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Master Student: Sanan Aliyev

Supervisor: Associate professor Gasham Zeynalov

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ABSTRACT

The project is explored Casing Drilling Technology and advantages of application this method which is investigated based on researching a number of technical papers published by the Society of Petroleum Engineers (SPE), Halliburton Company, Schlumberger Company, American Association of Drilling Engineers (AADE), as well as some books associated with corresponding drilling operations.

The scope of the project is commenced by researching, planning the work and analysing the specific problems associated with conventional drilling technology. It will guide the research to continue with background overview on Casing Drilling Technology, its design considerations and benefits in real world application. It will guide the research to continue with background overview on Casing Drilling Technology, its design considerations and benefits & drawbacks during its operation in industry environment.

One of the main advantages of casing drilling technology is a plastering effect which helps to minimise wellbore problems such as wellbore instability, lost circulation, etc. are discussed and demonstrated how these benefits are necessary in mitigating drilling problems. Likewise, the main target is aimed to investigate Casing Drilling technology while an application in South Pars gas field, Persian Gulf that was drilled before with Conventional drilling method.

Tədqiqatlar bu metodun dizayn imkanlarını təhlil etmək üçün

The studies are developed to analyse the design considerations that needs to be taken measurement prior to utilising of the method starts. Additionally, a further investigation is conducted to determine how the buckling, fatigue, hydraulics, torque and drag factors have an impacts on the casing while designing of Casing. This is then followed by specific formulas for calculations of these parameters. South Pars gas field data has been used to perform calculations on the following parameters. Results

from these investigations have presented that bending stress due to buckling has an impact on fatigue life of the casing. It has not been revealed the same effect as happens when trajectory is directional, however some other assumptions were realised. Investigations have proved that to solve the problems associated with conventional drilling method Casing Drilling technology can be alternatively suggested.

Disadvantages and limitations of this technology are also studied. During drilling operations, Casing Drilling technology has some challenges that should be estimated prior to operate the method in the area.

At last, some relevant recommendations are suggested to improve the technology in the future.

XÜLASƏ

Layihə çərçivəsində qazma kəmərlərinin texnologiyası və bu üsulun üstünlükləri Neft Mühəndisləri Cəmiyyətinin (SPE), Halliburton və Schlumberger şirkətlərinin, Amerika Qazma Mühəndisləri Assosasiyasının (AADE) texniki sənədlərində və həmçinin uyğun qazma işləri ilə əlaqədar bir sıra nəşr edilmiş məqalələrin təhlili əsasında öyrənilmişdir.

Layihənin miqyası ənənəvi qazma texnologiyası ilə əlaqədar olaraq, tədqiqat işləri, işlərin planlaşdırılması və konkret problemin təhlilinin başlaması ilə xarakterizə olunur. Bu işlər bütün dünyada qoruyucu kəmərlərin qazma texnologiyasında təhlilin davam etdirilməsi üçün tədqiqatları, onunla əlaqədar konstruktiv fikirləri və üstünlükləri istiqamətləndirəcək. Bu da sənaye şəraitində istismar müddətində üstünlük və çatışmamazlıqları qiymətləndirməyə imkan verəcək.

Qoruyucu kəmərlərin qazma texnologiyası əsas üstünlüklərindən biri möhkəmləndirmə effektidir ki, bu da sirkulyasıya itkisi, quyu stovolunun qeyri-stabilliyi və s. kimi quyu stvolu problemini minimuma endirməyə kömək etməsi və bu üstünlüklərin hansı dərəcədə qazma probleminin yüngülləşdirilməsində vacibliyi müzakirə edilir və həyata keçirilir. Bununla əlaqədar olaraq, əsas məqsəd kimi Qoruyucu kəmər qazma texnologiyası ənənəvi qazma üsulu ilə qazılan Fars körfəzinin Cənubi Fars qaz yatağında tətbiq olunmuşdur.

Tədqiqatlar layihələndirmə məsələlırinin təhlili üçün realizə olunur, hansı ki, bu üsulun istifadə edilməsinə qədər ölçmlər aparılmış olsun. Bundan başqa, koprpusun layihələndirilməsi zamanı dayanaqlıq, yorğunluq, hidravlik faktorunun, firlanma momentinin və müqavimətin korpusa təsir etməsini müəyyən etmək üçün əlavə tədqiqatlar aparılır. Sonra isə bu parametrlərin hesablanması üçün konkret tənliklər tətbiq edilir. Cənubi Fars qaz yatağının məlumatları açağıdakı parametrlər üzrə hesablamanşn aparılması üçün istifadə edilmişdir. Bu tıdqiqatların nəticələri göstərdi

ki, əyilmə nəticəsində yaranan bükülmə müqaviməti korpusun uzun ömürlü olmasına təsir göstərir. Trayektoriya zamanı belə effekt müşahidə olunmur, lakin bəzi başqa təsəvvürlər realizə oluna bilir. Tədqiqatlar göstərir ki, ənənəvi qazma üsulu ilə əlaqədar problemin həlli üçün həmçinin, qoruyucu kəmər texnologiyasını təklif etmək olar.

Həmçinin, bu texnologiyanın çatışmamazlıqları və məfhdudluğu öyrənilmişdir. Qazma işləri zamanı qoruyucu kəmər texnologiyası bir sıra problemlərlə üzləşir, hansı ki, bu rayonda istismara qədər qiymətləndirilməsi vacibdir.

Nəhayət, gələcəkdə texnologiyanı təkmilləşdirmək üçün bəzi müvafiq tövsiyələr təklif olunur.

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List of Abbreviations

σ_b	Bending stress
ΔP	Differential pressure (psi)
A_0 A_i	Outside and Inside casing area (in^2)
BF	Buoyancy factor
BHA	Bottom Hole Assembly
CDS	Casing Drilling system
DLS	Dog leg severity (degrees/100 ft)
D_B	Diameter of bit (in)
D_0 D_i	Outside and inside diameter of casing (in^2)
E	Young's Modulus (GPa)
ECD	Equivalent Circulating Density (ppg)
F	Axial Loads (lb)
f	Friction Factor
F_c	Critical Buckling Force (lb)
F_{eff}	Effective tension (lb)
F_{total}	Total Axial Load due to bending (lb)
P_o	External pressure (psi)
P_i	Internal pressure (psi)
HPHT	High Pressure High Temperature
I	Inertia Moment (in^4)
T	Torque (ft-lb)
w	Effective buoyed weight (lb/in)
λ	Helix angle (rad/in)
LWD	Logging While Drilling
NPT	Non-Productive Time
WOB	Weight on bit

INTRODUCTION

Over many years of drilling and exploiting operations of petroleum reserves has accordingly processed to optimise the production of easy oil. Nowadays, the companies working in oil industry are innovating technology, looking for alternative methods to deal with new undiscovered deeper and complex rock formations. It is not very easy to extract oil and gas from the reservoirs that are formed in complex formations. For drilling these type of reservoirs, conventional drilling method are properly unstable to manage and has provided very insufficient results.

Traditional conventional drilling method is basically designed by rotating a drill string with a bit attached to its BHA. A casing pipe is arranged down in a hole, after the each drilling intervals have been drilled. In the past, this method was very efficient and economical in drilling operations. As the oil reservoir profiles are getting deeper and complex, tremendous amount of challenges such as wellbore instability, stuck pipe, lost circulation etc. are revealed. If all the following concepts are not taken into account overall drilling project would be very unreliable, uneconomical and unsafe. The tendency related to such limited situation has obliged the industry to innovate new alternative drilling methods.

As a result of research analysing it has been suggested that to find a solution this problematic situation one of the best ways is to develop Drilling with casing technology or Casing while drilling (CwD). This is a unique method of operation that drilling and casing a well simultaneously. The method was discovered to mitigate relevant drilling challenges or to minimise real drilling constraints. One of the main achievements is to obtain minimised Non Productive Time (NPT) integrated with casing to be run.

By time, the popularity of this new innovative technology is being surrounded widely in all over the world. As it is getting developed it promotes additional benefits regarding with plastering effect, good hole cleaning, wellbore stability, rig time etc.

which all will be indicated with further details in the following chapters. [2]

Project Scope

As mentioned in abstract section, the scope of this project is aimed to investigate the problems associated with conventional drilling method, figure out the upcoming challenges and analyse how the Casing Drilling technology would be profitable to solve the problems that conventional drilling method could not deal with. Furthermore, study will also provide further information with different types of Casing Drilling, specific tools, benefits & drawbacks of this technology. Moreover, main comparison analysis between Casing Drilling and Conventional Drilling will be covered as a main part of project scope. Design considerations will give relevant comparable factors between two methods and investigations will be conducted why Casing Drilling technology should be utilised in given field area.

Project Objectives

Main relevant objective layouts of this project are classified as followed below:

- Making a research and collecting relevant material, case study
- Planning and determining the key objective points
- Reviewing the conventional drilling process and analysing its performance in terms of benefits, drawbacks
- Making a description about physical components, historical background of Casing Drilling technology specific equipment that are used in Casing Drilling Technology
- Describe operational aspects of the drilling with casing system which includes the different types of casing drilling systems
- Understanding and learning how Casing Drilling Technology is designed to operate in drilling wells
- Experience the advantages and disadvantages of Casing Drilling Technology
- Investigating Casing Drilling method in South Pars gas field, Persian

Gulf and proposing new well design to drill with CwD method.

- Conclusion and Future work

Project Methodology

The project will commence by exploring conventional drilling method. This will comprise a common study of the conventional drilling process, its associated assembly parts and certain drilling problems associated with its operation. The project will then be maintained information about Casing Drilling Technology based on a number of technical papers, journals published by SPE and other organisations. In order to understand some relevant impacts of Casing Drilling Technology on casing it will be designed a new well scenario based on the field data results that l computed.

Project Layout

This project layout is designed in eight chapters as followed below:

Chapter I – covers a common overview of the project layout and gives a detailed description about conventional drilling method. The chapter will provide a brief overview on what the conventional drilling method is and how it is operated in drilling industry.

Chapter II – looks at a detailed description about casing drilling technology. Reviewing the conventional drilling process and analysing its performance in terms of benefits, drawbacks.

Chapter III – gives a detailed explanation about the benefits casing drilling technology. the main advantageous factors providing by this technique such as increasing wellbore stability, reduce the risks to stuck pipe, plastering effect will be discussed.

Chapter IV – this chapter will mainly provide information on buckling, fatigue and hydraulics and torque analysis while Casing Drilling method is developed.

Chapter V– implementation of this technology in this actual well and mathematical approach in the designing well program will be discussed in this chapter.

Chapter I - OPERATIONAL RELIABILITY ASSESSMENT OF CONVENTIONAL DRILLING METHOD

1.1 Introduction

In the past the method utilised to drill the wells with the cable tools was recognised as the earliest technology in drilling history. Rotary drilling method was invented to drill the wells. Nowadays, there are large number of wells that are being successfully drilled by the rotary drilling method.

Rotary drilling method was considered one of the sufficient technique for drilling the wells until the Top Drive mechanism was discovered. Innovative changes and new technology were promoted by Top Drive. This system was mainly operated by hydraulic motor which rotates the casing in the wellbore.

The chapter will provide a brief overview on what the conventional drilling method is and how it is operated in drilling industry. Additionally, further considerations will also be stated about the problem (formation and mechanical) that which conventional drilling method is unavailable to deal with them.

1.2 Investigation of drilling mechanization and automation.

Cable tool drilling method and process

The *cable* tool drilling method is the earliest drilling technique in drilling industry. This method was mainly operated by a wire cable. A chisel was supported from the edge of a wire cable and was designed to make impaction continuously on the bottom of the hole, cutting off the formation. Water was used alternatively by pouring down the hole when the rock at the bottom zone had been collapsed. In other words, a long cylindrical bailer was placed down the hole to gather the rock chips. According to some literature sources, cable tool drilling method was developed until the 1930s and was able to drill around 7500ft depths. This method had surely serious drawbacks because it was an oldest and not professional technology.

Rotary drilling method & process

New drilling method was invented after cable technology and this was a rotary drilling technology. Rotary drilling system has been generated to use in drilling industry for many years. The system is mainly designed to drill a hole with drill bit by rotating the drill string in BHA.

The operational process was developed by using rotary drilling table and kelly to rotate a drill pipe. In other words, this is such drilling method that by rotating the drill string and providing mechanical energy to the drill bit destroy even the most complicated formations of earth's crust. Rotary drilling system and process have been given schematically in Figure 1-1 (refer to Appendix-1). As can be seen from this figure, after rotating process commences, drilling mud is pumped down to the annular area which are between borehole and drill pipe in order to lift the cuttings upwards. In other words, the main rig operation in rotary drilling method are prime mover, hoisting equipment, rotating & circulating equipment.

Rotary drilling method is operated as the hole is drilled by a rotating bit which is jointed to drill string in BHA composed by drill pipe and drill collars. At the surface of the rig, there is a rotary table (Figure 1-1) which is designed to provide rotation for drill string. Drill collar which is one of the drill string components that provides weight on the bit. Weight on the bit is very essential factor in drilling operation.

These operational processes are continuously repeated for each determined depth intervals. Therefore, after reaching to first definite depth, drill string is eliminated and casing pipe is located at the casing shoe. In conventional method, tripping operation of drill string is conducted during the drilling process.

Top Drive drilling method & process

In the 1990s, the rotary drilling method was replaced by a new drilling method called Top Drive drilling. This new system was mainly supposed to deep offshore drilling rigs in which top drive systems were installed in the surface derrick. A top drive system consists of a power swivel that is driven by a 1000 horsepower dc electric motor. This method is mainly designed as a mechanical device that is utilised to turn and prepare the drill string for drilling operations. As shown in in Fig1-2(refer to Appendix-1), system is suspended from the derrick or rig mast. It contains an electric or hydraulic motor which is connected to a short section of a pipe called the *quill*. As the top drive is suspended from a hook below the traveling block, it is able to travel along the derrick. On the rotary table, it is very common in practice to utilise slips on it, therefore the drill string cannot fall into the well. It makes supportive function for drill string.

In this system, the power swivel replaces the conventional rotary system, although a conventional rotary table would generally, also be available as a back-up. Top Drive method has some benefits that differs from rotary and Kelly system. One of the main advantages of this method is this system able to maintain stuck pipe problem and economically good method. The most important progress that this method achieve is in reduction the demand for labour work in drilling floor, which means reducing risk of human factor and safe environment.

1.3 Core Analysis Challenges and Solutions associated with Conventional Drilling Method

By operating conventional drilling method in some wells, it has been observed that there are some problematic and risky issues. As the reservoir profiles are getting complicated, to use conventional drilling not only creates some problems in drilling wellbore, but also cannot manage to deal with these problems. The problems associated with conventional drilling method are mainly related to well instability, stuck pipe, lost circulation. Therefore, this parameters will be discussed in the following part of this chapter.

