Universitetet
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# FACULTY OF SCIENCE AND TECHNOLOGY

# MASTER'S THESIS

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Title of Master's Thesis:

**FEASIBILITY STUDIES OF COMBINING DRILLING WITH CASING AND EXPANDABLE CASING**

ECTS: 30

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## ABSTRACT


Nowadays, the biggest challenges in the oil business are the cost of operations versus the sizes of the prospect. We are drilling smaller targets and over the last few years, rig cost, service company rates and materials have gone up significantly in accordance to the oil price. Industry is continuously searching for new technologies to make the drilling of well safer, more efficient and cheaper. This thesis explores the possibilities of combining existing technologies to solve these challenges.

Drilling with casing (DwC) is using standard casing as the drillstring, and leaving it in place to case the well. It has almost no limitations and has a potential of saving 20 – 30% of rig time by eliminating drillstring tripping and also minimizing downhole problems. With expandable technology, expanded casing can provide a larger diameter of the production casing. This can increase the productivity.

Since both technologies have the same operational procedure, they could be combined into one operation. The concept is to use expandable casing as drillstring which will be expanded when the target depth is reached. To be able to expand the casing, one needs to drill with an underreamer to obtain a bigger hole and the BHA must be changed from a drilling into an expandable BHA.

The conclusion of this thesis is that the drilling with expandable casing concept is possible. However, there are some technology challenges, especially on tools and on the strength of post expansion material. Limitations on drilling parameters such as: dog leg severity, RPM, mud properties etc also need to be considered to achieve a good expansion result.

The case example analyzed, indicates that we can save almost 23% of the operation time by running this combined technology. Expenses can be reduced through lowered rig costs and the operational risk can be mitigated. A better understanding of the technology and operational procedures will help to further reduce the risks and make the technology more acceptable. If this new method succeeds, there will have a high potential for cost savings, higher production and better well control.

# ACKNOWLEDGEMENT

Knowledge is a power.
It can break barriers, build the personality, and give us something to contribute to the society. I believe every single child brings their own hope, gift and inspiration. Teach and give them a chance and they will find their way. In this acknowledgement I would like to dedicate my special appreciation to these special people who has taught me a lot and given me chances:

First to my three supervisors in Chevron Norge:
Lars Øyno, thank for believing in my idea and providing me a way to realize it through this thesis. To my lovely friend and supervisor South Debbie, for teaching me in how to present my thought in systematic and good-writing ways and Gunnar Rørnes, who teaches me in how to package it into an understandable document. Because of their patient, efforts and time, I have learned and improved myself.

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Tusen takk to my university supervisor Bernt Åadnøy for his positive support and belief in me, my classmates who have been encouraging each other to finish the thesis. Moreover, my sincere gratitude to NORAD and Department of Petroleum Engineering at University of Stavanger for the learning opportunities. Having these experiences to study in Norway, meet a lot of good people and travel to many new places, I always consider it as my blessing….

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# TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

CHAPTER I

# INTRODUCTION

## 1.1 BACKGROUND

Nowadays, higher oil price and world demands on oil and gas supplies, have allowed the oil companies increase their production. To meet the demand, oil companies also try to explore new reservoir possibilities in difficult area such as deep water, HPHT reservoir and salt dome reservoir. Most of the reservoirs that were considered as non-economic are being developed now. The decisions to increase the production and to drill in the challenging condition bring consequents on technology challenges.

There are two technologies on drilling which could become the solution for these challenges; drilling with casing and expandable casing. These two technologies that were operated separately show promising results even the developments are still on going. On this thesis author would like to bring a step further by seeing the possibilities of combining these two technologies both technical and cost effective. The thesis also included a simple operation risks analysis.

Drilling with casing (DwC) is using standard oilfield casing as the drillstring, and leaving it in place to case the well. It has almost no limitations and could save 20 – 30% rig time by eliminating drillstring tripping. Additionally, it also minimizes downhole problems (loss of circulation, kick and wellbore instability issues). Casing drilling delivers all of the functionality of conventional drillpipe drilling. This safer and more cost effective process will change the way we drill the wells.

Expandable technology is next step of the development of mono-diameter technology. The technology has a potential to increase productivity, extend the reach of the well, and to make completion easier. Mono-diameter wellbore will become the future shape of oil well construction.

Since both technologies have the same operational procedure, they could be combined into one operation. The concept is to use expandable casing as drillstring which will be expanded when the target depth is reached. Since both technologies are expensive, the author has studied a new casing configuration that could be more cost competitive. In additional, it should be remembered that the possibility of combining its disadvantages and limitations of both technologies also exist.

