

*Review paper*

**REVIEW OF CASING WHILE DRILLING TECHNOLOGY**  
**TEHNOLOGIJA BUŠENJA SA KOLONOM ZAŠTITNIH CEVI**

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**Abstract:** Conventional drilling methods have been plagued with huge operational and financial challenges, such as cost of purchasing, inspecting, handling, transporting the drill equipment and most importantly, tripping in-and-out of the drill string whenever the Bottom Hole Assembly (BHA) needs a replacement, needs of wiper trip or when total depth is reached. The tripping in-and-out of the drill string not only contributes to Non Productive Time (NPT) but also leads to well control difficulties including wellbore instability and lost circulation. All this has led Oil and Gas industry, as well as any other engineering industry, to seek for new ways and methods in order to reduce these problems. Thanks to the advances in technical solutions and constant improvements of conventional drilling methods, a new drilling method - casing while drilling has been developed. Casing Drilling encompasses the process of simultaneously drilling and casing a well, using the active casing and thus optimizes the production. This paper presents a review of casing while drilling method (CwD) and its practical usage in drilling wells. The comparison of conventional drilling method and casing while drilling is also presented. The CwD method achieves significantly better results than conventional drilling method.

**Keywords:** casing, drilling, CwD, application

**Apstrakt:** Konvencionalne metode bušenja se suočavaju sa raznim operativnim i finansijskim izazovima poput troškova nabavke, inspekcije, održavanja i transporta opreme za bušenje, a najviše sa konstantnim manevrom bušačeg alata bilo da je potrebno da se proradi izbušeni interval, da se zameni kompozicija teškog alata ili po dostizanju konačne dubine bušotine. Konstantan manevar bušačeg alata doprinosi ne samo povećanju neproduktivnog vremena već i poteškoćama prilikom bušenja, uključujući i nestabilnost kanala bušotine kao i gubitak cirkulacije. Svi navedeni problemi doveli su do razvoja novih rešenja i metoda među kojima se posebno istakla nova metoda bušenja - metoda bušenja kolonom zaštitnih cevi (casing while drilling). Casing while drilling metoda objedinjuje proces bušenja i cementacije bušotina i na taj način rešava probleme konvencionalnog bušenja. Ovaj rad opisuje novu metodu bušenja pomoću kolone zaštitnih cevi – casing while drilling (CwD) kao i njenu praktičnu primenu u procesu bušenja. Izvršeno je poređenje konvencionalne metode bušenja i CwD metode i iz svih opisanih studija slučaja ustanovljeno je da CwD metoda pruža bolje performanse od konvencionalnog bušenja.

**Ključne reči:** kolona zaštitnih cevi, bušenje, CwD, primena

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## 1. INTRODUCTION

In the late 1990s, the idea of casing while drilling has finally been accepted in O&G industry. The conventional method of drilling a well has been fraught with challenges such as cost of purchasing, inspecting, handling and transporting the drill string. A common problem is the tripping in-and-out of the drill string whenever the Bottom Hole Assembly (BHA) needs to be replaced or when total depth is reached. The tripping of the drill string not only contributes to non-productive time (NPT) but also leads to well control difficulties such as wellbore instability and lost circulation. Since these problems had to be solved there was a need for a new method - casing while drilling (CwD) - to address these issues (Abubakar et al. 2012).

The first steps in developing this new method have been made in the 1890s, when engineers applied new approach, based on rotary drilling process for drilling the well with the casing and afterwards retrieving the hydraulically expandable bit (Tessari & Madell, 1999). Few decades later, precisely in 1926, a new patent, which included retrievable and re-runnable casing bit, was presented. Although it still has not been accepted very well, this patent had numerous advantages. Some of those advantages were: elimination of drill pipe, reductions in overall drilling time, stuck pipe, crew and drilling costs; application of few casing string, decrease in accident occurrence on the rig and the ability to drill every foot in the well. These advantages were first recognized by Brown Oil Tools Company. In 1960s, they developed a casing drive system, which comprised down hole and surface tools which were used to drill with the casing and retrievable bits, and applied it on drilling wells (Fontenot et al. 2005). This casing drive system is considered to be the ancestor of today's top drive systems, including Tesco casing drive system, which is now a standard for casing while drilling. Tesco system has been successful in reducing well costs and eliminating non-productive time in drilling industry.

Section 2 describes CwD in more details, while section 3 is a conclusion.