1.3.1 Well stability

The problems related to well stability are often happening as a result of tripping operation of drill string. The issues that tripping leads to are classified as below:

- Swabbing happens when the drill string is lifted up from the well bore. As a result of decreasing wellbore pressure, swabbing happens as the drill string goes up the wellbore. If this trend continuously occurs and pressure gets lower than the limited formation pressure, then well would go to kick.
- Surge (wellbore) pressure is being increased as a result of mud displacement while the drill string is being going down to the well. If the pressure increase is greater than the formation pressure, then formation damage can occur which will result in being lost circulation.

Furthermore, formation fluid begins to flow up the wellbore when the primary control of the well is lost and this would be resulted in BOP (blow out preventer) to be closed to seal annulus. [9] By maintaining this mud transport will be controlled in the wellbore. Therefore, the pressure in the well will increase until the pressure exerted by mud on the kicking formation will be the same as the formation pressure.

1.3.2 Stuck Pipe

One of the main drawbacks associated with conventional drilling is stuck pipe problem. Theoretically, it is said that “pipe got stuck” means pipe cannot be rotated or moved, which is resulted in serious problem in the drilling operations. In principle, there are three categories of stuck pipe which are:

- Differential sticking - as a result of changing mud pressure (getting higher than formation pressure) and this leads to occur differential sticking.
- Mechanical stuck pipe – this problem happens when the BHA is not possible to be contributed because of mobile formation.
- Pack off stuck pipe – this problem happens if there is large amount of junk around the drill string or BHA. This incident is also recognised as accumulation of

cuttings.

As a consequence, if the drill pipe got stuck, engineers usually pump proper chemical downhole in order to dehydrate the filter cake. Generally, prevention and remedy of stuck pipe depends on the reason to problem. If the pipe becomes stuck, every effort should be made to get rid of this problem quickly. [15]

1.3.3 Lost Circulation

Theoretically, lost circulation refers to the meaning that losing drilling fluid to the formation. This problem happens when very permeable formations have enough pore spaces that mud can easily go into the formation and fractures which have been formed during the drilling operation. As remedial treatment, Lost circulation material (LCM) is used which is mixture of clay, mica, ground nut shells and sawdust. BY pumping this LCM into the problematic zone, after a definite time there will be formed filter cake which behave as prevention.

In the South Pars field, the conventionally drilled wells experienced losses of fluids and on tremendous occasions this forced the operator to set the casing to a lower depth than planned before.

1.4 Summary

To summarise, it is stated that conventional drilling method was very successful in the past history but the scope of operational performance does not meet today's standards in some particular cases. Many problems are revealed which are associated with convectional drilling. To optimise drilling project, operators and proper related engineers are always keeping these issues under control and trying to find an alternative solution methods.

In the next chapter, the studies have been developed with Casing Drilling phenomena. This innovative technology can be considered as a modern invention to Drilling industry.

Chapter II – STUDY OF OPERARING METHODOLOGY AND DESIGN OF CASING DRILLING TECHNOLOGY

2.1 Introduction

As a result of drilling operations and petroleum reservoir exploration which have been lasting for many years, drilling processes have faced very complicated environment with full of problems. Today, most of the drilling jobs are operated in much depleted reservoirs, troublesome zones, HPHT wells, the areas enriched with shale gas etc. These zones are very challenging and can cause a big problem at any time. As we discussed in Chapter I, conventional drilling is not perfectly designed system to tackle all predicted problems it may has. Therefore, new technology is quite helpful in all possible problems that will be investigated.

Casing Drilling technology has been utilised in numerous wells that have complex structural zones. In order to drill through troublesome well sections that conventional drilling techniques have not been ideal to manage with difficulties. As a principle, in casing Drilling technology casing is operated to supply drill bit with mechanical and hydraulic energy. By optimising this technology it is not only achieved an easier way of energy transmission, but also saving time and cost, prevention with possible drilling problems. In these days, the issue associated with this technology is still unclear for some people that how it is proceeded if the well is drilled with casing instead of conventional drill pipe and what kind of risks and benefits are expected?

Consequently, this chapter of project layout will cover an introduction to the casing drilling technology which includes historical background, Casing Drilling types and appropriate equipment/tools that are used in drilling operation.

2.2 Historical development of Casing Drilling Technology

According to historical sources, date for the first patent of casing drilling back to 1890, in which a rotary drilling process was applicable for drilling the well with the casing and retrieving the expandable bit hydraulically. In 1926, another patent presented this technology with new designing drill bits, such as a retrievable and re-runnable casing bit. This patent was differed from the previous one due to its innovative designing as drill pipe is eliminated, reductions in overall drilling time, stuck pipe, crew and drilling costs. The first casing drilling system is shown in Figure 2-1 (refer to Appendix-2).

However, in the 1960s, the first substantial work on casing drilling was completed by Brown Oil Tools Company. This patent developed a casing drive system which comprised down hole and surface tools were used to drill with the casing and retrievable bits. Casing centralisers, wire line retrievable drilling assembly, under reamer, casing drive tool and top drive components all were covered in this patent's design. Unfortunately, at that time this model's performance were unsuccessfully operated due to the limited availability of the technology. Although a long time had passed from the time that last patent made, the same patent innovated and developed the model again. As a result of his/her contribution towards to new model, the first top drive was generated.

In the late 1990s, the casing drive system developed by Tesco Corporation Ltd was approved and licensed by Drilling industry. Consequently, this system made successful improvement towards well cost reducing and NPT minimisation.

2.3 Mechanical Design Considerations of Casing Drilling System

In real industry, Drilling with casing (DwC) or Casing while Drilling (CwD) has been alternatively optimised towards new drilling technology. Basically, this method is included coincidental drilling process with casing of well which comes with a casing string. In this method, drill pipe and drill string components in conventional method are replaced by casing string. Traditionally, casing is put into rotary motion and cemented in the well at the total depth (TD). Nowadays, this method is be utilised in a several of ways but can be classified into two main categories namely,

Retrievable - incorporates its BHA which is arranged inside the retrievable casing which includes a motor to rotate a pilot bit and under reamer. It also consists of a wire line winch, which is used to retrieve the drilling assembly

Non-retrievable - casing is operated as main tool but it is only used to make rotary torque and definite weight on the bit. Additionally, there is no any demand for extra tripping in order to retrieve the BHA after reaching a TD.

In Figure 2-2 (refer to Appendix-2) it has been illustrated the Bottom Hole Assemblies (BHAs) for two type of CwD and the conventional drilling method.

Retrievable Casing Drilling

In this type of CwD special retrieving tool retrieves the BHA after definite TD is achieved. By using this it allows the pilot bit to be replaced or kept away from the hole prior to cementing job. Generally, this type of casing drilling system is only compatible with directional wells, but can also be operated in vertical wells alternatively. In this case, for directional drilling designed casing size defines possible and expected build up rates.

Nowadays, in industry Tesco Corporation Ltd is recognised as a major provider of retrievable casing drilling. It has been revealed by Houtchens et al, 2007 [3] that over 280 wells and more than 2 million feets of hole have been drilled with casing drilling method between 1999 and 2007. In these wells, casing drilling technology has been successfully operated to drill in various complicated lithology. In the Table 3-1 below, the summary of statistics on the retrievable BHAs of CwD system is shown. The wells have been drilled with an application of CwD between January 2001 and June 2006 by Tesco Corporation Ltd. According to the table, totally 890 BHA retrievals were made and 822 out of total 890 were applied in vertical wells, the rest 68 retrievals were in directional wells. It is also significant to note that 857 of total number of retrievals were successful (96%) and 4% left in fraction of the wells were unsuccessfully performed. [3]

Table 2-1: Summary of statistics on Unsuccessful and Successful BHA retrievals

Retrievable BHAs	Vertical BHAs	Directional BHAs	Successful retrievals	Unsuccessful retrievals
890	822	68	857	33
100%	92%	8%	96%	4%

Equipment used in Retrievable Casing Drilling

Casing drilling method is generated by contributions of the both surface and downhole tools that are doing sufficient work during the processes of casing in and off the well. To drill the formation, standard oilfield casing is used. The main tools/equipment used in retrievable casing drilling are

- Casing Drive System,
- Retrievable BHA
- Drill lock assembly

And they will be discussed briefly in the following section.

Casing Drive System

It can be seen from the Figure3-3 (refer to Appendix-2) that the whole system has been divided into 2 parts, such as downhole and surface components. These parts both contribute the casing to operate and make a hole concurrently as drill string does in conventional drilling method. Basically, top drive in retrievable Casing Drilling is aimed to operate as the same functions as it does in normal drilling. Moreover, casing selection criteria due to its grade, size and etc. parameters is selected by the same criteria as it does in normal wells.

Connections of The casing may require a change from the conventional well design. In other words, in casing drilling systems for retrievable CwD method fatigue load, torsional load and enough flow hydraulic clearance have to be taken into account due to any change in casing connectors because casing is rotated. Here, both integral and coupled connections have been utilised successfully. Each joint of casing is picked up with hydraulically activated single joint elevators attached to the Casing Drive System arranged below the top drive. Casing Drive System also supports total weight of the casing string which applies torque in order to drilling and proceed circulation.

Casing Drive System in retrievable casing drilling system, also known as *casing quick-connect* is designed to have an internal spear assembly (casing fluid seal to pipe) and a slip assembly to control external and internal parts of casing. This contributes the casing to be placed into the drill string without screwing into the top casing coupling.

The use of the CDS accelerate operation of the casing handling and preserve damage to the threads. Casing connections are designed as fast as drill pipe connections, minimizes floor activity due to contributions of Casing Drive system and power slips. Hence, having perfect designed Casing Drive system and casing connections makes higher rig floor safety. [4]

Retrievable Bottom Hole Assembly (BHA)

In casing drilling technology, the casing itself is operated as hydraulic conduit and contributor of mechanical energy transmission to the drill bit, whereas these functions are referred to drill string in convectional drilling. As can be seen from the figure 2-4, very short wireline retrievable BHA contains a bit and under reamer which can be easily expanded. Practically, BHA is aimed to utilise to drill a hole and make a free place for casing to pass through the hole.

If we are talking about BHA system of retrievable casing drilling system, we should write talk about its wireline unit component, which is utilised to retrieve the BHA attached to a drill lock. The wireline retrievable drill lock assembly is the heart of the casing drilling system. Basically, it goes down in a lower part of casing containing of a shoe zone, torque lock profile, axial no-go and lock profile in a specially machined collar section. Furthermore, the drill lock is designed to deal with both a fluted profile to transmitting torque from the casing to the drilling assembly and transferring of compressive and tensional loads to the BHA from an internal flush no-go and axial lock profile. In order to diminish lateral motion of the assembly inside the casing, a stabilizer on the BHA is utilised, which is arranged opposite the casing shoe. In Figure 2-4 (refer to Appendix-2), BHA for retrievable type of casing drilling method is shown.

By covering the casing shoe with hard material to make sure that a full gauge hole is drilled ahead of the casing. However, if the under reamer drills into under gauge, then the casing shoe provides a torque indication. Whereas, centralizers on the casing make it stable within the borehole and prevent wear on the couplings. [5]

Drill Lock Assembly (DLA)

The retrievable drilling assembly is attached to the bottom of the casing in a profile nipple, come with the Drill-Lock Assembly (DLA) together. This is the main critical component that make conventional drilling tools to be run and retrieved through the casing. In other words, the casing is getting connected by conventional drilling tools with rotary-shouldered connections.

Moreover, DLA contributes the performance of these tools in and out of the casing. If we look at its profile sketch (refer to Figure 2-5, Appendix-2), it has been placed at the top of the BHA and main functions of DLA is to unlock the BHA by axial and torsion loads. And the seals in the casing to direct the drilling fluid (mud) through the bit and bypasses fluid around the tools for running and retrieving. The BHA can be run and retrieved in deviated wells with inclinations higher than 90° and the DLA can be released with a pump down dart before running the wireline. [4]

Non-retrievable Casing Drilling

Around 80% of the casing drilling operations are sufficiently made by non- retrievable systems. This is a non-steerable and costs less than retrievable system. Basically, it has been used in vertical drilling wells with a drill shoe connected to the end of the casing. Nowadays, the main provider of this type of Casing Drilling technology is Weatherford. Since January 2000, Weatherford has been operated over 300 drilling projects with non-retrievable casing drilling system. Weatherford also lately completed its first drilling with casing activity in the Java Sea, Indonesia from a floating drilling unit.

Equipment used in Non-Retrievable Casing Drilling

In practice, it is widely utilised the same top drive, casing connections as it is used in the retrievable casing drilling system. Specific tools that are used in this type of system will be briefly described in this part of the section.

Overdrive system

The overdrive system designed and evolved by Weatherford as can be seen in Figure 2-6 that is operated in Casing drilling process. As a tool component of non-retrievable system it is combined with rig's top drive system and compatible with any top drive system. Top Drive, Overdrive and Hydraulic Elevator components have been neatly labelled in the Figure 3-6.

One of the main components of Overdrive system is TorkDrive tool which is shown in Fig 2-7. Because of rotational power is generated by the top drive, the TorkDrive tool makes up or breaks out the casing thereby performing the duties, which would have required equipment, scaffolding and personnel on the rig floor. This device is utilised in order to circulate, reciprocate and rotate the casing during the operation. Moreover, it also provide ideal system with reducing any possibility of differential sticking and other related issues. [3]

Figure 2-6: Overdrive system [10]

Figure: 2-7 TorkDrive compact [10]

Float Collar

Before loading the equipment to offshore platform, the float collar and the drill shoe are made up to a casing joint. In the Figure 2-8, (refer to appendix-2) Float Collar is shown. It is already installed within the drill string during the drilling operation, cementing job is started after drilling operation is reached to TD. This contributed the operation to make a single-trip procedure which is not only resulted in reducing operational cost but also saving a time.

Casing Drill Shoe

In non-retrievable casing drilling type, casing drill shoe is also considered as its component of operational equipment. It is basically casing drill bit which has been attached to the end of the casing string. There are different type of drill shoes are designed and all are given in Figure 2-9. For design considerations, the drill bit is made to deal with any kind of formations that should be drilled in different drilling intervals. There are three types of drill shoes that Weatherford utilise widely in operations, which are drill shoe I, drill shoe II and drill shoe III. [3].The main featured differences among these drill shoes have provided in Table 2-2 below:

Table 2-2: Main features of different types of drill shoe [3]

	Drill Shoe I	Drill Shoe II (3 Blades)	Drill Shoe II (4 Blades)	Drill Shoe II (5 Blades)	Drill Shoe III
Drillable formation	Very soft, soft and unconsolidated formations	Soft to medium, soft formations	Soft to medium, soft formations	Soft to medium formations	Medium to medium hard formations
Compressive strength(psi)	2000	7000	7000	7000	15000
Cutting Structure(on casing body)	Carbide	Thermally stable Polycrystalline diamond(TSP)	TSP diamond	TSP diamond	Carbide
Cutting structure (Drillable core)	Dense, thin layer of tungsten carbide	Polycrystalline diamond Compact (PDC)	PDC	PDC	PDC on steel blades
Number of blades	3	3	4	5	5 through 9 5/8 x 2 ¼ could also have 6
Sizes (inches)	9 5/8 to 20	4 ½ to 30	4 ½ to 30	13 3/8 x17, 18 5/8x21	7x8 ½ , 9 5/8x 12 ¼
Casing string attached	Conductor and surface	Surface or intermediate	Surface or intermediate	Surface or intermediate	Surface or intermediate


Drill shoe I


Drill shoe II (blade4)


Drill shoe III

Figure2-9: Different types of drill shoe [3]

Commonly, in conventional drilling drill bit has been designed as non-drillable. However, for non-retrievable type of casing drilling technology, all type of drill shoes above should be capable to optimise hydraulic performance by integrating with their interchangeable nozzles. According to Table 2-2, it presents the different performances in various formations drilled by these drill shoes, their sizes, compressive strengths, cutting structures, blade and the casing strings attached to them. Consequently, it can be integrated with the idea that in assemble of a drill bit contribute with soft steel and hard cutting materials. Likewise, they can be utilised in soft to hard formations.