As our education institution is in an independent position, which gets sponsored by Oil Company and gets supported by many services companies, we are free to access and to evaluate the integration of both applications. Moreover, we will contribute the result of this research back to the E&P business. If the new methods investigated succeed, there will be a potential of cost saving, higher production and better well control that might become the answer for the drilling challenges.

## 1.2 PURPOSES OF THE THESIS

There are two main purposes of this thesis:

1 To see the feasibility of combining drilling with casing and expandable casing methods. The analysis will be done both on technical and cost effective point of view.

2 To study and propose the appropriate application for this method.

There are few questions that need to be answered for analysis:

1. How can this combined method works?
2. Are the expandable casing connections strong enough for drilling with casing?
3. How does the expandable casing perform after being used for drilling?
4. What are the expandable casing properties that need to be considered?
5. Is the cost competitive?
6. Are there any limitations and risks on this process?

## 1.3 HOW THE REPORT IS BUILT

The report is built in accordance to this structure;

CHAPTER 1: Introduction

CHAPTER 2: Relevant theory

CHAPTER 3: Analysis and results

CHAPTER 4: Discussion

CHAPTER 5: Applications of technology

CHAPTER 6: Conclusions

# CHAPTER II
# RELEVANT THEORY

The combination theory which author calls “Drilling with expandable casing” consists of two main concepts; Drilling with casing and Expandable casing. Since there is no exact theory for drilling with expandable casing, here is presented separately supporting theory for drilling with casing and expandable casing.

## 2.1 DRILLING WITH CASING THEORY [2]

Drilling with Casing (DwC) is a process of using standard oil field casing for the drillstring, so the well is simultaneously drilled and cased (figure 2.1). Both surface and downhole tools and components are necessary to make this process possible.

While many of the functions and activities are similar to the conventional drilling process, there are sufficiently different to warrant special drilling consideration. The drillpipe and drill collars are used and the logging, coring and perforating operations are the same with conventional. To meet the loading and bottom hole criteria, the modifications are done in surface lifting facility and bit.

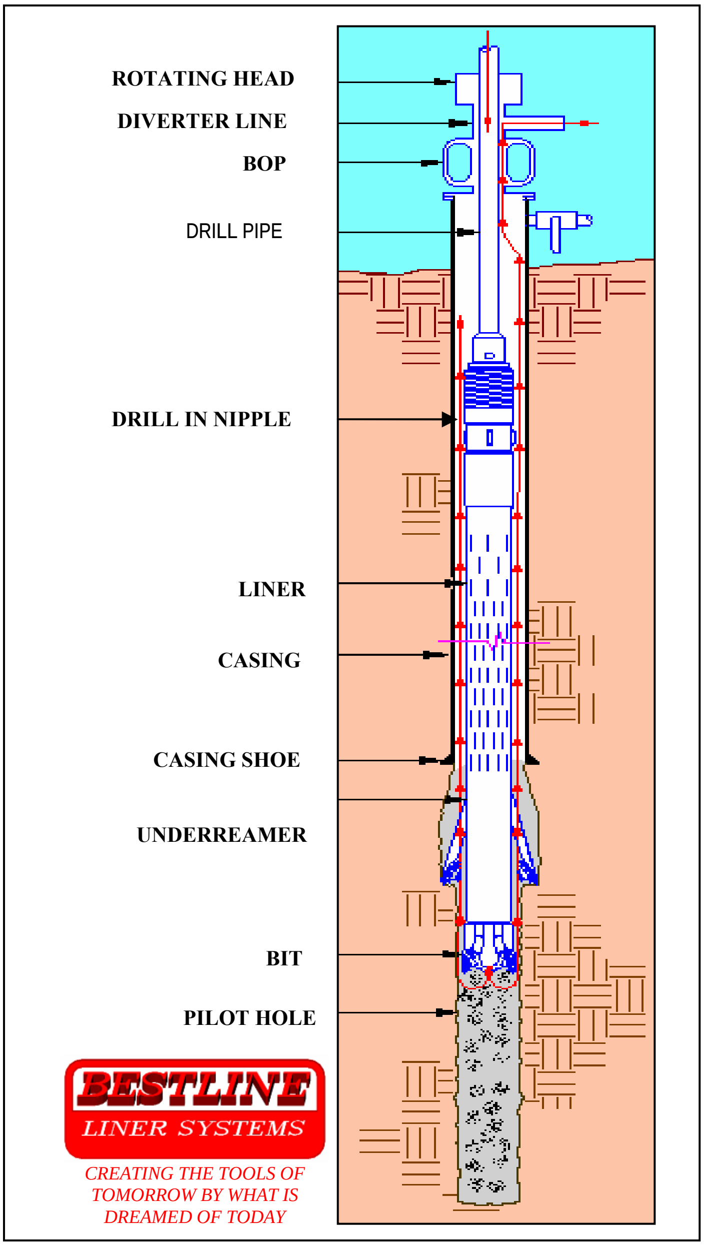


Figure 2.1-Drilling with systematic [20]

The connections were not very robust and over time, drillpipe evolved as stronger and stronger connection was developed and the resulting casing was not been used for drilling. In 1950's the idea of drilling with casing re-emerged, while there were many potential advantages of this technique, it was not commercially accepted because of the limitations in material and cutting tools that available at that moment. But the initiatives to development facilitated the process sufficiently so that it will become a successful commercial service in the future.