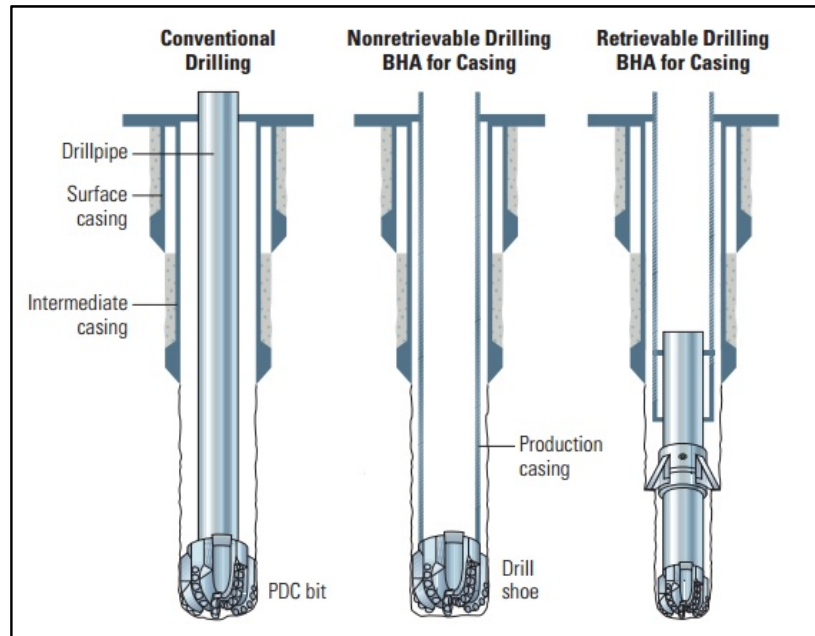
## 2. CASING WHILE DRILLING

Casing drilling, otherwise known as drilling with casing (DwC) or casing while drilling (CwD) is an alternative drilling technique to the conventional drilling method. Casing drilling involves the simultaneous drilling and casing of well with a (active-standard) casing string. It is mandatory to note that casing is the same grade and weight as in conventional drilling operation. With that in mind, there is no additional cost for casing string.

The casing string replaces the drill pipe and other drill string components used in conventional well drilling, providing hydraulic and mechanical energy to the drilling bit (shoe). This reduction in pipe handling improves wellsite safety and allows drillers to use standard size rigs or smaller rigs built specifically to drill with casing. The casing is

usually put into rotary motion and cemented in the well at the total depth (TD), but today there are many developed models to drill with casing. Generally, those models can be divided in two main categories as shown on Figure 1:

1. CwD with Non- retrievable system,
2. CwD with Retrievable systems.



**Figure 1** Conventional drilling and casing drilling BHAs (modified from Fontenot et al. 2005)

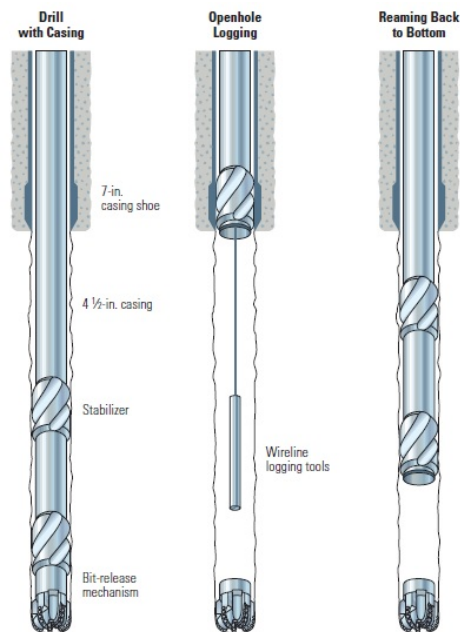
In 2001, BP and Tesco reported success using casing to drill surface and production casing intervals for 15 gas wells in the Wamsutter area of Wyoming, USA. These wells ranged in depth from 8200 ft. to 9500 ft. [2499 m to 2896 m] (Shepard et al. 2001). At about the same time, Shell Exploration and Production Company dramatically improved drilling performance in south Texas by drilling underbalanced with casing, realizing a cost reduction of about 30% (Fontenot et al. 2005).

Until 2005, operators have drilled more than 2000 wellbore sections using casing. More than 1020 of these intervals have involved vertical drilling with casing and non-retrievable bits, about 620 were drilled using partial liners, more than 400 used a retrievable BHA for vertical drilling, and about 12 used a retrievable BHA for directional drilling. All of these early applications helped casing while drilling evolve from a new technology with unproven reliability to a practical solution that can reduce costs, increase drilling efficiency and minimize nonproductive rig time (Fontenot et al. 2005).

## 2.1 Non-retrievable system

Non-retrievable casing drilling system utilizes a top drive and casing drive system (CDS) to rotate the casing. Single joints of casing are picked up off the pipe rack and set in the mouse hole. The top drive, with extend feature, is connected to the top of the joint which is then stabbed into the top of the casing string in the rotary table and drilled down in a conventional manner.

A non-retrievable, or fixed, assembly can be used to drill with short liners or full casing strings. Conventional drilling bits are replaced with drilling shoe that remains in the wellbore after reaching TD. The bit can remain on the casing and be cemented in place, or it can be released and left into the bottom of the hole to allow logging, which is presented at Figure 2.



**Figure 2** Procedure for logging after drilling with casing (Fontenot et al. 2005)

These systems are usually exploited in drilling vertical wells with variety of problems known in conventional drilling. The constraints to these systems could be TD (interval drilled with single bit) and casing rotation in the well.

Non – retrievable systems can be comprised of various tools depending on drilling conditions. Major BHA contains drillable bit, float collar, stabilizers and high-torque ring on connections which are described below.