2.4 Casing Protection Investigation

If we are talking about casing equipment in Casing Drilling, It is crucial to mention casing protection accessories which provide the casing with perfect coverage that makes it non-damageable(against damage) after drilling operations. In other words, casing is also necessary to utilise in well completion after drilling process. Thus, Casing wears protection accessories are very important in casing design considerations. Commonly, these accessories will be described in this section below.

Wear band - one of the casing protection accessories is wear band. The wear band is in a ring shape and made of metallic coated with tungsten carbide hard facing. To ensure casing strength of connection, wear band is used and placed below the coupling.

Wear Sleeve - this casing protection equipment is in a cylinder shape and made from steel with ample contact area. It can be placed on any part of the joint as required in design consideration. The main difference from wear band accessory is the sleeves are not coated with tungsten carbide hard facing. One of the casing protection accessories is wear sleeve is shown in

Centralizers - this accessory is used in order to provide stabilization, directional performance, wear management, key-seat control and centralization for cementing. The centralizer are usually placed on the outside diameter (OD) of the casing and Casing with a friction is connected with strong-faced and tough blades make it enable for rotation of the casing. However, in directional casing drilling, the casing is jointed with centralizers are non-rotating type made from zinc alloy. This is normally utilised in directional casing drilling to decrease torque.

2.5 Summary

To conclude, due to technological limitation in the past the patent could not be developed as a perfect system. However, in 1990s Tesco Corporation innovated the first casing drilling system, which is quite sufficient.

It is stated that there are two types of systems such as retrievable systems which were innovated by Tesco Corporation and non-retrievable systems which were innovated by Weatherford.IN retrievable drilling system, after casing is reached to the TD, the bottom hole assembly (BHA) is retrieved, whereas in non-retrievable systems, after casing is reached to the TD the bottom hole assembly (BHA) is stayed in the hole and drilled through.

In terms of equipment that used are designed in a same way for both Retrievable and non-retrievable Casing Drilling types, however the only difference is identified in their BHA tools.

The next chapter will cover the benefits of Casing Drilling technology as they are utilised in mitigating the problems associated with Conventional Drilling.

Chapter III - EVALUATION OF EFFECTIVENSS OF CASING DRILLING TECHNOLOGY (CwD)

3.1 Introduction

For many years, in drilling process Non Productive Time (NPT) has been a key factor that drilling engineers always try to find the ways of prevention and optimise drilling process. The problematic concepts are leads to NPT can be emphasized such as wellbore instability, stuck pipe, lost circulation, formation damage. Casing Drilling technology is an innovative method that is able to solve most of these problems. In other words, the original purpose of developing CwD technology is to eliminate NPT associated with running casing, saving time and cost, provide the drilling rig a safer environment to work. Some other necessary benefits of this technology have been obtained in different types of drilling wells.

In this chapter, the benefits of Casing Drilling methodology and characteristic differences with conventional drilling will be covered in details. Furthermore, the main advantageous factors providing by this technique such as increasing wellbore stability, reduce the risks to stuck pipe, plastering effect etc. will also be discussed.

3.2 Wellbore stability

One the main advantages of Casing Drilling technology is to help in solving the wellbore instability problems which are usually integrated with conventional drilling method. As it is known, in conventional method tripping process causes lots of problems related to wellbore instability. The most common issue is swab and surge pressure that cause well control incidents or lost circulation. In other words, if the well is not circulated properly from bottom of the wellbore this is risky concept and can leads to stuck pipe problem while tripping in the BHA. Consequently, this technology completely eliminates the problems associated with tripping operations. Furthermore, after reaching TD and before running the casing, there would not need any washing and reaming operations. This may result in wellbore instability issue as well.

Casing Drilling method also helps to save time in drilling process. This also means a decreasing the risk of wellbore instability occurrence. On the other hand, this new method gives the chance to operate cementing job as soon as the interval is reached at TD and ensure every foot drilled is kept. It means an advantage for selection of casing setting depths.[8]

Problems in the wellbore like barite sag, hole pack off and stuck pipe can be resulted by very poor borehole cleaning. These problems create much bigger issues if well scenario is designed for horizontal and directional drilling in which transportation of cuttings is quite difficult to deal with. From hydraulics design aspect, Casing Drilling are made to use a lower flowrate to produce an ECD is higher than observed in a conventional drilling method. This higher ECD is also considered a negative aspect of hydraulic design due to lost circulation and higher susceptibility of fracturing the formation. Consequently, Casing Drilling method with higher ECD is operated successfully to act against borehole collapse and improves wellbore stability successfully.

3.3 Stuck pipe

Stuck pipe is one of the most common drilling problems which is both expensive and time consuming. In the past, this was the one of the main drilling problems especially for large diameter pipes. However, experience over many years has proved that casing does not get stuck in troublesome zones and the method is invented tends to solve an associated risks for stuck pipe. Nowadays, wells with stuck pipe problems are considered as good candidates for Casing Drilling method. Generally, the term of “stuck pipe” means when the pipe cannot be rotated properly and this leads the drilling operation to be problematic. As discussed in previous chapter, stuck pipe is analysed based on three type evaluations, which are discussed below.

3.3.1 Differential Stuck Pipe

In order to calculate differential stuck pipe, formula provided in Equation 3-1 is applicable. According to this equation, in casing drilling technology contact area
(A) is noticeable large and it will promote the idea of stuck pipe as risky issue. On the other hand, this method provides very good filter cake quality and which decreases differential pressure in the system due to pressure transfer.
As a result of low differential pressure, there will be less differential sticking force. Furthermore, there is very small probability to have sticking at one point compared to conventional drilling as the casing is continuously rubbing and sliding in casing drilling method. [8]

$$F = A \times \Delta P \times f \qquad \text{(Equation 3-1)}$$

Where:

F – Differential sticking force (lb)
A – Contact are (in^2)
ΔP –Differential pressure (psi)

f − Friction factor

3.3.2 Mechanical Stuck Pipe

Mechanical stuck pipe is occurred when the bottom hole assembly (BHA) is pulled into either a mobile formation or under gauge hole. It is clear that tripping operation is a part of conventional drilling method and this allows the formation to occupy the wellbore. Luckily, CwD method is able to prevent the formation from collision with the wellbore and it is immediately cemented as the casing reaches TD. By keep doing this way, casing can be kept from related dangers.

3.3.3 Pack-off Stuck Pipe

When drilling through unstable formation which causes a mixing of an undrilled mud with solids. In this case, packing-off concept is concerned. In terms of wellbore cleaning operation, it is necessary that higher annular velocities and casing's continual agitation of cutting zone ensure about transportation of all cuttings out of the hole as quickly as possible.

On the contrary, for conventional drilling if the pipe gets stuck, some attempts are made to free the pipe, like jarring. If this does not work, then there is a risk that BHA goes off or well can be lost. However, with the aid of Casing Drilling, these danger risks are minimising to zero.

3.4 Formation damage

Formation damage may occurs during normal drilling process. Theoretically, this problem is caused by loss of fluid in the wellbore. In this case, plastering effect is optimised by casing drilling method (will be covered in the next section below) allows to prevent the fluid loss by creating a bridge in the wellbore after it has been drilled. Likewise, during CwD operation mud cake is formed which is less permeable and less porous. On the contrary, in conventional drilling such mud cake thickness and desirable filtration results cannot be achieved successfully and it leads to happening formation damage easily. And this is illustrated visually as in Figure 3-1 shown below.

As a result of good controlling formation damage will allow to stop movement of drilling fluid into the formation and provide safe wellbore. Therefore, reducing formation damage by plastering effect (as a part of Casing Drilling) gives an advantages to improve productivity of the wells drilled with the casing the reservoir section. [8] This means the reduction in skin factor and the damage radius caused by drilling which provide better productivity with casing drilled wells.
In the next section, it will be given further information on how plastering effect works in Casing Drilling technology.

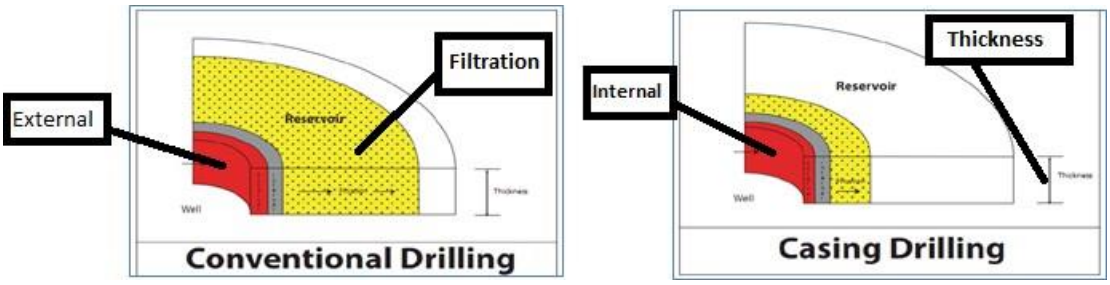


Figure 3-1: Mud cake formed by casing drilling prevents the fluid loss to the formation and therefore solves the drilling-induced formation damage. [8]

3.5 Lost circulation

The concept of Loss circulation can be explained as losing of drilling fluid to the formation. Casing Drilling reduce mud loss to the formation. Mud cake with very good quality maintained by plastering effect seals off the wellbore and helps to prevent fluids transfer to the formation from the wellbore.

3.5.1 Plastering effect

The cuttings in the wellbore are crushed and smeared against the formation in the drilling process. This action is related to combined force of high annular velocity, placing of casing closely to the wellbore and rotation of casing. As a result of these cases, a wall cake is formed which is much less permeable. Wall cake behaves as a filter cake and provide minimum loss of fluids to the formation.
According to the particle size analysis test results, casing drilling method provides smaller size cuttings than that conventional drilling does. Along the way of movement trajectory of the cuttings, these cuttings are crushed and grinded by casing string. And

cuttings meet with plaster on the wellbore wall. It is a barrier to stop the flow of drilling fluids to the formation.

In the Figure 3.2, the mechanism of plastering effect has been shown with different scenarios. [8]

In the first case - A, it is shown that the casing is forced against the bore wall as it advances into the borehole.

In the second case - B, it is shown that as mud is smeared into the formation, filter cake builds up on the borehole wall.

In the third case - C, filter cake and cuttings are plastered against the borehole wall and sealing porous formations.

At the end of the processes (case C), the thick filter cake and the cuttings are being plastered onto the formation face as the casing is rotated in the well. By creation of the barrier on the formation, there will be no additional space for the drilling fluid to move into formation. On the other hand, plastering effect also gives opportunity to increase the fracture gradient of the formation near the wellbore zone which is very good for mud weight selection.

A B C

Figure 3-2: Plastering effect mechanism [8]

In comparison with conventional drilling, for casing drilling method small annulus and lower flow rate is required in order to have an effective mud circulation. Lower flow rate not only helps to reduce the loss of mud, but also controls ECD to prevent additional exerted pressure on the formation. On the other hand, higher annular velocity provides very efficient wellbore clean-out result. And small annulus helps in operations of filling up the back side of the casing. Overall, according to these following advantages casing drilling method helps in cooling off the connections and optimise very good well control.

While drilling conventionally, the losses as described above happen the drilling process has to be stopped so as to cure the losses by arranging cement plugs which in turn results too many time of NPT. Casing Drilling method allows the operator to perform drilling as once the casing has passed the loss zone, trouble is behind and the well is cased, secured and ready to be cemented. This method has specific advantage that if the drilling process is continued and plastering effect starts to heal the loss zone which is resulted in mud returns are re-established. It is significant case if the loss zone is in the section above the bit.

3.6 Study of associated drawbacks.

Casing Drilling technology has provided a number of benefits to the drilling operations in an effective way. By operating this method, it has been obtained huge amount of improvements towards in solutions of conventional drilling problems, such as borehole stability, stuck pipe, lost circulation. However, this new technology has some challenges that are inevitable. Limitations are mainly associated with CwD are as stated below:

- Changing/replacement of bits or bottom hole assembly (BHA)
- Casing Connection and Dog Leg tolerance
- Formation Evaluation
- Cementing

In this chapter, it will be discussed about the drawbacks and limitations of CwD technology.

3.6.1 Replacement/Change of bits or bottom hole assembly (BHA)

As we know, in Drilling with Casing technology that tripping operation is removed and downhole tools are retrieved by wireline through the casing. Replacing/changing the bit or BHA is also operated by wireline retrieval performance. However, very frequent wireline retrieval performance most likely leads to some unpredictable problems which means wellbore instability.

3.6.2 Casing Connection and Dog Leg tolerance

In terms of design considerations of CwD technology it is fact that casing connections are unable to bear high fatigue, torque and compressive loads in buckling environment. Therefore, drilling with casing technology is limited to drill with relatively low torque, low WOB and with reduced hole sizes buckling is kept as low as possible. Also, as a result of buckling effect, dogleg tolerance is limited. It can be predicted to learn all effective factors to casing connections by utilising finite element analysis. [3]

3.6.3 Formation Evaluation

While the casing is placed, there is no possibility to conduct logging operation with traditional methods unless the casing is pulled above the zone and logged below the bottom. For solution LWD (logging while drilling), electromagnetic tools should be used. In order to figure out what type of logging to be operated depends on the formation and logging zone. All these jobs are generalised as a formation evaluation. [3]

3.6.4 Cementing

In this type of drilling method, once the casing is drilled to the defined setting depth, the BHA is retrieved by wireline. Therefore, the casing will not have a float collar to land the cement plug. In order to get solution for this problem, the displacement plug should be used and latch into the casing to serve as a float.

3.7 Conclusion

To conclude, tripping performance in conventional drilling is the main reason for tremendous problems that can be possible to be prevented by Casing Drilling benefits. It should also be noted that in Casing Drilling method, plastering effect has very large number of benefits. It allows the operators to solve lost circulation and formation damage problems, as well as optimising wellbore stability, wellbore quality, wellbore cleaning. Although the Drilling with Casing technology has some limitations and challenges, it is increasingly accepted as a practical method of reducing costs and solving relevant drilling problems. The method is very successful in softer formations and larger casing sizes. By optimising the technology with new approaches and solutions it can be overcome these followed challenges effectively.

