrieved from http://doc.simulationx.com/4.0/1033/Content/Libraries/SubSea/SubSeaHydraulics/Actuators/WellheadConnector.htm

Subseapedia. (2022, March 01). Retrieved from Subseapedia.org: http://www.subseapedia.org/w/images/7/72/Configuration_Comparison.png

Tawekal, R. L. (2022, March 19). *Nfatmala.blogspot.com*. Retrieved from http://nfatmala.blogspot.com/2016/02/horizontal-and-vertical-x-mas-tree.html

Vidvei, T. L. (2012). *The Environmental and Cost Impact of Dynamic Positioned- versus Anchor Positioned.* Stavanger: University of Stavanger.

Yang Jin, T. H. (2022, March 18). *Research gate.* Retrieved from Petroleum exploration and development, Vol 40, issue 5, october 2013: https://www.researchgate.net/publication/259167355_Prediction_model_of_casing_annulus_pressure_for_deepwater_well_drilling_and_completion_operation

Yuldashev, A. (2022, March 16). *NDLA.no*. Retrieved from Nasjonal digital læringsarena: https://ndla.no/nb/subject:1:01c27030-e8f8-4a7c-a5b3-489fdb8fea30/topic:2:182849/topic:2:147173/resource:1:140658

Øksnes, A. L. (2017). *Permanent plugging and abandonmen.* Stavanger: University of applied scienses Stavanger.

Øveren, K. M. (2022, March 28). *Slideshare.* Retrieved from Litteraturstudie som metode: https://www.slideshare.net/higbibl/litteraturstudie-som-metode

12 Attachments

Attachment A - Interview guide

Page intentional left blank

Interview guide

A1 Introduction

The interview will start with some general questions surrounding the typical operations from when a rig is in position above an wellhead, until the rig and reservoir is connected. This is to get an understanding of which part of the operation, is the most natural to mention from the participants perspective.

As agreed upon the planning of this interview, there will be no storage of personal information involved with this interview. The researcher will write down some notes during the interview, and this will be summarized in a minute of meeting. The minutes of meeting will be attached to the research report, and will be referenced to in the report itself. There shall not be possible for others to identify the participant thorough the report.

A2 Theme

The theme for this research project is to investigate how to ensure well control when performing permanent plug and abandonment operations, on subsea orientated wells on the Norwegian continental shelf. Permanent plug and abandonment (PP&A) operations are performed when a well is on the end of the wells lifetime, when the reservoir is plugged off and the seabed is returned to its natural conditions. During the operation different types of material, like production tubing, needs to be removed from the well. It will also be installed several plugs in the well to ensure that there will be no leaks in the future. During this part of the operation, it is necessary to have some form of well control, making it possible to close, and seal of the reservoir, if necessary, typically this is done with the usage of a blow out preventer (BOP). For this research project the initial thought is to make a version of a BOP that could be operated from a smaller vessel than a traditional semisubmersible.

One of the reasons that this is an interesting problem to investigate could be divided into two different aspects. The first aspect is that there are over 2000 wells on the Norwegian continental shelf (NCS) already drilled, and will in some time in the future have the need to be plugged and abandoned. The other is that it is large cost associated with the PP&A operation, and one of the larges costs with the operation is the day-rate for the rig. Hence, the possibility to move the operation from a rig to a smaller vessel that would require a smaller day-rate cost is considered to be an attractive solution to offer to the industry, that will be cost effective solution.

The reason for this interview is to get confirmation on some of the thoughts that the researcher has made during the literature study part of the project, together with industry standards and commonly known thoughts, that not are implemented in laws and regulations.

A3 Questions

- How will you describe the most important functions of a BOP?
    - Which of these would you think of natural to have on a SSD?

- Can you describe, from your perspective, the scenes of events from the rig is located over the wellhead, and up the time when the rig is connected to the reservoir?
    - What does you think of as the most critical parts of this operation?
- Historical the weight of a typical BOP was 100 tons, now it is 300 – 400 tons.
    - What is the reason for the increased weight?
    - What is the lowest weight of a used BOP today?
        - what is the different to other BOPs?
        - How does the increased weight influence the performing of the permanent plug and abandonment operation?
-

- Geometry
    - Which limitations surrounding the geometry of a BOP can you think of?
    - Which parts of the BOP does contribute the most for the total weight of the BOP?