### 2.1.1 Drilling shoe

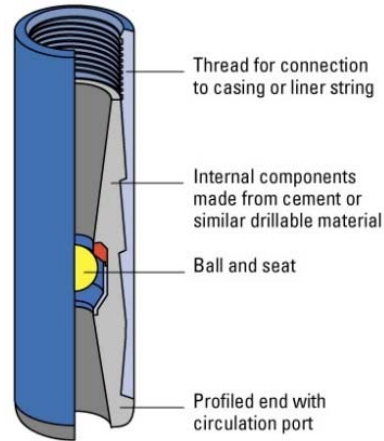
The casing drill shoe, used for drilling, is a drillable casing drill bit attached to the end of the casing string. There is no difference in selection these type of bits then bits used in conventional drilling. At the beginning of CwD operation bit balling, dynamic stability and penetration rate problems usually have been appearing. Today we have a lot of companies that advertise their drillable bits but the company who emphasized the most in this section is Weatherford. The Weatherford Defyer DPA (Figure 3) is a drillable casing bit designed for drilling with casing in medium to medium-hard formations. The innovative design of the DPA series includes a selectable blade count and configurable cutter size to suit the formation type and application. The nose is made of aluminum, and the blades are made of a special steel alloy. Polycrystalline-diamond-compact (PDC) cutters are optimally mounted on the face of the tool to maximize drilling efficiency and durability (Weatherford, 2014).



Figure 3 Weatherford Drill shoe (Weatherford, 2014)

### 2.1.2 Float collar

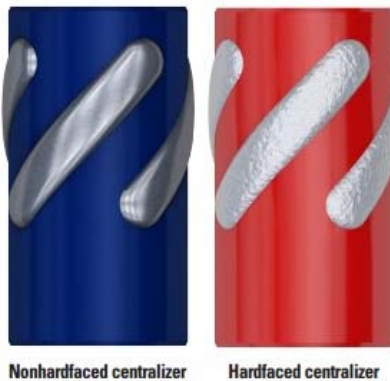
Float collars (Figure 4) are placed one to three joints above the drill shoe. They provide a seat for the cement plugs, the bottom plug pumped ahead of the cement and the top plug behind the full volume of slurry. Once seated, the top plug shuts off fluid flow and prevents over-displacement of the cement. The space between the drill shoe and the float collar provides a containment area to entrap the likely-contaminated fluids from the wiping action of the top cementing plug, securing the contaminated fluid away from the shoe where a strong cement bond is of primary importance. Float collars include a backpressure valve which prevents cement from flowing back into the inner diameter of the casing after the cement has turned the corner into the annulus and the top plug has been bumped (Halliburton, 2016).



**Figure 4** Float collar (Kerunwa and Anyadiegwu, 2015)

### 2.1.3 Centralizers

Centralizers used in CwD technology have similar role as in conventional drilling but they differ in design (Figure 5).



**Figure 5** Hydro-formed casing centralizer by Schlumberger Company (Schlumberger, 2013)

These centralizers were developed specifically for the casing drilling system. Centralizers were needed to prevent wall contact and wear of the casing body or connections.

The hydro-formed casing centralizers provide positive center positioning for cementing in vertical and deviated wells. The centralizers are placed on the outer diameter of the casing string to create standoff between casing and the borehole for casing or liner

drilling. The centralizer's design promotes the plastering effect, which strengthens wellbores for an effective cement bond that helps protect well integrity. An optional tungsten carbide hard facing on the blades provides excellent wear resistance while drilling abrasive formations. Available sizes and properties are shown in Table 1 (Schlumberger, 2013).

**Table 1** Available sizes and properties of centralizers (modified from Schlumberger, 2013)

<i>Available Sizes</i>				
Casing Sizes (in)	Attachment <sup>1</sup>		Number Of Helical Blades	Maximum Blade Diameter <sup>2</sup> (in), [mm]
	Rotating	Nonrotating		
4 ½	■	■	2	6 ½ [165]
5		■	2	7 [178]
5 ½	■	■	2	7 ½ [191]
6 ⅝		■	3	8 [203]
7	■	■	3	9 [229]
7 ⅝	■	■	3	9 [229]
8 ⅝	■	■	3	11 [279]
9 ⅝	■	■	4	12 [305]
10 ¾	■	■	4	13 [330]
11 ¾		■	4	14 [356]
13 ⅜		■	7	16 [406]

<sup>1</sup> Rotating means the centralizer is firmly attached to the casing outer diameter, nonrotating means the centralizer has a slip-fit allowing the casing to rotate independently of the centralizer.

<sup>2</sup> For hard facing, add ¼ in to the maximum outer diameter.

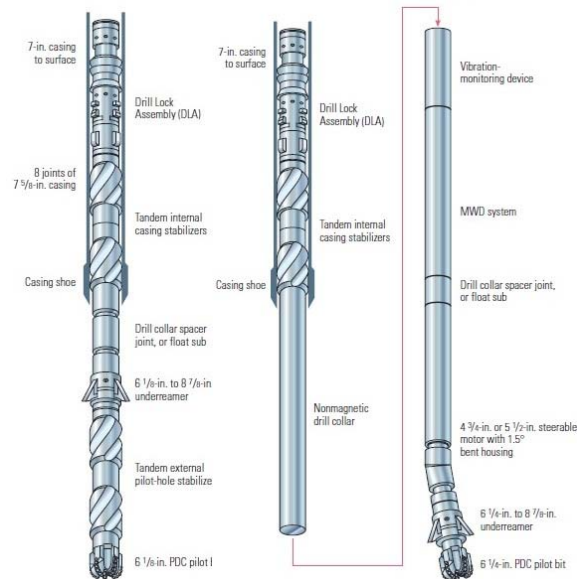
The casing string is rotated by top drive and casing drive system (CSD) for all operations except slide drilling with a motor and bent housing assembly for oriented directional work.