Design considerations of Casing Drilling technology (CwD) will be discussed in the next chapter.

Chapter IV – DESIGN CONSIDERATION OF CASING DRILLING TECHNOLOGY

4.1 Introduction

Designing a well with Casing drilling technology is similar to design a well by conventional drilling. In designing plan, the first and one of the most important parameter is BHA concept. Mechanical energy is transferred to the drill bit by drill pipe and drill collar which are designed with a drill-string is the main design consideration for conventional drilling method.

In order words, drill string component in CwD method also allows a hydraulic conduit for the drilling fluids. However, the drill-string is pulled out of the hole each time the bit or bottom hole assembly needs to be altered or the final casing depth is reached. Hence, casing is run into the hole to make permanent access to the wellbore. Therefore, by utilising a casing for the drill-string, Casing Drilling System (CDS) makes an alternative approach to the conventional drilling method. While drilling a hole with conventional method, it may happen problematic situations while drilling process. But, CDS may not only reduce hole problems that are related with tripping operations, but also saves capital costs of rig equipment, operating costs. Additionally it eliminates costs associated with purchasing, handling, inspecting, transporting, and tripping the drill-string.

During a drilling operation well control, borehole stability, mud properties, casing setting depths, directional planning and bit selection should be controlled. These parameters are the most common considerations in designing process for conventional drilling as well.

One significant difference between them is that the casing is subjected to additional stresses while Casing Drilling. The main features, parameters for CDS considerations is shown in Figure 4.1. According to Figure 4.1, parameters for casing consideration such as elastic loads, fatigue, and wear are classified on the right hand side, whereas the parameters for operator control such as operating parameters, pipe properties, connector design, and well design are grouped in the left hand side.

Complex interactions relate parameters directly under operator control to the ultimate casing integrity. There is very significant point should be considered that most of the parameters/factors grouped in the Figure 4.1 can be deal with by operating conventional drilling method. However, three very remarkable factors such as buckling, fatigue and hydraulics are considered to pay attention while operating Casing Drilling method.

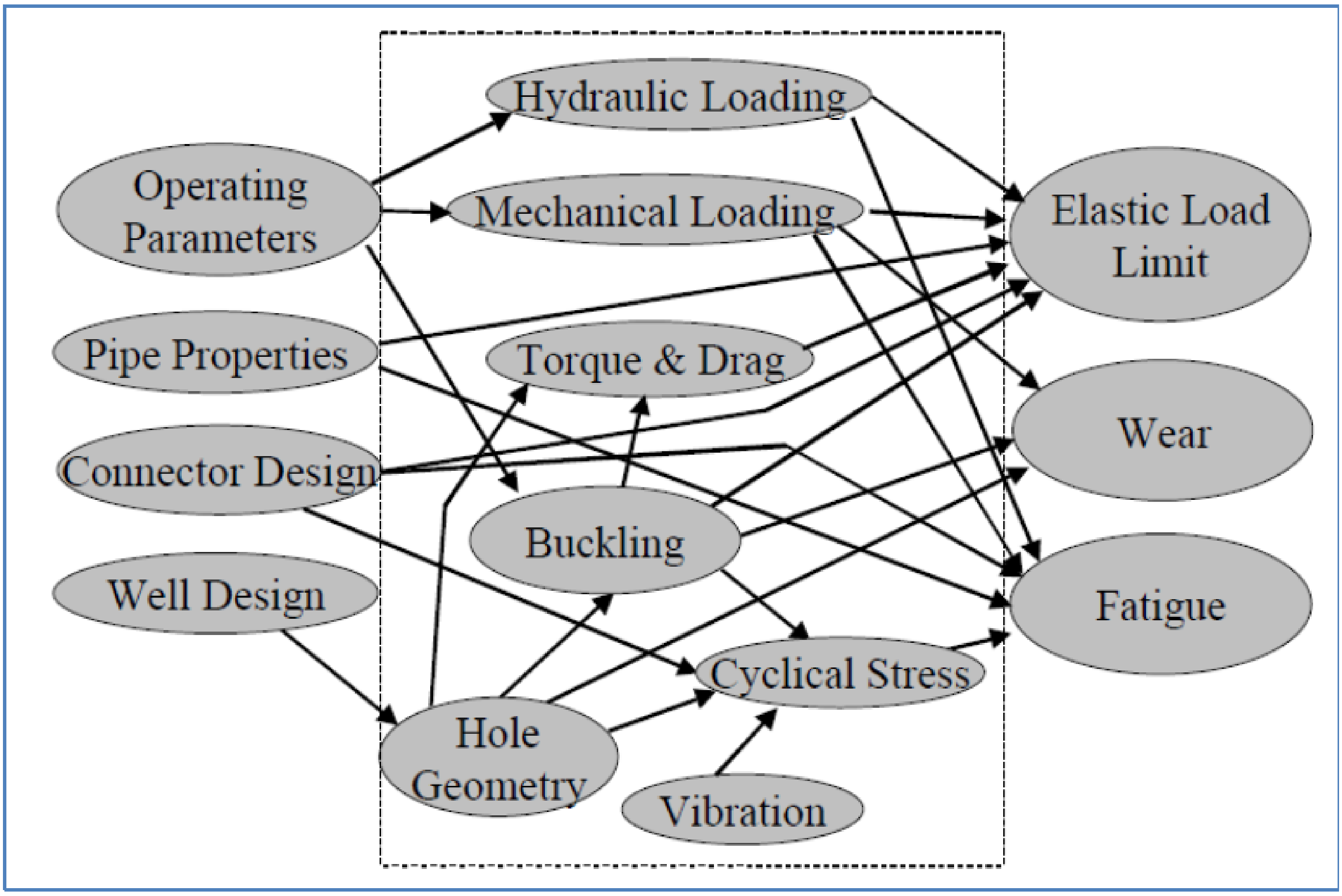


Figure 4-1: Design interactions affecting casing integrity for Casing Drilling applications [5]

4.2 Buckling

The main_difference between drilling with a conventional drill-string and Casing Drilling is that in Casing drilling method drill collars are not used to have weight- on-bit (WOB). According to drilling studies, it is needed to run drill collars in order to not having a buckling damage on drill string. However, the case will be different for Casing Drilling, because of not running drill collars.

The lower portion of the drill-casing will support only a limited compressive load before it buckles. Hence, buckling factor happens when the compressive load and casing/hole geometry provide required bending moment so that the casing becomes unstable. To have buckling in the system does not refer to a structural failure. The borehole wall around the casing allows the system lateral support to control the lateral deflection for any given set of parameters. [5]

Basically, buckling in the system can cause the issues following below

- Due to lateral contact forces, wear on the casing is created and it will increase the torque which is important for casing rotation.
- Due to the casing to be in a curved geometry within the borehole which will not only increase the stress in the pipe, but also increase the issue toward lateral vibrations.

For casing drilling application it is very necessary to figure out whether if the buckling is happened in the casing or not. Also, it is crucial to check the buckling issue out whether it will lead to serious problems such as high torque, high stress. In straight profiled holes, the compressive loads leads to occurrence of buckling which is determined by the stiffness of the pipe, lateral gravity force (pipe weight and hole inclination) and radial clearance. Whereas, buckling in a perfectly vertical holes is always caused by compression if the bore hole does not make lateral support through centralizers. Therefore, the normal wall contact force from the pipe on the low side of the hole gives a stabilizing influence and compressive load is increased that can be supported before the drill-casing buckles, if the well is straight, but not vertical.

By contrast, as the inclination going up in a curved hole the casing becomes more stable and becomes less stable, whereas the inclination is going down at a low curvature. The main reason for this case is related to casing becoming firmly against the borehole wall, because of axial compression which push the casing into the outside curve. Normally, when the buckling starts it turns the casing into planar, sinusoidal shape, whereas as axial loads grow up it makes it a helix, spiralling around the inside of the borehole.

As it was mentioned above, one of the two factors that buckling can lead to have wear on the casing. First, the bore hole wall contact force affects both the torque required to rotate the drill-string and the wear experienced by the casing. And the location of the contact figures out if the wear is localized to the casing couplings or if it also affects body of the casing.

Secondly, due to buckling case pipe curvature will affect the stress. If the stress level is high enough, the pipe can yield and fail. However, this level of stress is very rare experience for practical casing drilling conditions. At a lower level, the stress may influence the pipe fatigue life.

Consequently, many factors in addition to buckling have effects on both the wall contact force and pipe stress.

4.2.1 Approach to buckling calculation

In drilling engineering, determination of buckling factor can be determined in different ways. To approach the problem mathematically it is required to find out the formula and its basic considered assumptions. One of the solving methods is identified as followed.

While external pressure and the tension according to reducing casing weight is likehood of buckling, buoyancy and internal pressure contributes casing buckling due to weight on the bit (WOB) from compression. This phenomena can be described as following equations below:

$Fe = F\text{total} + p0A0 - piAi$ (Equation 4-1)

Where,

Feffective − Effective tension (lb)

Ftotal − Total axial load due to bending (lb)

P_0 −External pressure (psi)

pi − Internal pressure (psi)

$A0$ −External casing area (in^2)

Ai −Internal casing area (in^2)

Therefore, as can be seen from the equation 4-1, if the effective tension (Feffective) is < critical force (Fcritical), then buckling will happen in the system. Conversely, if effective tension (Feffective) is > critical force (Fcritical), then buckling will not happen in the system. On the other hand, casing can lead to be buckled if it is completely in tension according to high internal pressure(pi).

Therefore, critical force can also be determined by the formula generated by Lubinski et al [7]. According to his contribution towards critical force consideration, different type of buckling is determined and formulas derived based on the assumptions that Lubinski et al made as following:

- Casing is buckled into a helical shape, wellbore is considered as straight and vertical
- Pressure forces in the system are vertically distributed, friction forces are not considerable.

Appropriate formulas for critical forces affected by two type of bucklings are as below

- For helical buckling ,the critical force :

$F\text{critical} = 4.05(EMw2)1/3$ (Equation 4-2)

- For sinusoidal buckling, the critical force

$F_{critical} = 1.94(EMw^2)^{1/3}$ (Equation 4-3)

Where,

$F_{critical}$ − Critical force (lb)
E− Young's modulus of material (Pa)
M− Inertia moment (in^4)
w− Effective buoyed weight (lb/in)

Note that, M- Inertia moment can be calculated with casing diameter values

As can be seen from equation 4-2 and 4-3, as long as casing has larger size of diameter it will be achieved greater values for critical forces. The reason is that critical force proportionally depends on inertia moment and effective buoyed weight.

On a whole, according to different source of information there are various assumptions predicted for critical force and buckling determinations. On the other hand, these following equations can be considered as quite good approach to the buckling calculation. It would be necessary to note that there is also different approximations to determine buckling and critical forces in a deviated wells, which are out of our project objectives.

4.3 Fatigue

In designing performance of Casing Drilling, one of the main factors is fatigue that should be considered. The trend of fatigue failure occurrence is an inevitable that design engineers should focus on attentively. It basically happens when cyclical loading at stress levels well below the elastic strength. After this occurs, a small cracks starts at a point of localized high stress and develops through the body. This danger continues until the remaining cross sectional area is not sufficient to support the static load. Particularly, the number of factors effects on causing of failure which is required to have the number of stress cycles. However, trend range can change from a few to infinity cycles. In nature, fatigue failures are highly non-predictable for local conditions.

Another aspect of this failure has been observed on drill-string. Specifically, oscillating bending loads rather than torsional loads are main reason for drill- string fatigue failures. They mostly happen in the lower portion of the drill-string rather than at the top where the static tensile stresses are highest. In many cases a fatigue crack will result in a leak.

Therefore, most of the “wash outs” that are found in drill-strings are basically sign of fatigue cracks. These failures are often located in either the threaded portion of the connection or in the slip area of drill pipe. Theoretically, S-N curve is developed to investigate the fatigue life in a particular zone. Generally, S-N curve is integrated the alternating stress level with the number of cycles leading to failure. Generated S-N curve is shown in Figure 4-5 for D and E grades of drill pipes. According to the Figure 4-2, it can be clearly seen that fatigue is not plotted as a single line, it is observed as a group of failure zone.

The reason for this trend is related to fatigue testing nature. As the mean of the data, the S-N curve is mainly reported as a result of scatter plots for fatigue testing. Fatigue life varies with many small imperfections in the material and surface end.

Therefore, the result data shown in Figure 4-2 represents an endurance limit (failure does not happen if stress is below this limit) for the drill pipe which is nearly 20,000 psi. [5]

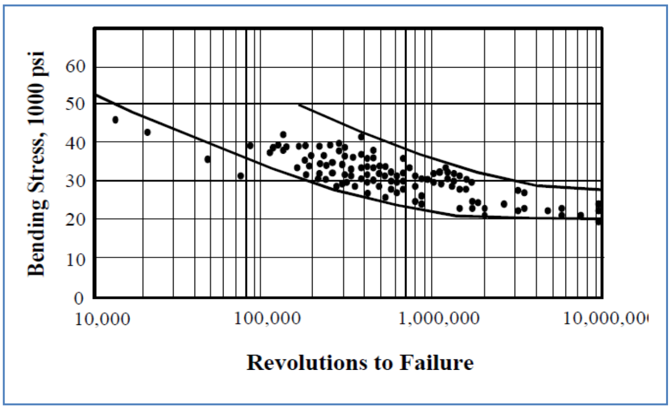


Figure 4-2 S-N curve developed for D and E grade pipes [5]

According to the literature about concept of fatigue, number of revolutions (cycling) is important to predict assumptions about fatigue failure by developing S-N curve. Thus, bending stress can be calculated with the equation 4 below.

$$\sigma_b = \frac{ED_0\pi\alpha}{360 \times 12 \times 100} \qquad \text{(Equation 4 − 4)}$$

Where
σb – Bending stress (psi)
$D0$ – Pipe outside diameter (inch)

It can be realised that the number of revolutions may lead to failure from the S- N curve can be determined by utilising bending stress value.

4.4 Torque and Drag Analysis

During the running of casing strings that resulted by frictional forces acting between the wellbore and the casing, the phenomena of torque is considerable. Casing drilling technology has been experienced higher rate in torque and drag rather than conventional drilling method. This associated with casing interact with wellbore conditions such as tight-hole conditions, sloughing shale, differential sticking and sliding during drilling process. The drill pipe is smaller than the size & weight of the casing.