- Forces
    - How would you describe the forces impacting a BOP during the time when it is lowered from the rig, down towards the seabed?
    - How would you describe the forces impacting a BOP when it is connected to the wellhead?
    - How does the high weight react exactly on the wellhead, what will happen?

- Signal
    - How would you describe the signals in between the rig and the BOP?

- Ergonomic
    - Does you know of any typical problematic areas on a BOP, when considering ergonomic?

- Transport
    - Lets say that an SSD is produced, how would you describe the optimal way to move the SSD from location to location?
        - Do you think of this as a possible solution?
            - If no, how could it be adjusted?

- Maintenance
    - How would you describe the maintenance of a BOP?

- Oil wells
    - Can you describe the difference between a 10k oil well and a 15k oil well?
    - How would you describe the distribution of wells with the requirement of 10k vs 15k?

- General
    - Lets assume an SSD should be built, what would you point out as the most important thing to consider?

- Specific
    - Which components would you think of as the minimum components in a BOP to ensure well control?
        - From API it is stated: wellhead connector, BOP with dual ram block, annular, mandrel or other connection, fail safe, and accumulator rack.
        - Which of the manufactures of these components does you have experience with?

        - Can you point out one of these to be more weight efficient than others?
    - Can you describe the function of fail safe valves?
    - It is possible to change local conditions to work against the overloading?

  - What is the disadvantage of the weight? Is it the movement/handling and positioning of the BOP or is it the load on the installation or other parts in the process?

  - How does the increased weight influence the performing of the permanent plug and abandonment operation?

Short presentation of idees, with possibility for the participants to comment.

- Ideas
  - Using and existing BOP with a connected buoyance
  - Transporting the BOP under water, removing the need for lifting capacity
  - Using existing components to create a lighter version of a BOP, an SSD.
  - Counterweight
  - Suction anchors around wellhead

Before rounding up:

- Do you have any other ideas than what have been discussed her in this session?
- Any other questions or comments?

Attachment B -Minutes of meeting-Object 1

Page intentional left blank

Questions 1

Can you describe, from your perspective, the scenes of events from the rig is located over the wellhead, and up the time when the rig is connected to the reservoir?

Answer:

The rig is placed in a safe zone, located near the wellhead, but not directly above.

The BOP is skidded into the moonpool and connected with two marine riser joints. The reason for using two joints is so the BOP can be lowered, and fully soaked in water in one operation. Limiting the time, the BOP is in the splash sone.

The BOP is driven into the sea.

Running of marine riser, two and two marine riser joints are connected, and lowered down towards the seabed. This step is repeated until the BOP is in a acceptable high above the template.

To adjust the distance between the rig and the template, pup-joints are installed in the riser string. The pup-joints varies in length from 5ft to 30ft.

The telescopic joint is connected to the riser string, and locked in minimum stroke position.

The landing joint is connected to the riser string.

The rig moves over the template.

Guide wires are installed between the template and the rig.

An overpull test is performed

The weight of the BOP and marine riser string is moved from the telescopic joint over to the tension system on the rig.

The diverter and upper flex-joint is installed

The telescopic joint is released, landing joint removed, and telescopic joint is connected to diverter, leaving the inner barrel in approximately mid stroke position.

Function testing of BOP and pressure testing of choke and kill lines.

The rig is ready to start well intervention operation.

Question 2

What does you think of as the most critical parts of this operation?

Answer:

The most critical parts of the operation is the

Running of BOP and marine riser, as there are forces being moved between the running tool and the spider.

That the BOP is set to the correct running procedure. This to ensure that there are no pressurized systems on the BOP, that could lead to and disconnect of the lower BOP stack. There is and separate control panel for connecting the BOP to the wellhead, where only the necessary operations are installed. This is an important measurement so no functions that could lead to an disconnect, is operated before the wellhead connector is locked.
That the water limitations for connecting the BOP to the template is correctly defined, and followed to ensure no collision between BOP and template.

Question 3
Historical the weight of a typical BOP was 100 tons, now it is 300 – 400 tons. Was is the reason for the increased weight?
Answer:
The requirements for cutting capacity have been increased over the years. The required working pressure have been increased, leading to larger and heavier components. There required redundance have been, today it is normal with yellow and blue pod, acoustic supply and ROV supply leading to four separate control systems.