## 2.2 Retrievable system

After using non-retrievable systems for vertical drilling a logical step forward was application of CwD to directional drilling and retrievable systems. Casing string stays in place while retrievable BHA can be deployed and retrieved with smaller jointed pipe, coiled tubing or wireline cable without tripping casing into and out of a well in any time. This presents a practical solution since the components used for directional drilling such as MWD, LWD, downhole motors, RSS are very expensive and can be tripped to the surface in any time. These tools can be retrieved and re-run at inclinations exceeding 90 deg. and the casing can be reciprocated and circulated while running or retrieving the tools to assure that the casing does not become stuck. For example, BHA recovery from app 1200 ft. (first section) required only 45 minutes on the third well from the time the retrieval tool was ready to run until the BHA was back on the surface, including surveying time, on BP and Tesco project in Wamsutter area (Shepard et al. 2001). That

represents how retrievable system can be quick-cost effective and safety model for further operation.

The retrievable bottom hole assembly (BHA) for vertical drilling (Figure 6, left) includes a pilot bit with smaller diameter that drills a guide hole, an under-reamer with expandable and retractable cutter pads expands this initial borehole to accept the full diameter of the casing being used. Stabilizers between the pilot bit and the under-reamer maintain borehole inclination. Upper stabilizers located inside the casing reduce BHA vibrations and protect the Drill Lock Assembly (DLA), which provides an axial and torsional connection to the casing (Fontenot et al. 2005). All equipment is sized to pass through the casing string.



**Figure 6** Shows the typical drilling assembly that is used to drill vertical (left) and directional (right) wells (modified from Fontenot et al. 2005)

Other downhole tools in addition to the bit and under-reamer are used as appropriate. For directional drilling, a steerable motor or rotary steerable system, MWD, and non-mag collars are included in the BHA (Figure 6, right).

Today, several service providers are committed to developing tools, techniques and equipment for drilling with casing. From the beginning Tesco Corporation grew into a leader with extensive experience in the design, manufacture and service of technology based solutions for the upstream energy industry. Their CwD process has been twice recognized by World Oil magazine as “Best New Drilling Technology”– first in 2002 and again in 2008.



As a major provider states that over 280 wells and more than 2 million feet of hole have been drilled with casing drilling method between 1999 and 2007. These wells have been drilled in formations with varying lithology for both offshore and onshore environments. Table 2 below presents a summary of statistics on the retrievable BHAs that have been applied on commercial wells, which were drilled from January 2001 to June 2006 by Tesco Corporation Ltd for vertical and directional applications (Houtchens et al. 2007).

**Table 2** Statistics for Unsuccessful and Successful BHA Retrievals (Houtchens et al. 2007)

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

As shown on Figure 6, the BHA generally consists of a pilot bit and under reamer, but may include other tools needed to perform almost any operation that can be conducted with a conventional drill string.

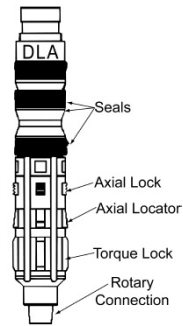
Initial casing directional drilling was done with steerable motors and major problems were related to BHA design. Since CwD was developed on land (onshore) drilling while RSS have been popular for offshore drilling operation, combination of these two techniques had different environment and mode of application. Conoco Phillips, Tesco and Schlumberger proved test program through two well where combination CwD and RSS secures the advantages of casing drilling and at same time preserves the directional efficiency of the RSS. Results showed that directional wells can be drilled with casing using steerable motors but success is difficult to achieve in holes smaller than 8 ½ in. The smaller sizes of BHA components required to fit through small holes give less-than-optimal power to steer the under reamer and bit (Lesso et al. 2005).

### 2.2.1 Drill Lock Assembly (DLA)

The drilling assembly is attached to the bottom of the casing by DLA, so the top component in the drilling assembly is a drill lock (DLA) (Figure 7) that provides the mechanical (axial and torsional) coupling to the casing, as well as providing hydraulic seals and a mechanism to facilitate insertion and retrieval.

The DLA provides the ability to connect conventional drilling tools with rotary-shouldered connections to the casing and facilitates running the tools in and out of the casing. It provides the capability to axially and torsional lock and un-lock the drilling BHA to the casing, seals in the casing to direct the drilling fluid through the bit, locates itself in the profile nipple without relying on precise wireline measurements, and bypasses fluid around the tools for running and retrieving. A releasing and pulling tool is run on wireline to release the DLA and pull the BHA out of the casing in a single trip

for vertical and low angle wells. In the unlikely event that the BHA cannot be pulled on the first attempt, the releasing tool can be disconnected from the DLA so that remedial measures can be taken (Warren et al. 2005).



**Figure 7** Drilling Lock Assembly (Warren et al. 2001)

### 2.3 The Rig for casing drilling

Drilling rig for conventional drilling does not differ too much from the Rig for casing drilling (Figure 8). Actually, the main differences are reflected in the system which provides connection, rotation and circulation of casing string, named Casing Drive System (CDS) and attachment of an additional mud pump and enhancement on the gas-handling and well- control equipment. These improvements make it possible for large influx of gas to be safely handled by the rig in situations where high-pressure gases are experienced in natural fractures (Abubakar et al. 2012).