When designing the well that will be operated with casing drilling method, it is very important to consider the torque and drag concepts. Torque and drag forces applied to the casing can also be analysed with the aid of a software such as Halliburton Well plan.
Torque can be determined with the aid of the Equation 5 as shown below [3]

$$T = \mu \frac{D_b WOB}{36} \qquad \text{(Equation 4 – 5)}$$

Where

T – Torque (ft-lb)
μ – Friction factor (dimensionless)
Db – Drillbit diameter (inch)
WOB – Weight on bit (lb)

It is relevant to note that drag can be estimated approximately as 20% of torque value, because of complicated calculation contents.

4.5 Hydraulics

Casing hole dimensions play significant role in hydraulics concept as they characterise a fluid flow path. There is a significant difference between the casing drilling and conventional drilling technology, since in CwD very small pressure loss within the casing ID (internal diameter) observed is related to excessive and unrestricted casing path. Hydraulically, the casing while drilling annulus usually makes a bigger restricted flow path which leads to higher pressure losses. With more restrictions to the flow path, it increases, making the annular velocities to be nearly uniform from the casing shoe to the surface. And this provides effective transport for cutting within the annulus and the hole to be cleaned with small flow rates in spite of many considerations need be made to the drilling fluid properties.

Therefore, in order to clean the bit and under reamer effectively there is demand for sufficient hydraulic energy. On the other hand, equivalent circulating density (ECD) factor also should be considered in the following cases above. Mainly, for casing drilling technology, ECD has been rated much more rather than that for conventional drilling method, even though it presented lower flow rates. [3]

4.6 Summary

To conclude, the relevant design parameters considered are very important which were covered in this chapter.

Buckling caused by compressive load that would never lead to failure of casing.

Due to cyclic loadings, fatigue can lead to be failure. Crack starts to appear at the localized point high stress and repeated loading can cause the crack propagating through the body.

Higher annular fluid velocity which is contributed by smaller annulus between the casing and borehole helps in the processes of cuttings removing and clearing. Well cleaned wells results with higher ECD which is appropriate for Casing Drilling.

The basic formulas are shown in this Chapter. However, the application of these calculation will be developed based on the real field results/data will be investigated later.

Chapter V - CASE STUDY OF CASING DRILLING TECHNOLOGY WELL DESIGN

5.1 Introduction

As a new drilling technology Casing while drilling provides operator with simultaneous drilling operation and case a wellbore section in only one run without the necessity to pull the drill string out of the hole. This new innovative technology plays significant role when oil and gas well drilling faces a number of challenges such as influx of formation fluids, formation instability, excessive lost circulation etc. It also improves wellbore stability, eliminates problems related to tripping of string, reduces loss of circulation, and has some environmental impacts. In other words, it is sufficiently applied into today's drilling activities in order to safely and economically deal with these real drilling challenges.

Last year, South Pars gas field has been successfully investigated as a part of "Petroleum Design" course from university. And the well design program was completed and drilling program was generated for Conventional Drilling method. As a result of studies in this well, some constraints have been identified. In this project it is suggested to investigate this well with Casing Drilling method and to analyse how it mitigates the corresponding problems associated with Conventional Drilling method.

In this chapter, it will be given further information about implementation of this innovative technology in this actual well and new well design will be created by CwD. As well as, design considerations for CwD such as buckling, fatigue, torque and drag, hydraulic optimisations while drilling a well using casing drilling technology. And it will also be analysed mathematical approach in the designing well program.

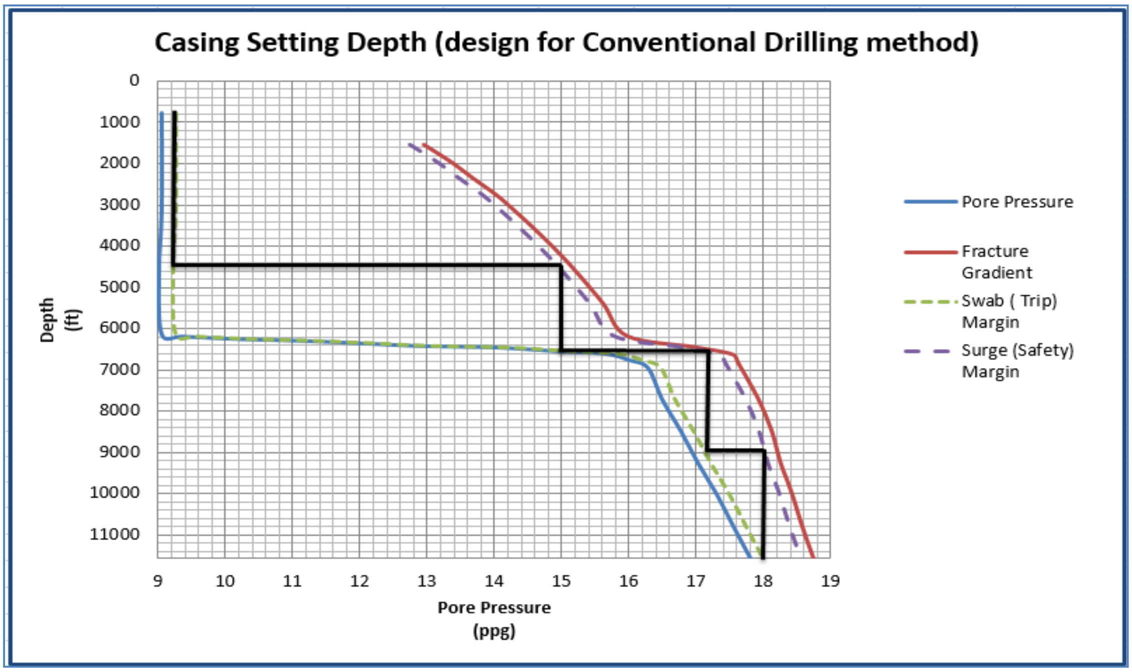
5.2 Overview of Field data/information

The South Pars field is located in the Persian Gulf and it is the world's largest natural gas condensate field that is operated by Qatar Petroleum and NIOC. The project was mainly aimed to create a drilling program for an Appraisal well, safely and as economical as possible. Appraisal Wells were drilled by conventional method to further explore the potential hydrocarbon reserves that were located in a discovered oil or gas field.

As a result of further research into well area some potential drilling challenges have been detected. In design considerations of well planning these challenges were analysed and taken into consideration. The main target is to analyse both drilling methods in terms of their design configurations, casing setting depth graphs, hole geometry, hydraulics, pump parameters and etc.

5.3 Actual Well design by Conventional Drilling method

An actual well design has been completed based on drilling program by implementing of conventional drilling method. The casing setting depth was designed using industry standards, throughout the project it had been faced many problems and issues. Using the tested methods it has been overcome these problems, such as the having H2S influx from the formation in some depths. Additionally, a hole geometry was determined by considering safety factor first to choose sizes that are large enough to avoid any possible differential sticking and thus good cement work can be done. This would mean that our cost would be higher to drill bigger holes with our biggest hole as 36”. All possible constraints were specified and analysed an operation of drilling with Conventional Drilling method.



Design for Conventional Drilling method			
Casing name	*Setting depth*	*Hole size (inch)*	*Casing size (inch)*
Conductor casing	300 ft	36	30
Surface casing	4750 ft	26	20
Intermediate casing	6600 ft	17.5	13.375
Production casing	9000 ft	12.25	9.625
Production liner	11566 ft	8.5	7

Figure 5-1(a): Actual well design configuration for Conventional drilling method

In Figure 5-1(a), the actual well design configuration has been given. The well was exploited by conventional drilling method in the previous year as a part of Petroleum Design course.

5.4 New Well design by Casing Drilling (CwD) method

Before starting to apply this innovative technology to this basin area it has been explored case study for whether the method is applicable for this well or not. It has been proved that CwD application will have great benefits for this field due to its successful operations for various unscheduled events and numerous unexpected problems. Therefore, utilising CwD and making new design for this method would provide an operational company with great benefits which will be specified and summarise in this section.

5.4.1 Design Assumptions

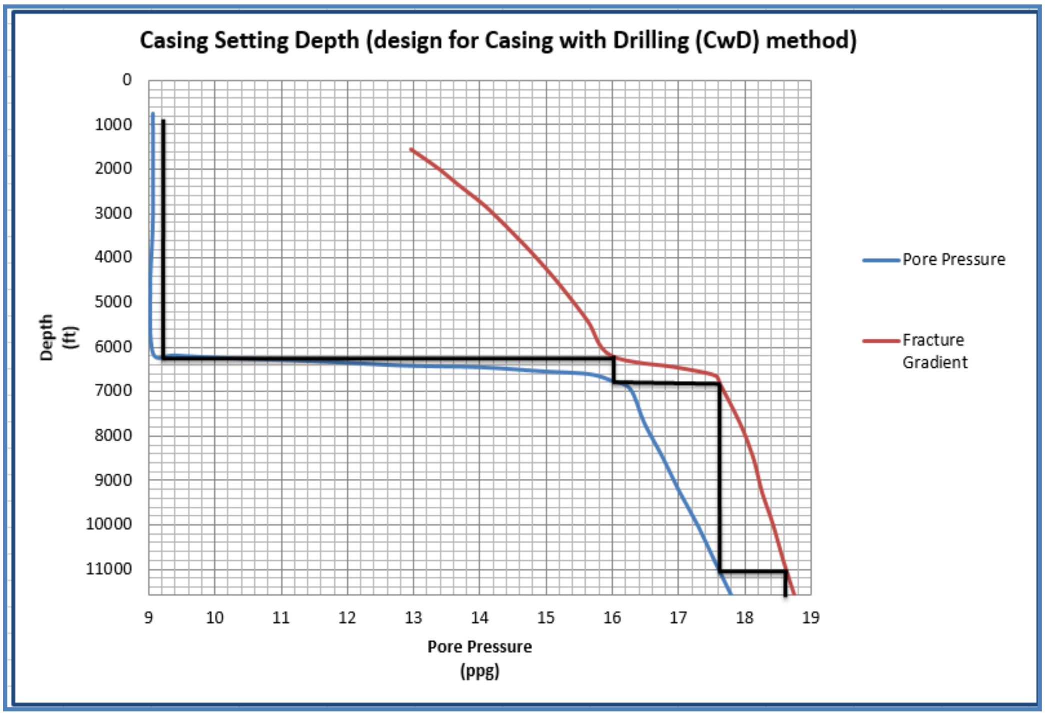
To make the new well design much clear it has been identified some relevant assumptions

- Well is designed in a vertical trajectory. However, it does not happen practically and there is some deviations in the profile.
- Fatigue calculations, bending stress is measured due to buckling. Additionally, stress due to torque should also be considered if the casing is being rotated. For this complicated calculation, software for drilling plan – Halliburton Well Plan would be relevant.
- All the calculations are made based on new casing setting depth scenario.

5.4.2 Casing and Casing setting depths design

The casing string designed for isolating the hole from undesired constraints and unstable formations must satisfy collapse, burst, tension, static and fatigue loads requirements. If there is a demand for rotating casing during conventional casing operations, torsional resistance must be sufficiently done. Whereas, in CwD casing string design it is required special considerations in addition to the fulfilment of common criteria of casing design for the conventional drilling. For CwD operation, as casing string is utilised to supply rotation and weight on the BHA and drilling bit, the main emphasis is given to the accessories that are relatively linked to stress and torsion resistance of the casing string and its connection. Therefore, the design of the casing string for CwD must satisfy safety factors of different loads acting on the string (compression and tension loads).The formulas to determine collapse, burst, tensile resistance of the casing string will be used to calculate these factors for each casing intervals.

To design a new configuration of casing setting depths, first job was to analyse if there is overpressure or under pressure cases for the defined mud window. As can be seen from Figure 5-1(b) that mud window is very narrow in the middle trajectory. This means that pressures in these layers should be attentively checked and controlled for CwD application. Therefore, all specific assumptions (given in details in Chapter IV) made for CwD and new well design configuration has been generated (Figure 7-1(b)). Casing setting depths and hole geometry design are made based on CwD design criteria.The most appropriate trajectory is chosen in the mud window after eliminating swab/surge trip margins and relatively small diameters are chosen for new well design with CwD technology.



Design for Casing while Drilling (CwD) method

Casing name	*Setting depth*	*Hole size (inch)*	*Casing size (inc*
Conductor casing	300 ft	36	30
Surface casing	6200 ft	26	18.625
Intermediate casing	6800 ft	16	13.375
Production casing	11000 ft	12.25	9.625
Production liner	11566 ft	8.5	7

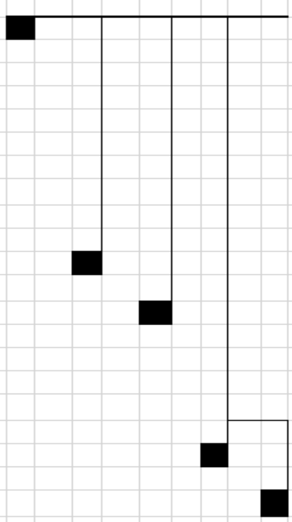


Figure 5-1(b): New well design configuration for Casing Drilling method

As it was in an actual well design, the same casing types, grades and weight were utilised for new design. The only different point of the design is obtained in the casing sizes, mud weights, casing depths and lengths. These changes will have significant impacts on optimisation of drilling rate with CwD in the well. Summary of the proposed casing string design for the new well design is given in the Table 5.1

Table 5-1: Casing and Mud specifications for the new well design

Casing Type	Grade	Setting Depth (ft)	Length (ft)	OD (inch)	ID (inch)	Weight (lb/ft)	Mud weight (ppg)
Conductor	X80	300	300	30	26.5	527.91	9.2
Surface	J55	6200	5900	18.625	17.563	106	9.2
Intermediate	N-80	6800	600	13.375	12.415	68	16
Production	Q125-1	11000	4200	9.625	8.535	53.5	17.6
Production Liner	Q125-1	11566	566	7	6.094	32	18.6

5.4.3 Effective Loads and Neutral Point calculations

In order to calculate effective loads which affect casing string first it is significant to determine buoyancy factor and buoyancy weight of the casing. The formulas for these calculations are given in a range from Equation 5-1 to Equation 5-8 (refer to Appendix-2). To proceed buoyancy calculations, it is then needed to find out Total Weight of the Casing and Buoyant weight of Casing.

(Equation 5-2). Therefore, to determine Tensile Load and Compressive Load results it is significant to make calculations by the formulas (equation 5-3, 5-4, 5-5).

As a result of these calculations, the relevant values have been obtained and these data will be helpful to generate graph of the total axial load vs depth. This relationship is very necessary to determine effective axial load and hence the neutral point. All these calculations and plotting operations have been done by Excel software.