A conventional drillstring must be tripped out of the hole each time the bit or bottom hole assembly needs to be changed, the casing point is reached or the bore hole needs to be "conditioned". Casing is then run into the well as a completely separate process to provide permanent access to the well bore. DwC systems integrate the drilling and casing process to provide a more efficient well construction system by eliminating these drillstring trips and allowing the well to be simultaneously drilled and cased.

### 2.1.1 Advantages and disadvantages of Drilling with casing (DwC)

**Advantages of DwC**

- Avoiding possibilities of hole problems by eliminating tripping process

  Saving result from eliminating cost related to purchasing, handling, inspecting, transporting and tripping the drillstring, reducing hole problems that are associated with tripping, reducing trouble time associated with lost circulation, eliminating trouble time for running casing and the problems within, and also saving on rig equipment capital costs and operating costs could be achieved. The potential savings from reducing drillstring tripping and handling can be identified quite easily for any particular situation, but the savings from reducing hole problems are more difficult to quantify. There are many situations where problems such as lost circulation, well control incidents and borehole stability problems can be directly attributed to tripping the drillstring.

- Avoiding possibilities of running casing problems

  In other cases it is difficult to run the casing after the conventional drillstring is tripped out because of poor borehole quality. Some of theses difficulties are related to boreholes stability problems directly attributed to drillstring vibration, while others are related more to the particular well geometry and formation condition being drilled. The DwC system reduces these incidents by installing the casing immediately as the well is drilled.

- Drilling with Casing can make the well deeper

  DwC offers the opportunity to drive the casing setting depth deeper than may be obtained with the conventional drilling. The need to drill with a sufficient mud weight to provide a trip margin before tripping out the drillstring to run casing is eliminated. Especially in deep wells the pore pressure and fracture pressure has a close margin.

- Drilling with casing can reduce the lost circulation problems

  The DwC process also mechanically enhances the wellbore wall "filter cake" to reduce lost circulation. The effect of reducing the loss circulation in DwC is not fully explained, but it seems to be caused by the casing mechanically plastering drilled solids into the wall of the borehole. This plugs small fractures in the wall and reduces the effective permeability at the rock face. This affect, which called "smear effect", also reduces fluid flow into the wellbore, making well control safer for casing drilled well.

- The DwC process is safer than the conventional drilling process

  Personal exposure to pipe handling during tripping and casing running operation is reduced. The DwC process also provides a circulation path to the bottom of the well at all times which reduces risk associated with well control operation.

- Under balance drilling can be applied using DwC for over pressured formation.

  Under balance drilling can be applied with the DwC system for drilling into over pressured formation with a lower mud weight that this method cannot be implemented with conventional system. With appropriate well design, surface equipment and planning, the dynamic friction of the flowing mud can be used for well control.

**Disadvantages of DwC**

- The cost of drilling with casing is comparable with conventional drilling.

  Fundamental reason to use DwC is we can eliminate the risk and the cost of drilling through the trouble zones. The well control and lost circulation problems when we drill through trouble zone can be eliminated. Well cost might be also reduced, such as:

  - By reducing tripping time
  - By saving cost from loosing lost circulation agent and mud.

  However due to small number of vendors, the cost tends to be high and be monopolized.

- DwC needs a special or modification rig and top drive system.
- DwC needs a special bit and bottom hole assembly system.

### 2.1.2 Industry overview [9]

This subject can be divided into two general areas: 1) Casing Drilling, where the casing is extended to the surface and is used to drill the hole much like drillpipe is currently used; and 2) Liner drilling where only short sections of pipe are drilled into the ground and it is generally carried and rotated using drillpipe.

#### 2.1.2.1 Casing Drilling

This technology has been mostly developed and deployed by the Tesco Company. Tesco has several rigs that are routinely drilling in casing in Southern Texas. Two operators have embraced the technology and are now using it to develop fields. ConocoPhillips is using the technology in their Lobo field of South Texas and Apache Oil Company in their Stratton Field. These two applicators of casing drilling are responsible for more than 90% of the wells that have been drilled.