Besides containing usual conventional rig equipment, CwD Rig also contains top drive and wireline winch, utilized to run and retrieve the downhole tools.

For example, one of the Tesco Casing Drilling rig were designed on standard oilfield skids, so the entire rig can be moved in 12 loads, rather than the 23 loads required for conventional rigs. The most modern conventional rigs used in the Lobo development area require about 33 truckloads to make a move, with move time averaging about 2.2 days. The new rigs can be moved with standard oilfield winch trucks without the use of a crane. A rig move requires 12 hours from release to start of the next well (Fontenot et al. 2005).



**Figure 8** Automated Casing Drilling Rig (Fontenot et al. 2005)

### 2.3.1 Casing Drive System

A top drive unit rotates the casing and applies torque to make tubular connections. The Tesco quick-connect Casing Drive System (Figure 9), which is operated by the top drive hydraulic control system, speeds up pipe handling and prevents damage to casing threads by eliminating one cycle of making and breaking connections at tubular joints (Fontenot et al. 2005). Once the connection is made up, circulation can be initiated, and the CDS may manipulate the entire string of casing.



**Figure 9** CDS connected to the top drive (Fontenot et al. 2005)

A slip assembly grips either the exterior or interior of the casing, depending on pipe size, and attaches the casing to the top drive without threaded connections (Figure 10). An internal spear assembly provides a fluid seal inside the pipe (Fontenot et al. 2005).

The use of the casing drive system accelerates the casing handling process, reduces the manpower, removes one make/break cycle, avoiding damage to the casing threads and improves safety. Depending on the hoisting capacity some basic parameters of Tesco casing drive system are presented in Table 3.

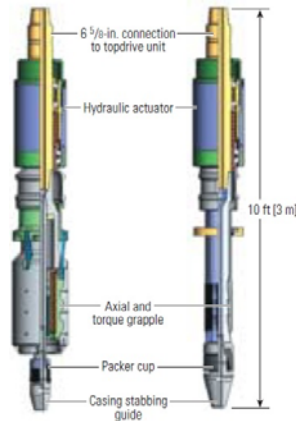


Figure 10 Tesco exterior and interior CDS (Fontenot et al. 2005)

Table 3 Tesco CDS Specification (Tesco, 2016)

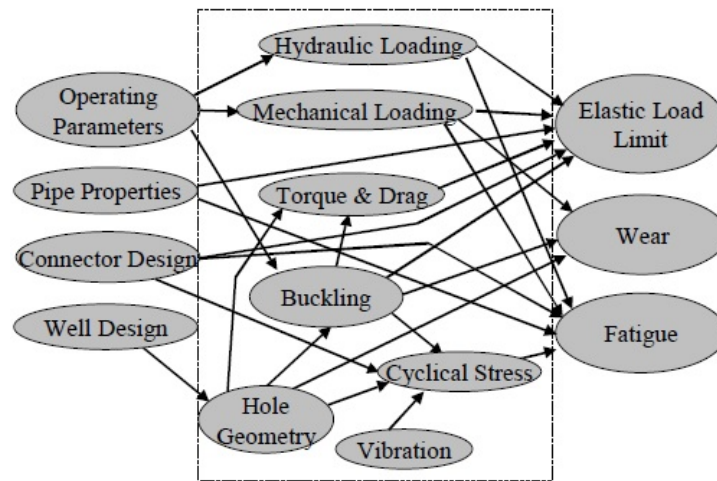
<b>Specifications:</b>			
<b>Hoisting Capacity</b>	<b>350 Ton External</b>	<b>500 Ton Internal</b>	<b>750 Ton Internal</b>
<b>Casing Sizes (in.)</b>	3 1/2 - 8 5/8	4 1/2 - 20	9 5/8 - 20
<b>Length (ft)</b>	10	10	19
<b>Maximum Torque (ft/lbs)</b>	40000	40000	80000
<b>Maximum Drilling Fluid Press. (psi)</b>	5000	5000	5000
<b>Maximum Operating Speed (rpm)</b>	200	200	100
<b>Maximum Push Down Capacity (lbs)</b>	25000	25000	25000

## 2.4 Well and Casing design approach

Most of the engineering problems that could affect the integrity of casing used for Casing Drilling needs to be addressed before carrying out the casing drilling process. Therefore, design calculations like casing diameter, setting depth, grade and weight, bore hole stability, well control, directional planning and bit selection are very similar to designing in conventional drilling. The casing connections and additional stresses may require a

change, because they must provide adequate torsional strength, fatigue resistance, hydraulics and flow clearance. Also, buckling and wear of casing are not strange factors while casing drilling. All that phenomena will be discussed below.

Figure 11 shows some of the interactions that affect the integrity of casing used for Casing Drilling. The three primary considerations for casing integrity are shown on the right, while the things that are under the operator control are shown on the left. Complex interactions relate parameters directly under operator control to the ultimate casing integrity (Warren et al. 2000).