Table 5-2: Summary calculation results on Total Tensile and Total Compressive Force

Casing Type	BF	Total Casing weight(lb)	Buoyant Weight (lb)	Shock Load (lb)	Buoyant Force(lb)	WOB (lbf)	Total Tensile Force(lb)	Total Compressive Force (lb)
Conductor	0.8595	158373	136128.2	791865	22244.8	55000	927993	-77245
Surface	0.8595	625400	537557.6	159000	87842.4	52000	696558	-139842
Intermediate	0.7557	40800	30833.6	102000	9966.4	20000	132834	-29966
Production	0.7313	224700	164322.6	80250	60377.4	23250	244573	-83627
Production Liner	0.7160	18112	12968.7	48000	5143.3	17000	60969	-22.143

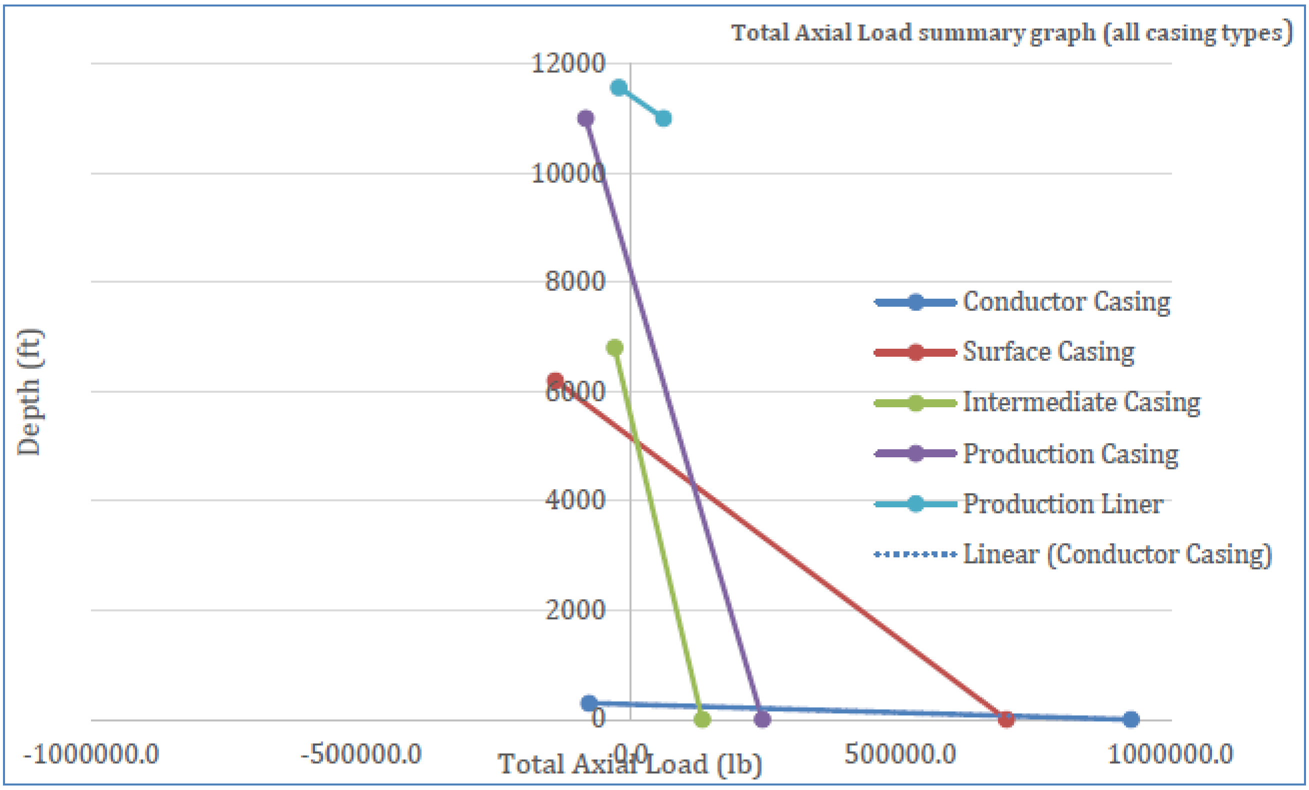


Figure 5-2: Summarised graph representing Axial Load vs Depth for all casings

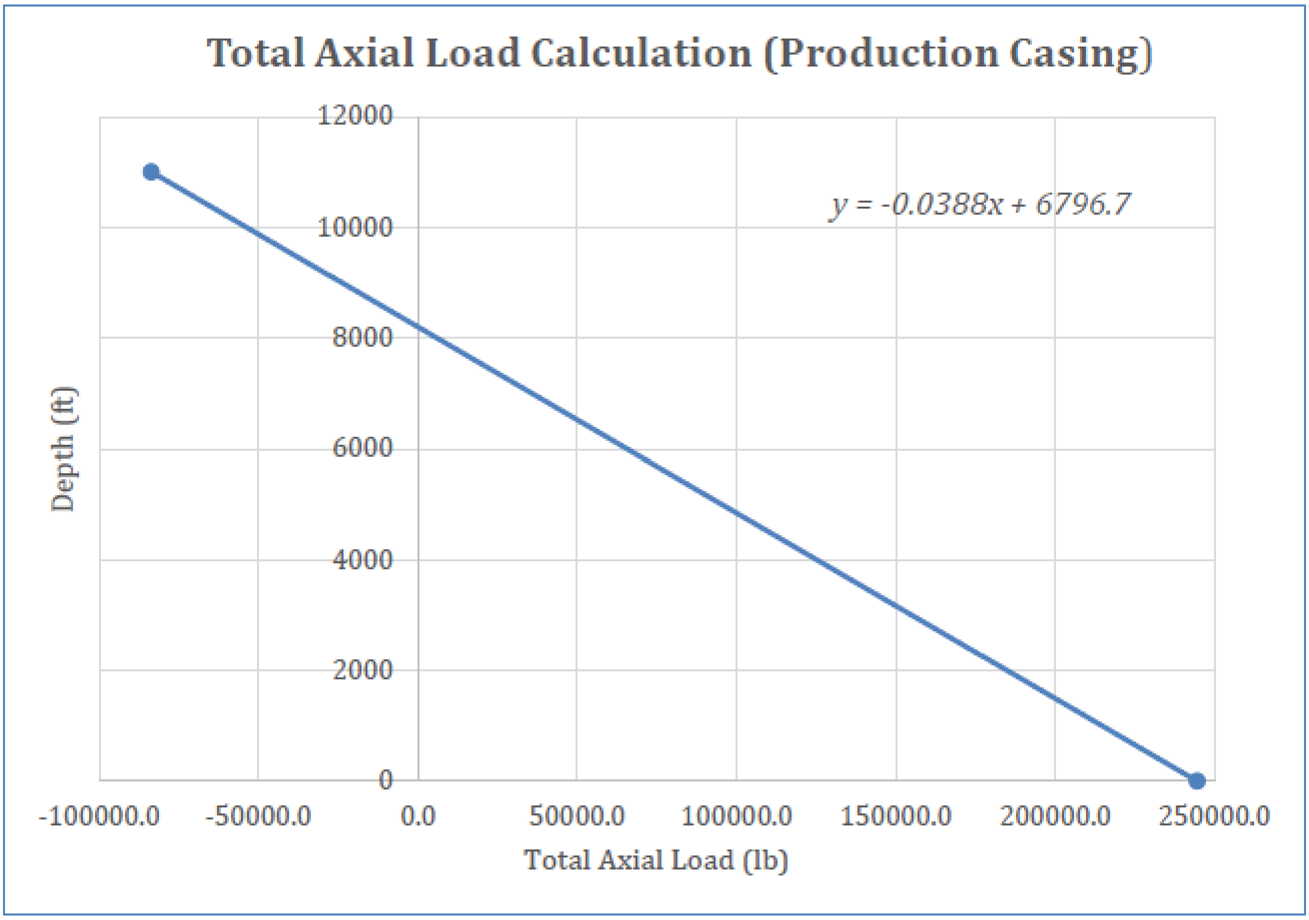


Figure 5-3: Graph demonstrating Axial Load vs Depth for Production Casing

In Figure 5-2, the axial loads which affects casing that have been calculated and generated one plot with all casing data. But, in Figure 5-3, the plot is extracted from Figure 5-2 for Production Casing to give an accurate idea about Effective Load determination.

As a reason, production casing is chosen because it is the longest casing lengths and shows better results with CwD operation.

For neutral point calculation, it is required to calculate effective axial load. Generally, casing is affected by internal and external pressure same as the MW pumped in the inner and outer diameter of the casing are the same.The pressure is determined as

$(psi) = 0.052 \times Depth(ft) \times MW(ppg)$ (Equation 5-9)

For production casing, effective axial load is calculated and summarised in a Table 5-3 below:

Table 5-3: Effective Load Calculation for Production Casing

Depth (ft)	**F total(lb)**	**P (psi)**	**A_oP (lb)**	**$A_{in}P$ (lb)**	**F_{eff} (lb)**
0	175172.7	0	0	0	175172.7
900	151976.8	823.68	59930.77	47125.44	164782.1
1800	128780.9	1647.36	119861.5	94250.89	154391.6
2700	105585.1	2471.04	179792.3	141376.3	144001
3600	82389.18	3294.72	239723.1	188501.8	133610.5
4500	59193.3	4118.4	299653.9	235627.2	123219.9
5400	35997.42	4942.08	359584.6	282752.7	112829.4
6300	12801.55	5765.76	419515.4	329878.1	102438.9
7200	-10394.3	6589.44	479446.2	377003.6	92048.3
8100	-33590.2	7413.12	539377	424129	81657.76
9000	-56786.1	8236.8	599307.7	471254.4	71267.21
9900	-79982	9060.48	659238.5	518379.9	60876.66
10800	-103178	9884.16	719169.3	565505.3	50486.11

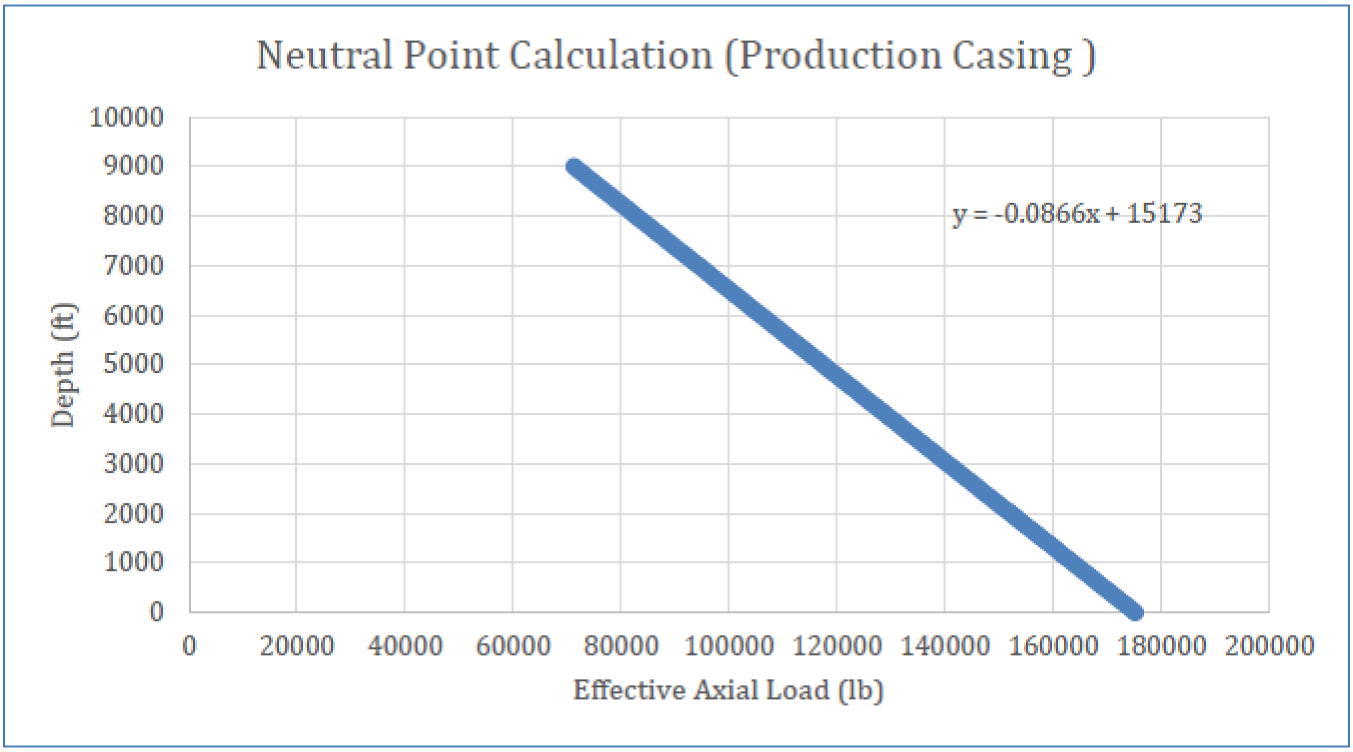


Figure 5-4: Graph presenting neutral point for Production Casing

Analytically, the neutral point is determined as the point in which the effective axial load is with zero(x-axis). From Figure 5-4, the neutral point can be estimated for production section, as the trend line the equation is:

$y = -0.0866x+15173$

It can be seen from this relationship, the neutral point is situated at 15173 ft. Therefore, the part of the casing below this point is under compression and buckling can occur.

5.4.4 Buckling

It is relevant to note that when Feff - Fc is less than zero, buckling will occur. This is only true when the casing is in compression which is below the neutral point. As can be seen from calculation results, buckling environment will be occurred in the production casing depth level at the bottom depths of casing, where the tendency is matched (Feff-Fc =0). And the helix angle and dogleg severity are calculated using equation 5-7 and 5-8. (refer to Appendices). Therefore, the bending stress is then determined using Equation 4-4.

Table 5-4: Fc (sinusoidal) and Fc (helical) calculations

Casing Type	Young Modulus GPa	Moment of inertia (inch^4)	Effective buoyed weight(lb/in)	Fc (sinusoidal),lb	Fc (helical), lb
Conductor	20	15553	37.81	1480862	3091489
Surface	20	1236	7.59	218332	455796
Intermediate	20	405	4.28	102722	214444
Production	20	161	3.26	62962	131442
Production Liner	20	50	1.91	29890	62400

The scenario in this well is designed vertically. Bending stress has been effected by some loads and tensions. Because of profile is vertical and loads are under control, therefore significant trends have not been investigated. As a result of calculation summary, It has been obtained not too much challenges in casing design factors such as helix angles, bending stress and dogleg severity (DLS).

5.4.5 Fatigue

In order to determine the revolutions to failure for fatigue occurrence, bending stress is analysed. Additionally, it can be determined the revolutions of failure for different bending stress using the S-N curve. Whereas, buckling in a perfectly vertical holes is always caused by compression if the bore hole does not make lateral support through centralizers.

As a result of calculations, it has been investigated that maximum bending stress (refer to Equation 4-4) that can happen is 20442 lb which is considered as good result. An S-N curve for N-80 Production casing is presented in Figure 5-5.