Question 4
Which limitations surrounding the geometry of a BOP can you think of?
And which parts of the BOP does contribute the most for the total weight of the BOP?
Answer:
Limitations surrounding the BOP can be the subsea template and the handling system for the BOP. A typical problem is that the company installing the template tries to save money, by making the template as small, and simplified as possible, as the BOP have been heavier and heavier, the strength margin of the template have been reduced.

The BOP components that contribute the most for the total weight of the BOP is in my opinion the BOP body with bonnets, framework, and accumulator bottles.

Question 5
How would you describe the forces impacting a BOP when it is connected to the wellhead?
Answer:
There is a formidable bending moment applied to the wellhead. Studies has shown that the buoyance element on the marine riser joints creates a larger drag force than expected,

increasing the bending moment additionally to the forces that occurs from misalignment of the vertical axes.

To ensure that the LMRP is moved up and away from the lower stack, the tension system is adjusted to an overpull position. The origin for the weight is approximately between the LMRP and lower stack. The overpull is adjusted to the weight of LMRP, marine riser, and the friction in the connection between LMRP and lower stack.

Question 6

How would you describe the signals in between the rig and the BOP?

Answer:

There are three different systems for signals between the rig and BOP:

Simple hydraulic supply

Electric supply with MUX cables

Acoustic supply

The hydraulic system can be described as common supply down to a manifold with separate pilot hoses to different functions. The hydraulic supply is limited to between 800-1000meter water depth. For deeper waters, the delay in hoses will be to long to meet the requirements for cutting time. Then the MUX cables must be used. The MUX uses electric signals between the BOP and rig, operated through a POD. The MUX pod weighs around 15ton each, and the hydraulic pod weighs around 5ton each.

Question 7

Does you know of any typical problematic areas on a BOP, when considering ergonomic?

Answer:

There is typically narrow space for working on equipment, and there are large and heavy components that should be moved. There is a significant difference between manufactures. Cameron is known for being hard to work on, in regard to maintenance, and Shaffer is known for being easy to work on.

Question 8

How would you describe the maintenance of a BOP?

Answer:

The minimum maintenance interval for components installed on the BOP should be six months. It is more and more common for semisubmersible to move between different wellheads, without pulling the BOP to the surface, and increasing the time a BOP can be under water, has a large economic benefit.

Question 9

Can you describe the difference between a 10k oil well and a 15k oil well? How would you describe the distribution of wells with the requirement of 10k vs 15k?

Answer:

The difference between an 10K and a 15K oil well, is the expected pressure from the well. The rig owner often sets the requirements for the BOP to be as large as possible, making the rig capable to take on as many different jobs as possible.

The well pressure is always known when performing well intervention operations, as it is calculated before drilling the top hole, and measured when the top hole is drilled.

There is a large number of wells that do not require a 15k BOP, as the well pressure is under 10k, and sometimes under 5k. There should be possible to perform a large number of PP&A operations with a 5k BOP.

Question 10

Lets assume an SSD should be built, what would you point out as the most important thing to consider?

Answer:

Low weight

Components adjusted to the well pressure

Investigate the possible clients requiring a 15k BOP. It can be stated that this is a so small market share, that the design for an SSD should be limited to 5 or 10k BOP.

The standard lifetime of BOP components are 20years, with increased maintenance and reduced lifetime, it could be possible to increase the pressure rating for components. One example could be to increase a 5k BOP to working pressure of 7,5k, to be able to perform PP&A on wells just over 5k well pressure.

Question 11

Can you point out one manufacture of BOP components to be more weight efficient than others?

Answer:

Camron or Shaffer

Question 12

Do you have any other ideas than what have been discussed her in this session?

Answer:

Save weight by placing accumulators on separate unit.

If the operation is performed with risers, the different flex-joints can give a different magnitude of bending moment on the wellhead.

Move the weight from the wellhead to the guidepost, by using jacks.

Electrical BOP.

Attachment C - Minutes of meeting-Object 2

Page intentional left blank

Question 1:

Can you describe, from your perspective, the scenes of events from the rig are located over the wellhead, and up the time when the rig is connected to the reservoir?

Answer:

With a general focus on performing permanent plug and abandonment operations:

The rig comes to location

Seabed survey is performed

The hatch in template is opened with an ROV.

There is a difference between vertical and horizontal xmas trees. For wells with a vertical xmas tree, the xmas tree would need to be removed before a BOP can be connected to the well. Horizontal xmas trees are most used, and the BOP can be connected directly at the xmas tree before continuing the process.