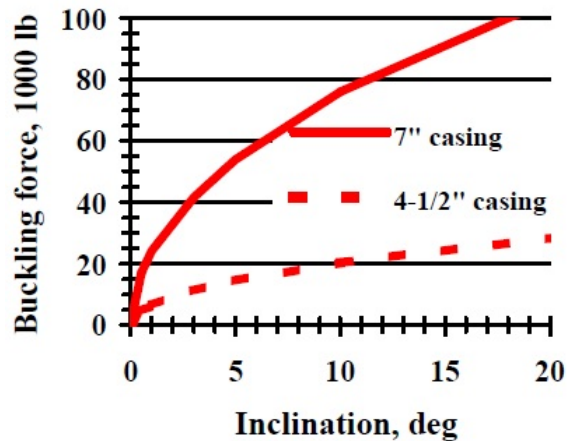
**Figure 11** Interactions affecting casing integrity for Casing Drilling applications (Warren et al. 2000)

#### 2.4.1 Casing Buckling

At beginning of 21<sup>st</sup> century, it was not easy to take for sure there is no drill collars. The drillers immediately were thinking how to provide weight on bit. Drilling Engineer calculations, such as neutral point, buckling, hydraulics and fatigue resistance, seemed to be not real in casing while drilling operation. Evidently, the industry was changing and we had to follow it.

Buckling produces two main problems, caused by operating parameters and hole geometry. First, the lateral contact forces between the drill casing and borehole wall can cause wear on the casing and will increase the torque that is required to rotate the casing. Secondly, the buckling causes the casing to assume a curved geometry within the borehole that increases the stress in the pipe and may increase the tendency toward lateral vibrations.

The buckling curves on Figure 12 represent the load for which 23 lb/ft 7" casing in an 8 1/2" hole and 9.5 lb/ft 4 1/2" casing in a 6 1/4" straight holes helically buckle (Abubakar et al. 2012)



**Figure 12** Helical buckling force for 4 1/2" 9.5# casing in a 6 1/4" straight hole and 7" 23# casing in 8 1/2" straight hole (Warren et al. 2000)

In vertical well, the compressive load that causes buckling is determined by three factors: the stiffness of the pipe (EI), the lateral force of gravity (pipe weight and hole inclination) and distance from the bore hole wall (radial clearance). If the well is straight, but not vertical, the normal wall contact force from the pipe lying on the low side of the hole provides a stabilizing influence and increases the compressive load that can be supported before the drill-casing buckles (Warren et al. 2000). The location of the contact determines if the wear is localized to the casing couplings or does it also affects the casing body.

For example, BP Company encountered this problem while casing drilling production section with 4 1/2" casing at pilot project on Wamsutter area, Wyoming. Drilling the first two wells they tried to solve it by applying rigid centralizers (Figure 13) but it was unsuccessful. On the third well problems with wear, lateral vibration, torque and fatigue were solved using twenty-four joints of 23.2# 5" casing that were run on the bottom to replace the 4 1/2" centralized casing used in the previous design. This casing has sufficient weight so that the coupled 4 1/2" casing is not in compression, provides a smoother surface to reduce the friction that increases the tendency to whirl, and provides a thicker wall to better withstand the wear on the casing body (Shepard et al. 2001).



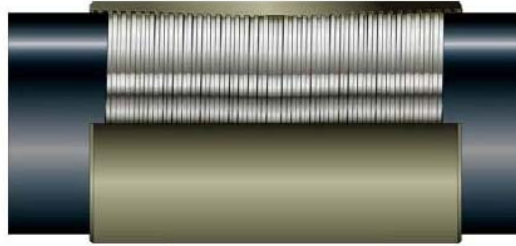
**Figure 13** Rigid centralizer (Shepard et al. 2001)

#### **2.4.2 Casing Fatigue**

Fatigue failures are caused by cyclical loading at stress levels well below the elastic strength. Under repeated loading, a small crack begins at a point of localized high stress and propagates through the body, until the remaining cross sectional area is insufficient to support the static load. The number of stress cycles that are required to cause failure is dependent on a number of factors, and may range from only a few cycles to infinity. Fatigue failures are highly susceptible to local conditions and are somewhat statistical in nature (Warren et al. 2000). Resulting from oscillatory bending loads, failure usually appear in leaking shape (wash out) before final rupture. These failures are often located in either the threaded portion of the connection or the slip area of drill pipe.

#### **2.4.3 Casing coupling and threads**

The casing connections play one of major roles in drilling process. Connection is exposed to high torsional and axial forces, fatigue resistivity and banding loads. Beside that desirable connection characteristics include also repeat makeup, easy handling, maintenance high-integrity pressure seal and good flow clearance. The design is developed based on knowledge gained from developing fatigue resistant connections for offshore production risers. Mainly, connections are API buttress BTC, additionally upgraded with an integrated load ring for torsional and sealing capability, and threads treated with a molybdenum di-sulfide preparation in order to reduce galling during make-up. Some of manufacturers are Grant Prideco (Figure 14), Hydril, Hunting Energy Services, Vam, and GB Tubulars (Kerunwa and Anyadiiegwu, 2015).