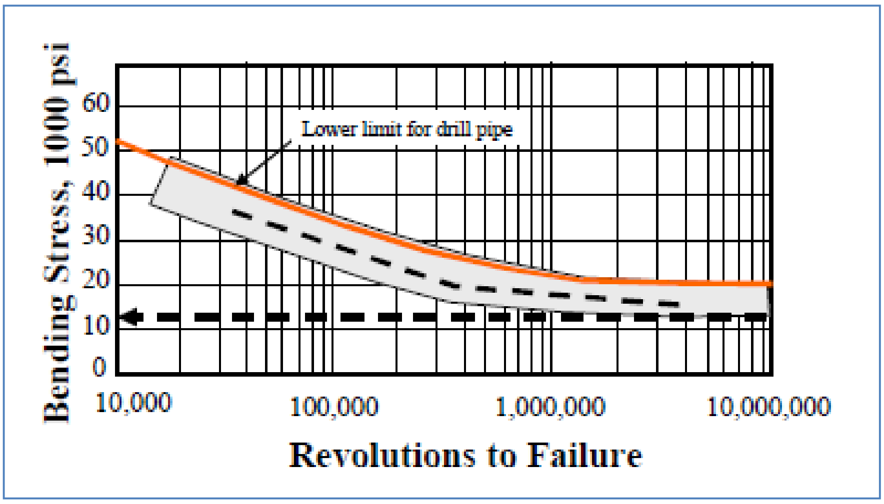


Figure 5-5: Fatigue Band for N-80 Casing [5]

5.4.6 Bottom Hole assembly (BHA) design

Casing Drilling technology provide different level of BHA for its applications on various well type. Different level of BHA has been given in Figure 5-6 (refer to Appendixe-3). For new well design, it will be utilised Level 2 type BHA as it is specified for vertical or tangent sections without the need for active directional control (Non-Retrievable BHA). It is compatible to use for this well and it will effectively provide the system with good rotation of Casing string, mud circulation and other related components.

5.4.7 Torque and Drag

One of the most important factor of Casing Drilling method is Torque and Drag determination. As it is very significant when designing CwD. For new well design with Cwd method, torque and drag have been calculated using Equation 4-5. Drag is estimated approximately as 20% value of the torque. The summary results of these parameters can be found in Table 5-5 below.

Table 5-5: Torque and Drag estimations

Casing Type	WOB (lbf)	Drillbit Diameter(inch)	μ, friction factor	Torque (lb-ft)	Drag (lb-ft)
Conductor	55000	36	0.4	22000	4400
Surface	52000	26	0.5	18778	3756
Intermediate	20000	16	0.45	4000	800
Production	23250	12.25	0.4	3165	633
Production Liner	17000	8.5	0.5	2007	401

5.4.8 Mud Program and Hydraulics Design Mud Program

For new design, mud program will not be changed properly and it will be followed as it was for actual design. However some changes will be made for design consideration as mud weight is not the same as it was before. The previous mud design and lithology profile is given the Table 5-7(refer to Appendix-3) and new design is given in Table 5-6 below.

Table 5-6: New mud design configuration

Casing Type	Hole size × casing size	Mud weight (ppg)	Mud type to drill with
Conductor	36”× 30”	9.2	Seawater&Spud mud
Surface	26”× 18.625”	9.2	WBM
Intermediate	16”× 13.375”	16	OBM
Production	12.25”× 9.625”	17.6	OBM
Production Liner	8.5”× 7”	18.6	OBM

Conductor section- it will be drilled without returning at surface with seawater and super sweep pills for hole cleaning considerations.

Surface section- inhibited WBM system will be will be treated from the beginning with KCl to enhance the inhibition properties and properly face shale formation. The high fluid loss inherent to the system will ensure the deposition of an adequate filter cake across loose surface sands thereby minimizing their sloughing into the wellbore.

Intermediate section- OBM will be used to drill this section. Mud Density should be closely maintained to avoid any excessive mud weight as this can cause borehole instability problems. The hydrostatic pressure exerted by the column of fluid can cause an increase in near wellbore pore pressure, which may in turn lead to a failure of formation integrity. OBM used to minimize ECDs by controlling the amount of Low Gravity Solids (LGS) build-up in the fluid and by optimizing flow rates. Furthermore, provide inhibition of hydrate-able shale, prevent bit/BHA balling, hydration and swelling of cuttings, and provide good borehole stability. Finally effectively seal porous zones, minimize fluid loss to the formation and provide a good filter cake.

Production section- OBM will be used to drill this section .Mud Density should be closely maintained to avoid any excessive mud weight as this can cause borehole instability problems. The hydrostatic pressure exerted by the column of fluid can cause an increase in near wellbore formation pressure, which may in turn cause a failure of formation integrity.

Production Liner section- there is extreme care need to be taken while drilling this interval due to the smaller hole size, depth and the types of formation exposed. A minimum mud weight is required to avoid any differential pressure sticking and tight control on fluid loss will also be required. A good quality filter cake is essential in order to minimize any pay zone formation damage and avoid any differential pressure sticking. Loss of circulation can be expected and conventional LCM is not recommended in order to avoid any formation damage through this reservoir zone.

Overall, CwD can be used efficiently in this case in South Pars gas well as wellbore stability is a critical issue due to the presence of the smear effect which achieved better wellbore stability in all previous wells drills all over the world. Moreover, loss of circulation can be eliminated or even prevented by the same effect, which will reduce the cost of using loss of circulation materials or other chemicals which used to treat the loss of circulation. An application of CwD in this well will be helpful in minimising loss of circulation dramatically and improve wellbore stability and can be used in drilling depleted zones with higher mud density.

Hydraulics

Mud hydraulics is very essential parameter during drilling process. By generating sufficient mud hydraulics, it can be achieved better hole cleaning, rate of penetration, optimised flow rate and pressure drop across bit. In terms of hydraulic plan, Casing drilling considerations are differ from conventional drilling. In drilling with casing mud hydraulics is very critical issue due to having small annular clearance which may lead to turbulent flow as this small clearance increase the actual velocity. As well as it may decrease the difference between the critical and actual velocities. The slip velocity should also be taken into account, thus as to be less than the actual velocity to ensure that mud can manage to transport cuttings out of wellbore. As an impact factor on the bit, flowrate should be designed attentively to ensure better hole cleaning in the wellbore. Rate of penetration (ROP) is also necessary for optimising mud hydraulics, as it is increased by optimising hydraulic horse power. To obtain optimum flow rate hydraulically means actual velocity in annulus more than slip velocity, managing laminar low in annulus, higher ROP by achieving efficient hole cleaning.

To identify some relevant hydraulic parameters, it has been made calculations based on the Production Casing results. As a reason, Surface casing interval data has been exampled because of it shows longest casing length (11000ft TVD) and potentially applicable with CwD technology to drill.

Calculations for flowrate have been made based on some assumptions as following below:

During designing the hydraulic programs, same mud weight, viscometer readings, cuttings density etc. have been used to calculate different parameters. For slip velocity, smaller cutting diameter was assumed as it was observed form the previous case study. To optimize the impact factor and for bit hydraulic horse power, the ratio between total pump pressure to the fluid loses across the bit taken to be 0.5 and .65 respectively. Power law model is justified to calculated pressure drops in the different elements to achieve better hole cleaning a rule of thumb stated that the flow rate value should be range from 30 to 50 gallon per minute for each inch of hole size. Rock bit is utilised with three nozzles and pump pressure with flowrate is 2250 psi.(estimation is made)

Table 5.7 (a) Summary of hydraulics design comparison between conventional drilling and CwD in Surface hole

Drilling Technology	Annular velocity (ft/s)	Critical velocity (ft/s)	Flowrate (gal/min)	EMW (ppg)	Nozzle size (inch)	ECD (ppg)
Conventional	4.05	7.15	800	12.2	3× 18	8.89
CwD	2.35	7.15	480	12.0	2×12× 14	9.25
	4.3	7.15	530	12.3	15×2×16	

Table 5.7 (b) Summary of hydraulics design comparison between conventional drilling and CwD in Surface hole

Drilling Technology	ΔP total (psi)	ΔPstring (psi)	ΔPannulus (psi)	ΔPbit (psi)	Bit Horsepower (HP)
Conventional	1151.5	445.6	3.2	699.8	228
CwD	751	6.8	54.8	599	176
	489			336.9	155

In table 5.7 (a) and 5.7 (b), the summary results of main hydraulic parameters have been provided. All these calculations have been made and some approximate estimation have been justified.

Hydraulically mud flow rate in CwD should be 0 to 100% of the appropriate rate of the conventional drilling method. The reason is related to have larger casing inside diameter with less pressure drop within it and higher annular velocity that might lead to borehole washout. Decreasing mud flow rate in CwD results in reduction of standpipe pressure down around 55% of the corresponding values of the conventional method. Therefore, hydraulics is one of the most important factor that should be design attentively in CwD technology. Summary of hydraulics design for new well has been given in Table 5.7 a,b.

5.4.9 Drill bit design

Drill bit design which is one of the most necessary factors in application of CwD method. As drilling with casing method aims to drill and case with the same run, target should be applied to minimize trips required to change drill bit. Therefore, bit details, cost per foot carried on an offset area play vital role in CwD bit design. Generally, bits successfully used to conventional drill in a proper area can also be opted in CwD applications in the same area. Table 5.8 represents bit selection criteria for the new well plan of CwD technology.

Table 5.8 Summary of bit selection criteria for the new well plan of CwD

Hole Section	Bit type	Conditions and main reason to use
Surface	DS I & II	Used in non-retrievable system in order to drilling entire section in one run
Intermediate	Rock bit	Utilised in retrievable system
	PDC	Used in retrievable system for improved ROP in deeper sections
Production	Rock bit	Utilised only if allowable ROP is achieved
	PDC	Mainly utilised for hard carbonates and firm shale within the section

5.4.10 Time and cost considerations

In well designing, cost estimation for overall project program is very important. In Persian Gulf area, number of wells cost about $20,000,000 or may be more depending on the water depth and the depth of the well. Generally speaking each wells needs about 80 to 90 days to be drilled successfully to total depth. This well was drilled and estimated by Conventional method with some constraints.

This new well design is generated and its cost estimation is very important to identify main differences between two drilling methods. Generally, CwD eliminates the need of tripping after drilling each section, by turn this will also decrease the total time of the well from around 81 days to 52.7 days (in the case below). Table 5-9 shows productive time and non-productive time for each section by both techniques.

Table 5.9 Summary of PT (productive time) and NPT (non-productive time) comparison between conventional drilling and CwD technology

		Conventional Drilling		Casing Drilling	
Operation	*Depth(ft)*	*PT(days)*	*NPT(days)*	*PT(days)*	*NPT(days)*
Site Preparation	0		4.81		4.81
Conductor casing	300	3.5	1.23	3.5	0.39
Surface casing	6200	5.4	12.5	5.4	3.5
Intermediate casing	6800	8.4	9.5	14.9	15.1
Production casing	11000	6.5	16.8		
Production Liner	11566	1.01	11.3	1.01	4
Total	11566	24.91	56.14	24.91	27.8

According to the table, it can be seen that by utilising CwD the NPT will be reduced by 33% or 26.1 days and if we assume rig rate of about $120,000 per day so total reduction in cost will be $3,132,000, or 15% of the well cost.

5.5 Summary

Casing while drilling technology can be an alternative approach for the conventional method in the conditions of excessive lost circulation, stuck pipe problems due to formation instability. The method is not an innovative technique to be absolutely replace of conventional system, it is an alternative method to optimise drilling productivity by overcoming unforeseen drilling problems.[23]

According to case study, problems in formation like lost circulation and stuck pipe,

H2S influx obliged operators to either drill ahead with huge risky consequences or abandon the well after time and money wasting for project.
However, application of Drilling with Casing technology in South Pars gas field can provide better drilling quality by preventing relevant drilling problems.

New design is proposed for the well has been regenerated by Casing Drilling. New casing setting depths configurations are made and new interval depths are chosen. The main parameters which are essentials were taken into account, such as BHA design, Casing designing factors, Mud and hydraulics design, Bit design and Cost estimations. As one of the main considerations, buckling caused by compressive load cannot lead to failure of the casing by itself. However, it can cause two effects that can lead to failure: contact between casing and borehole wall due to buckling can cause increased wear on the casing and the curved surface assumed by the casing due to buckling growing up the stress in the casing and this can increase the tendency toward lateral vibrations.

Another essential factor is fatigue failure which can occur due to cyclic loading. Crack starts to appear at the point of localized high stress and repeated loading can cause to the crack propagating through the body until the remaining cross sectional area is unable to support the static load.
In terms of hydraulic considerations, in casing drilling it has been observed decreasing cross sectional area, which provide smaller annulus between the casing and borehole. It leads to achieving higher annular fluid velocity which provides better cutting transports to the surface. As well as, higher ECD is obtained for casing drilling applications compared to conventional drilling. Calculations completed in this section have represented that most care has to be taken in designing some casing factors, such as buckling, fatigue, torque and drag. The results from these calculations have provided rough estimations on how important these factors are in designing CwD methods. However, WellPlan software by Halliburton can be worked and all these calculation can be accurately computed.

CONCLUSION AND RECOMMENDATIONS

Conclusion

This project study was undertaken with the aim of investigating Casing Drilling technology. Casing while Drilling is very reliable method that brought new innovations to drilling industry in improving drilling performance compared to the Conventional Drilling method.

There are some drilling challenges range from wellbore incidents and drilling hazards to NPT that conventional drilling method has not properly dealt with them. Although vast amount of techniques are available to solve these problems, they are required higher cost or they are not perfectly designed to achieve required target. All these limitations obliged the industry to discover an alternative ways to drill safely and effectively.

Casing Drilling method promotes huge amount of benefits. One of them is decease of NPT as tripping was eliminated. In mitigating complications elimination of tripping operation helped, as well as swab and surge pressures. This method promotes plastering effect which is quite advantageous. Cutting are plastered onto the borehole wall which results in preventing lost circulation problems. On the other hand, quality of filter cake is being improved which helps the system to balance the pressures in the formation and in the wellbore.

Moreover, risks of casing stuck are minimised as the casing is continuously rubbing and sliding. If the casing got stuck, BHA can be retrieved and problem may surely be mitigated by doing cementing operation. Hydraulically, casing is designed to small size to generate narrow annulus in order to achieving annular flow velocity. This is important because of better cutting removals from the wellbore to the surface. The design regenerated in the South Pars gas well has outlined how CwD method overcame

most of the challenges that could not have done with Conventional Drilling.
On the other hand, this new technology has its own limits and complications. Casing Drilling method has been lately worked by some different companies that they promote their own promotions. As a result of such complications, information data has been become prejudiced.

Another fact is related to its application condition that when the casing or drill bit has to be tripped out of the wellbore and this may results in increasing of NPT. Therefore, if the main target is to diminish NPT due to tripping operation, to apply this technology in the well is ineffective. Additionally, availability of plastering effect should also be checked prior to utilise the operation. Another complication is associated with ECD prediction. To have lower flow rates in the system will result in lower ECD, whereas annulus area is small in CwD method.