Function testing of BOP

Overpull test

Filling marine riser with mud.

Wireline operation to remove the crown plug.

Pulling of tubing with drill pipe

(The step below is already often performed with the usage of vessels, to minimize the costs and the forces loaded on fatigue wellheads)

Kill the well

Install deep set plug with wireline

Cutting of tubing with wireline

Install crown plugs with wireline

Close hatches

During the last steps mentioned it is necessary will well control. Often gas is built up between the tubing and the casing, when the tubing is pulled the gas is released upwards. During this operation the annular BOP is normally closed around the tubing, and the gas is circulated out through the choke and kill lines. This function is important to include when designing a simpler BOP. The rest of the operation will be standard PP&A operation.

Question 2:

What does you think of as the most critical parts of this operation?

Answer:

The most critical part of the operation is when the crown plug is pulled, then the operators need to have trust in the valves installed in the tubing, since there is no backup before the BOP is connected. When the BOP is connected there is a second barrier, and the most critical part then could be the pulling of the tubing. The status of parts of the tubing can be assumed to be unknown, and it is important to know the orientation of potential non cuttable items in the tubing string. Onwards some would say that there is always a risk involved with wireline operations, as the wire can snatch leaving tools or equipment inside the well. Then a fishing operation must be performed which requires time and are in general difficult to perform.

Question 3:

Which limitations surrounding the geometry of a BOP can you think of?

Answer:

There are given dimensional limitations a BOP must be designed within, if designing an SSD should be easier to be within the limitations, since the SSD is less complex compared with a BOP.

Question 4:

Historical the weight of a typical BOP was 100 tons, now it is 300 – 400 tons what is the reason for the increased weight?

Answer:

There are several reasons for the increased weight, the number of ram blocks has been increased, the area of use has increased, and the requirements have become stricter. There are several new control systems. Where it previously was common to send the return fluid from the BOP directly to sea, there are requirements to send it back to tank, this would off course also increase the weight with more piping, and room for the return liquid.

Question 5:

Can you describe the difference between a 10k oil well and a 15k oil well?

How would you describe the distribution of wells with the requirement of 10k vs 15k?

Answer:

From a drilling perspective there is no difference in the operation. The advantage of 15k equipment is that there in wells with several drill paths, the pressure is often higher than in wells with a single drill path. With equipment with a lower rating than 15k there could be

limitations to the usage of equipment. Looking at the wellhead, the weight would be a notable higher weight when using 15k equipment, compared with 10k or 5k.
From the top of my head, I would assume that around 70% of the drilled wells are 10k or lower.

Question 6

Which of the function of a typical BOP would you think of as natural to have on an SSD?

Answer:

Keeping it to an minimum, only include what is needed for qualifications.

Question7:

Lets assume an SSD should be built, what would you point out as the most important thing to consider?

Answer:

Reliability in the control system, and that there are enough cutting capacity

Question 8:

Can you point out one manufacture of BOP components to be more weight efficient than others?

Answer:

Personal, I am a admire of Cameron and GE BOP’s. They are weighing approximately the same, but are more easy to work on than others like NOV.

Question 9:

Can you describe the function of fail safe valves?

Answer:

The function of the valve is only a simple open close function with fail safe in closed position. Meaning if the valve does not get any signal or pressure, it will close.

Question 10:

Short presentation of idees, with possibility for the participants to comment.

Ideas:

- Using and existing BOP with a connected buoyance
- Transporting the BOP under water, removing the need for lifting capacity
- Existing solutions

Answer:

- Would increase the side forces on the BOP, creating a larger bending moment on the wellhead. Not favourable in regard to fatigue wellheads.
- Would not be practical possible. Large limitations in operation conditions when moving the BOP under water, and no possibility for maintenance in between wells.
- Complex operations, with large costs involved.

Question 11

Do you have any other ideas than what have been discussed her in this session?

Answer:

One possibility can be to use banding, with wires connected the top of a BOP down to the template, moving the bending moment from the wellhead to the template. The large disadvantages are time and cost, since it is a complex operation, and requires rebuild of a BOP.

The horizontal forces on the BOP, and marine riser system or similar must be the dimensional limitation for an SSD.