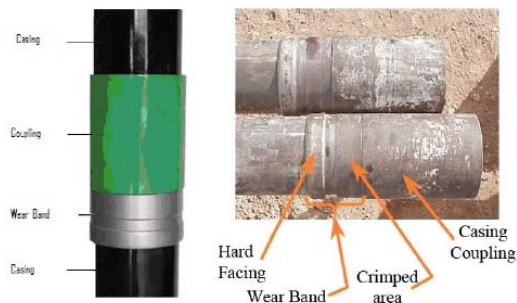


**Figure 14** Grant Prideco casing connection (Kerunwa and Anyadiegwu, 2015)

#### 2.4.4 Wear protection

This safety issue is quite similar to wear protection for drill pipe. Driven by the fact that casing will be cemented in place and serve in further operation, wear protection is very important for casing integrity while casing drilling operation.

The wear band, shown on Figure 15, is a metallic ring coated with tungsten carbide hard facing. It is placed below the coupling to maintain the strength of the connection (Abubakar et al. 2012)



**Figure 15** Casing wear band protection (Modified from Abubakar et al. 2012; Gaurina-Medjimurec, 2005)

#### 2.4.5 Hydraulics

In comparison with conventional drilling, CwD with the large-diameter casing increases the total internal fluid-flow area and reduces the annular flow. Larger diameter provides a small pressure drop inside casing but also increases in annular space (Sanchez et al. 2012). That means ECD could be higher, which can be alarming, especially in drilling horizontal wells. However, the process of casing drilling utilizes the higher ECD to act against borehole collapse, improving wellbore stability.



Restricted flow area in annular space provides enough velocity, with relatively low flow rates for efficient cleaning (n factor), but on other hand, flow rate is important for bit balling factor.

Consequently, the hydraulic energy was the major power-component used to optimize drilling efficiency of the system as an alternative to mechanical energy. Therefore, the team should be focused on providing enough hydraulic energy to clean the bit and prevent the bit balling with high jet velocity, remove cuttings rapidly in order to avoid accumulation inside tight-clearance annulus and flowline, and reduce overall energy consumption (Sanchez et al. 2012).

Mostly applied Casing Drilling technology has circulation fluid of equivalent effective density (ECD) one that higher than conventional drilling, even volumetric flow run away speed fluid that pumped last low. It insufficiently reasonable being applied on mostly had out drilling, in consequence needs to be developed a hydraulic model that valid to been applied on fluid input diameter that high and annulus was tight. Hydraulic model in annulus this give effect on eccentricities and rotes are pipe in annulus that narrow. The high drilling flow rate and hydraulic energy (hydraulic horsepower) will increase the penetration on soft formation at surface. Buntoro, in 2008 states that penetration can increase until 78% greater of previous if increase volumetric flow rate until up 800 gpm (3028 lpm) with HSI 1.5 on Casing Drilling utilizes casing 13 3/8 in. for hole 17 1/2 in. (Buntoro, 2008).

Hydraulic design for drilling with casing Fiqa formation, Sultanate of Oman, for 13 3/8 in. and 18 3/8 in. sections are presented in Table 4 (Sanchez et al. 2012).

**Table 4** Calculated hydraulics parameters at different flow rates (Sanchez et al. 2012)

Parameters	Units	Drilling with 13 3/8 in. Casing at 750 m			Drilling with 18 3/8 in. Casing at 894 m		
Flow Rate	m <sup>3</sup> /min	3.8	3.4	3.0	3.8	3.4	3.0
	gpm	1000	900	800	1000	900	800
Stand pipe pressure	kPa	13700	11200	8986	8935	7299	5838
	psi	1992	1629	1303	1296	1059	847
Casing ΔP	kPa	34	34	21	68	66	64
	psi	5	5	3	9.7	9.4	9.14
Bit ΔP	kPa	12545	10159	8028	7561	6053	4713
	psi	1819	1473	1164	1096	877	683
Annulus ΔP	kPa	566	545	524	706	689	670
	psi	82	79	76	/	/	/
HSI	HP/in <sup>2</sup>	4.47	3.26	2.29	1.71	1.23	0.84
Jet velocity	m/sec	148	133	118	111	99	88
	ft/sec	484	436	387	365	326	288
ECD at bit	kPa/m	12.34	12.34	12.23	13.29	13.27	13.25
	ppg	10.5	10.5	10.4	11.3	11.3	11.3
Annular velocity	m/min	59	53	47	55	49	43
	ft/min	192	173	154	179	161	142

### 2.4.6 Torque and Drag Analysis

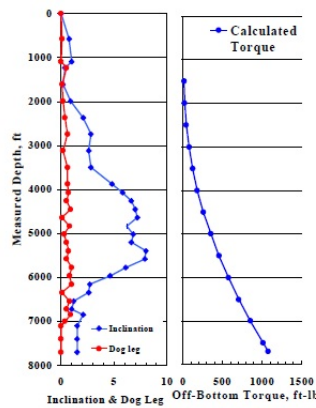
Torque and drag analysis are always subject of discussion and research. Today we have modern sensors for measuring and quick response before failure was observed.

Torque and drag are induced by frictional forces acting between the borehole and the casing string. It is more striking in deviated wells, where larger contact area has consequence of lateral vibration. Maintaining of good RPM in different formation, in order to avoid natural frequency, is also important factor.