This leads to an increase in annular velocity which in turn results in higher friction losses which makes ECD higher. According to some SPE papers it has been stated that both ECD values are productive, but not all the time. On the other hand Casing Drilling promotes ECD with higher value by lower flow rate. In this case lower flow rate should be potentially able to remove cuttings from the wellbore, otherwise the situation with higher flowrate and ECD will result in formation damage in the system.

As a result of investigation of this project, it has been obtained some uncertainties that are under question. One of them is associated with BHA design, what will be carried out if the BHA is stuck which is unable to be retrieved? Is it possible to mitigate this problem by side tracking the well? If the problem cannot be solved, then BHA cannot be retrieved either that will lead to huge amount of damage to operational drilling cost.

To sum up, by inventing this innovative technology Petroleum industry has achieved great improvement in drilling operations. It is potential method that overcome significant drilling problems such as wellbore stability, lost circulation, stuck pipe and all these scenarios have been mitigated successfully by applying the method in South Pars gas well. It will be anticipated that the company will not only save huge operational cost but also improve drilling performance and maximize recoverable reserves.

Future plans and suggestions

The project was mainly aimed to investigate CwD technology from different contexts like its design considerations, benefits, limitations, application in South Pars gas well. Calculations were made for the well data are not precise. Because all these calculations are made based on some theoretic assumptions. In particular cases, some factors were ignored not to have much influence on result. As a future plan it would be recommended that the project would be worked by using industrial drilling software, such as Wellplan by Halliburton licence. Calculations associated with buckling, fatigue, torque and drag would be very neatly calculated and achieved precise results.

It can be suggested that in order to improve the technology lots of investigations would be conducted and new areas would be discovered to apply Casing Drilling technology that has not been operated before.

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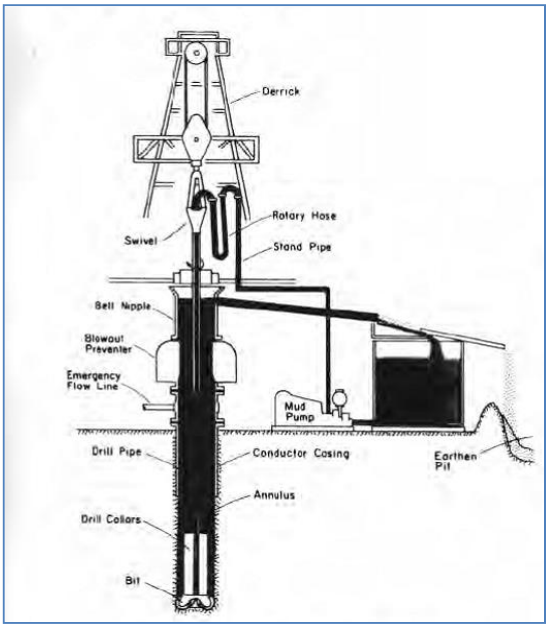
Appendices

Appendix 1- Conventional Drilling method



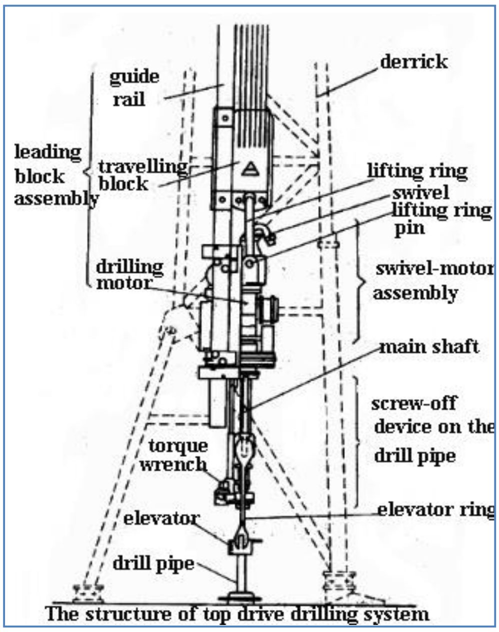
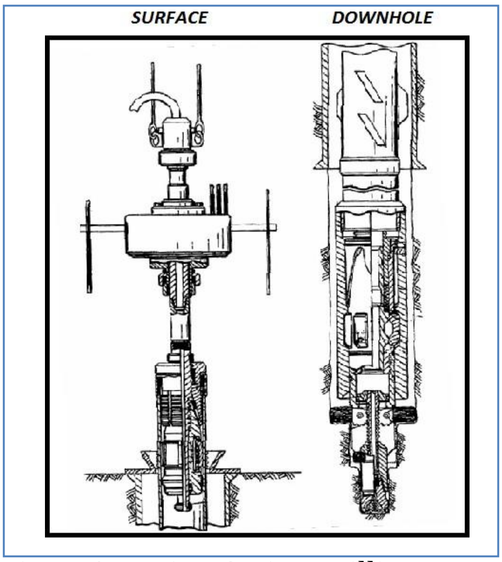


Figure 1-1: Schematic view of rotary drilling process [1] Figure 1-2: Structure of Top Drive Drilling System [13]

Appendix 2 – Casing Drilling method



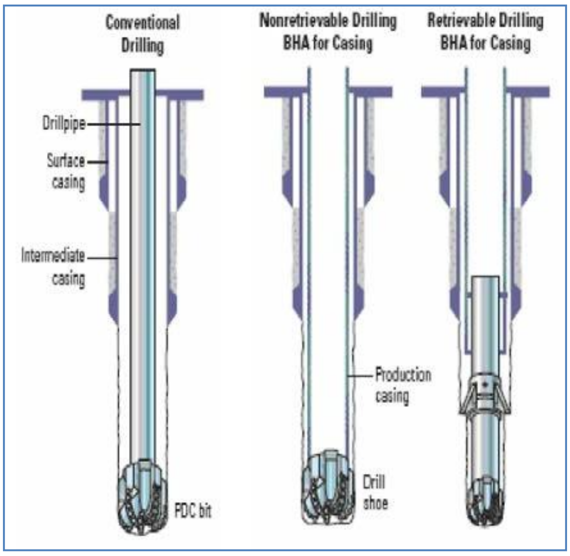


Figure 2-1: First Casing Drilling systems [11] Figure 2-2: Conventional and Casing Drilling BHAs [3]

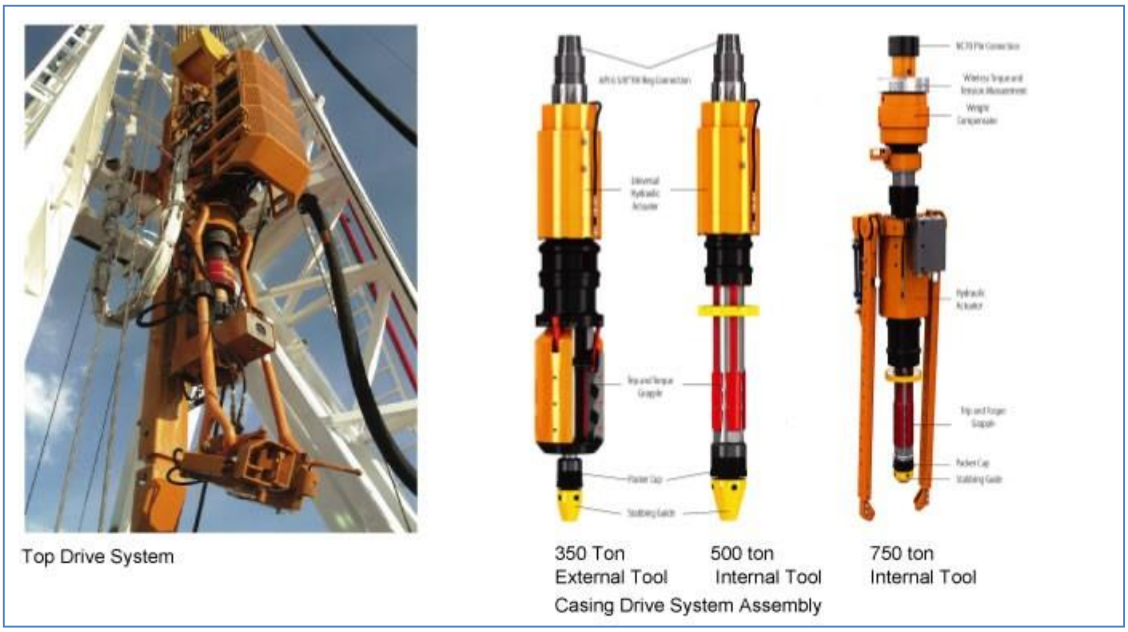


Figure 2-3: Tesco's Top Drive system and Casing Drive Assembly, Internal Tool [16]

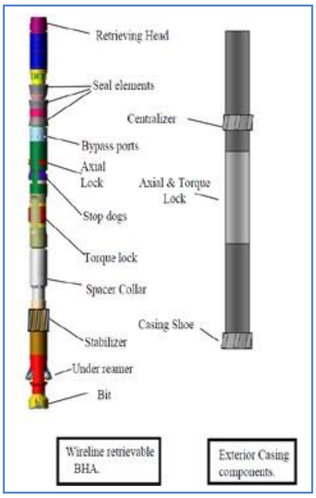


Figure 2-4: Bottom Hole Assembly BHA [5]

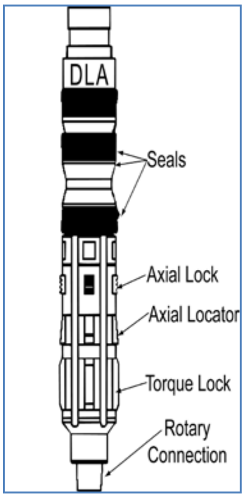


Figure 2-5: Drill Lock Assembly [3]

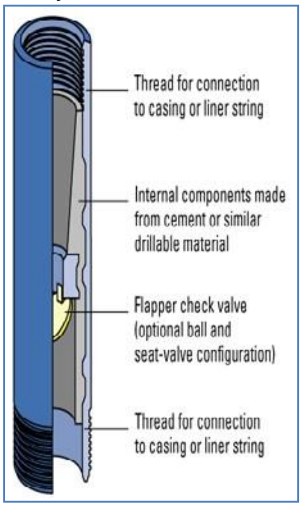


Figure 2-8: Float of Retrievable Collar [3]

Appendix 3- New Design with Casing Drilling (CwD) method

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- Buoyancy factor: $BF = 1 - \frac{MW}{65.5}$ (Equation 7-1)
- Total Weight of Casing (lb) $= Wt\left(\frac{lb}{ft}\right) \times Length\ of\ Casing\ (ft)$ (Equation 7-2)
- Buoyancy Weight of Casing (lb) $= BF\ \times Total\ Weight\ of\ Casing\ (lb)$ (Equation 7-3)
- Shock Load (lb) $= 1500\ \times Wt\ (\frac{lb}{ft})$ (Equation 7-4)
- **Total Tensile Force (lb)** $= Buoyant\ Weight\ (lb) + Shock\ Load\ (lb)$ (Equation 7-5)
- **Total Compressive Force (lb)** $Buoyant\ Force\ (lb) + Weight\ on\ Bit\ \ (lb)$ (Equation 7-6)
- Helical buckling $\lambda = (\frac{F_{eff}}{2EI})^{1/2}$ (Equation 7-7)
- The dogleg severity (Degree per 100ft): DLS=68.755 $\lambda^2 r_c$ (Equation 7-8)

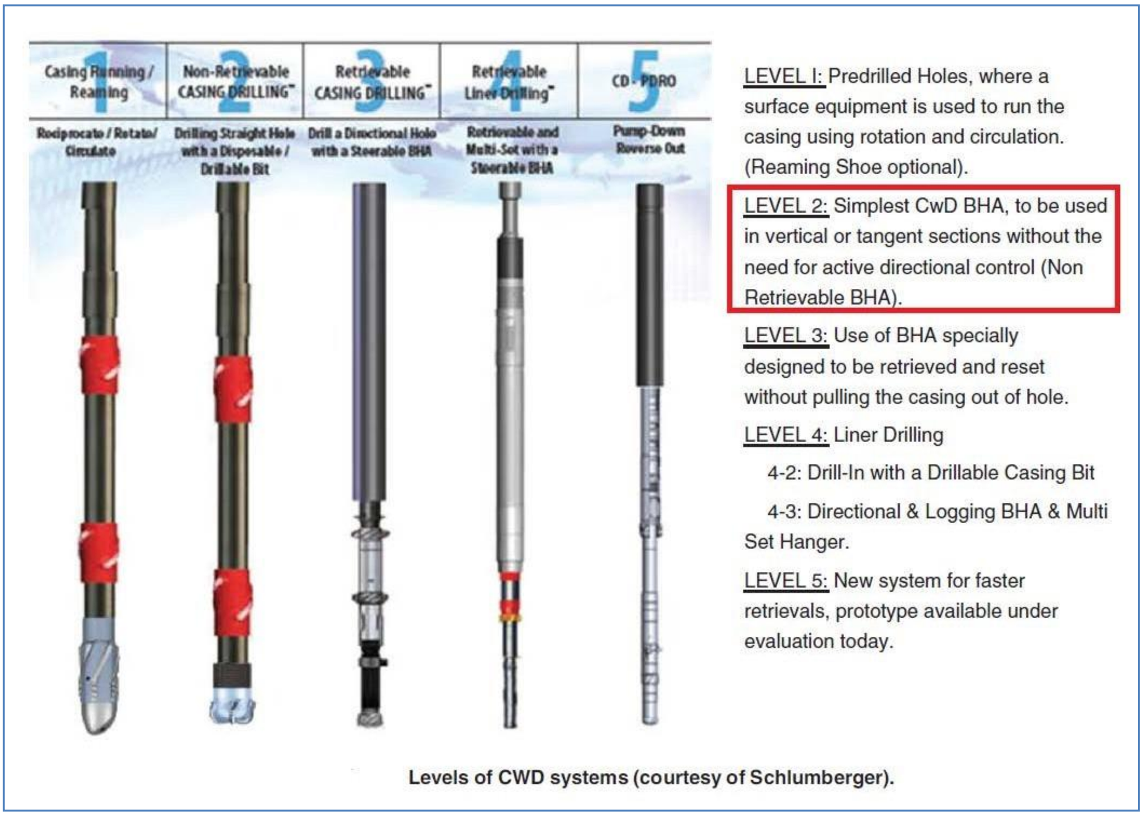

Figure 5-6: BHAs for Casing Drilling technology [22]

Casing Selection	Depth intervals in well (ft)	Hole selection size (inch)	Casing size (inch)	Mud weight (ppg)	Rock type in Lithology
Conductor Casing	300	36	30	9.2	Limestone
Structural Surface Casing	300 – 4750	26	20	9.2	Limestone/dolomite/shale
Intermediate Casing	4750 – 6600	17.5	13.375	15.0	Limestone/Anhydrite/Shale
Production Casing	6600 – 9000	12.25	9.625	17.1	Limestone/Shale/Dolomite/Claystone
Production Linear	9000 – 11566	8.5	7	18.0	Dolomite/Anhydrite/Limestone

Figure 5-7: Mud specification for actual well (Conventional drilling)