Attachment D - Minutes of meeting-Object 3

Page intentional left blank

Question 1:

Can you describe, from your perspective, the scenes of events from the rig are located over the wellhead, and up the time when the rig is connected to the reservoir?

Answer:

The rig moves into position

Makes the BOP ready

Runs BOP with riser down towards wellhead after the rigs procedures

During the run, testing of choke & kill lines, and main bore are performed.

Landing the BOP on wellhead

Locks wellhead connector

Connects the riser to the tension system on the rig.

Connects telescopic joint to riser system.

Runs test program.

Question 2:

What does you think of as the most critical parts of this operation?

Answer:

Unplanned release of lower stack from LRMP. Can occur if pressure is allowed to build up in the control system.

Question 3:

Which limitations surrounding the geometry of a BOP can you think of?

Answer:

The footprint of the BOP has geometrical limitations depending on the template. There are limitations in regard to dimensions of the BOP, so it fits inside the pocket on the template. Large and heavy BOP's can damage the wellhead. If the BOP is too high, it can lead to an increased bending moment on the wellhead.

If the tension system has a slow response time, it can lead to large forces on the wellhead. If the rig is lifted by the waves, and the tension system does not move fast enough. The overpull force will increase, and also bending force if rig is offset of template.

Question 4:

How would you describe the forces impacting a BOP during the time when it is lowered from the rig, down towards the seabed?

Answer:

Forces from the weather

wind forces

heave on the rig.

Question 5:

How would you describe the forces impacting a BOP when it is connected to the wellhead?

Answer:

Upwards pulling force from the marine riser.

Well pressure

Bending moment

Question 6:

How would you describe the signals in between the rig and the BOP?

Answer:

Emergency communication is performed with acoustic, or by hot stabs and ROV. Normal communication is performed with either MUX-cables and pods, or by hydraulic umbilical. The hydraulic umbilical is often used on shallow waters, on deep waters the response time is too long.

Question 7:

Does you know of any typical problematic areas on a BOP, when considering ergonomic?

Answer:

Heavy equipment, working on different hights with limited access. Personnel can be exposed to water based hydraulic fluids.

Question 8:

How would you describe the maintenance of a BOP?

Answer:

The maintenance can be divided into different time intervals, every 14 day, 3 monthly, 6 monthly, in between well, and 5years re-classification.

The 14 days maintenance is a test of the BOP functionality, and is performed subsea connected on the wellhead. Every function on the BOP is runed, to verify the function of the BOP. Normally it is rotated between the yellow pod, blue pod, and acoustic control system, to verify that they all work. On a in between well maintenance the most critical part of the BOP is inspected. For the 3 and 6 monthly inspection a more thorough inspection is performed, by opening up the bonnets for inspection of ram block and cavities. For a 5years re-certification the BOP is stripped to small parts and inspected.
It is important to know the state of the equipment, to ensure that the BOP will fulfill its requirement. Soft seals are normally replaced due to limited life time of these.

Question 9:
Lets assume an SSD should be built, what would you point out as the most important thing to consider?
Answer:
Needs to be designed after established laws and regulations. Should be easy to perform maintenance. Investigate the possibility to build an electrical BOP.

With an electrical BOP the maintenance will be verry simple, and the possibilities for control increases. The company Electric Subsea & Drilling has a solution where the bonnets of a traditional BOP is changed with electrical bonnets, that closes mechanical. There has been a problem for several years to get the components field proven, but the owner of several rigs are getting closer to the idea of testing the solution. With an electrical solution the need for maintenance will decrease and the reliability of the system would increase, since there are less possible failures. Hence, the SIL level would increase.

Question 10:
Short presentation of idees, with possibility for the participants to comment.
Ideas:
Using and existing BOP with a connected buoyance
Transporting the BOP under water, removing the need for lifting capacity
Using existing components to create a lighter version of a BOP, an SSD.
Answer:

Several operational problems with solution. Can be helpful for decreasing the weight on the wellhead, but can also increase the bending moment.
Large cost involved with solutions, a complete solution would be better.
Combined with an electrical solution would be a good solution.

Question 12:
Do you have any other ideas than what have been discussed her in this session?
Answer:
Is it possible to reduce the main bore of components? The wellhead connector must be 18-3/4" in, since most of the wellheads are of this dimension. Anyhow, it could be possible to reduce the main bore diameter for other BOP components. This would reduce the total weight of the design.