In many situations with larger casing, the aggregate normal force while drilling with casing in a directional well is greater than when drilling with drill pipe, because the casing weight is greater. The effective diameter of the casing is also larger than for drill pipe drilling. Both of these effects can contribute to higher rotating torque with casing. If the hole is tortuous, the stiffness of the casing may also contribute to the torque (Warren et al. 2005).

The casing string design for casing-drilled directional wells may require more centralization than in vertical wells. Directional wells have more side forces and are more susceptible to differential sticking (Warren et al. 2005).

Since contact between the centralizer and borehole wall creates torque and results in wear of the centralizers, Warren T. showed evidence of the correlation between downhole recorded acceleration data and surface torque, shown on Figure 16, that supports this explanation that lateral vibration was responsible for the torque, wear, and ultimate fatigue failure of the casing experienced in the first well drilled in Wamsutter area (Shepard et al. 2001).



**Figure 16** Inclination and torque on the first drilled well, Wamsutter area, Wyoming (Shepard et al. 2001)

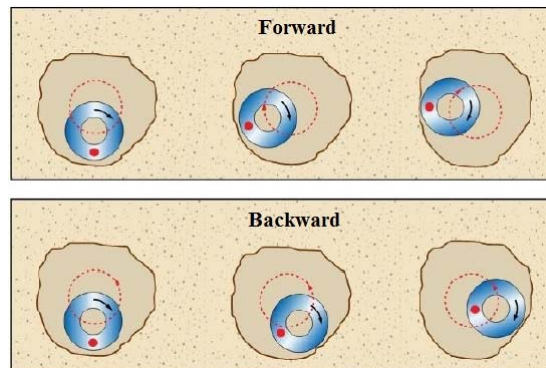
Thanks to technology development, we are able to use various sophisticated software for detailed analyses and improving the well integrity.

#### 2.4.7 Vibrations in casing string

Vibration analysis deserve discussion in separate paper since it is natural, never 100% solved, problem in history of drilling engineering. It is known that there are three basic models of vibration and combinations thereof. Looking at the axis of propagation – action of vibration, there are axial (bit bounce model), lateral (Bit/BHA whirl model) and Torsional (Stick slip model).

All models have specific impact on drilling efficiency, ROP, fatigue, equipment damage and well instability. Vibrations are caused by many factors while drilling operation and pose a higher challenge in drilling with casing string, being weaker than conventional drilling string.

Appearance of lateral vibration and BHA whirl model (Figure 17) are observed in many fields especially in those whose inclination is expressed.



**Figure 17** The direction of movement of BHA in “BHA whirl” model

#### 2.5 Cementing

Cement job, equipment and procedure used for it are quite different than in conventional drilling cementing process. In first observation, while drilling vertical wells with non-retrievable systems, drillable drilling shoe has served as casing shoe. The world’s first convertible casing drill shoe job is performed onshore Brunei in September 2003 during a 0.2445 m (9 5/8”) surface casing job on S-816 well in the Seria field (Gaurina-Medjimurec, 2005). After reached section TD cement job can start immediately. Problem with float equipment was exposure to high flow rates for considerable time while drilling the entire hole section.

By developing retrievable system, cementation process has encountered a change in terms of equipment and procedures for cementation. Initial solution was to pump wiper plug before start pumping cement slurry and then a latch down cement plug behind the slurry, which lands in the DLA locking profile. The problem with this procedure was the risk of the cement plug landing improperly on DLA seat, especially casing sizes.

This problem was solved by designing a pump-down float (PDF) that can be pumped into place before the cement is introduced to the well. A positive pressure signal indicates when it lands and a wireline run can be used to confirm that it is in place if there is any doubt about its location. Once the PDF is in place, the cement job then is conducted as with a conventionally drilled well. The casing can be rotated and reciprocated while pumping the cement (Warren et al. 2000).

In the retrievable system, where the bit has to be replaced before drilling to the next casing point, the CwD process requires full-bore access to enable the retrieving and running of the BHA through the ID of the casing. This makes it unsuitable to use floating equipment (Kerunwa, 2015). Equipment for casing must provide integrity for casing during drilling and cementing operations as well as safe conduct further operations.

### **3. CONCLUSION**

From the start of its application, casing while drilling technology bared numerous benefits in O&G industry. First with non-retrievable system and convertible drillable drill shoe idea of casing while drilling has confirmed benefits but also revealed new problems which are solved on the fly. As in conventional drilling, logical improvement in technology after vertical wells was implementation of technology to directional drilling. The implementation of CwD to directional wells resulted in developing retrievable systems whose application showed even better results in cost reduction and drilling performances.

Day by day casing drilling stands for one of the biggest improvements in drilling engineering domain. It's cost-effective technology with less equipment used, with better efficiency and safer environment.

Since the advantages are numerous, it is difficult to single out just one of them as most important. The entire industry was engaged in research and development, starting from engineering consideration, new equipment developing to making procedures guidance. All these efforts and knowledge led to cutting down cost related to all operations with drill string, reducing problems with and during tripping, reducing NPT as well as total time required for drilling the well. Reduced capital and logistic costs attributable to a lighter weight substructure and derrick, lower horsepower, less maintenance, fuel consumption and manpower are just some of the benefits.

Influenced by low oil price, current system modifications are slowed down, but hopefully casing while drilling in deep water applications, underbalanced drilling, drilling with air, drilling HTHP and geothermal wells will continue to develop.

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