The system requires several pieces of equipment that are unique to casing drilling operations. Those pieces of equipment can be grouped as listed below:

1. Surface lifting and circulating system
   - A Casing Drive System.
   - Powered catwalk
2. Sub-surface or downhole equipment
   - A non-retrievable BHA (bit)
   - A retrievable BHA. (Bit and retrieval pin-box tool)

Each of these pieces of equipment is required to conduct Casing drilling. Each will be described briefly.

**The casing drives system.**

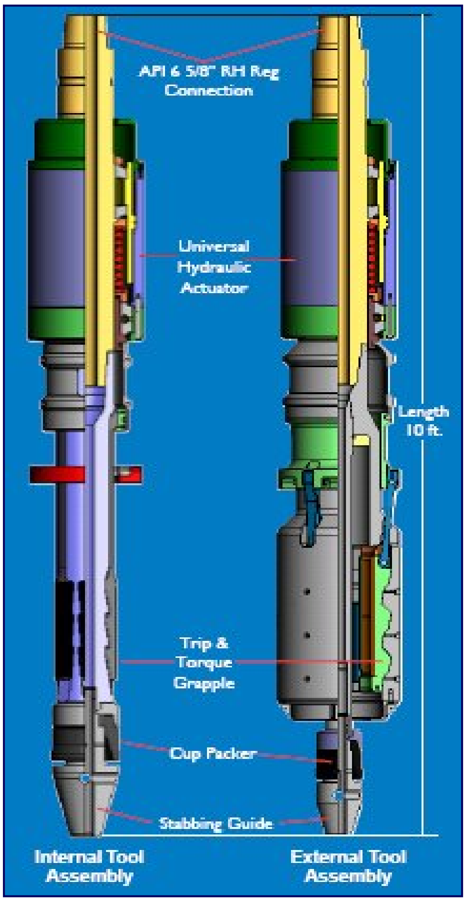


**Figure 2.2-Casing drive system [9]**

The Casing Drive assembly is used to grab and seal against the casing so torque can be transmitted to the casing and mud can be pumped through it. Tesco uses two different drive assemblies, depending on the size of casing being handled. An external gripping system is used for casing sized from 4 1/2" to 8 5/8" and in internal gripping system for 7" to 20" pipe. Both assemblies use swab-like cups to seal on the inside of the casing so mud can be circulated down the pipe (figure 2.2).

The gripper assemblies are hydraulically controlled and have a 40K ft-lbf torque rating. The external gripping mechanism has a 350 tons API 8C load rating while the internal system is rated at 500 tons. These assemblies both mate to a Top-Drive assemble that is required conducting the Casing Drilling operations.

The Top-Drive supplies the torque through these Drive assemblies to make-up the casing connections and drill. A modified elevator link-tilt mechanism is part of the Casing Drive assembly, and used to pick the casing up from the "V"-door area and to hold the casing as it is screwed into the next piece hanging in the slips (figure 2.3).

**Figure 2.3-Casing Drive system [9]**

The normal procedure is to lift the casing with the link-tilt mechanism and stab the pin of the casing joint into the box of the casing hanging in the slips. Once stabbed, the top drive is lowered, stabbing the drive assembly into the new joint of casing. The drive assembly is then activated to grip the casing and the top drive is used to spin the casing into the box. Final make-up is also accomplished with the top drive.

**Powered Catwalk**

Tesco casing drilling rigs have several modifications that simplify pipe handling. One of these is their powered catwalk. The powered catwalk is a pipe handling system that is designed to automatically move pipe from the pipe rack to the drill floor without rig hand assistance. Pipe can be loaded or off-loaded from either side of the Catwalk. Hydraulic arms lift the pipe from the pipe rack to the catwalk trough. The catwalk trough then lifts and positions the pipe so the casing collar is located on the rig floor ready for the next drilling connection. This whole system is designed to automatically adjust for different lengths of pipe and can be completely controlled by the driller. Use of the powered catwalk and the link-tilt mechanism on the top drive and elevator link-tilt allows casing connections to be made with very little roughneck intervention. Joints of casing can be picked up from the Catwalk tough and lifted until they are vertical (figure 2.4)

**Figure 2.4-Power catwalk for DwC[9]**

**Non-retrievable system**

The non-retrievable system could consist of drillable bit or non-drillable bit (figure 2.5). A drillable bit is made of soft steel and hard cutting materials; therefore it is proper to be used on the soft to medium formation. When the drilling reaches the target depth, a ball is dropped and will fall into a ball catcher and totally closes the circulation inside the casing. The pressure then is built up and forces the cylinder to push the bit to open. This piston force makes the bit expand from inside and leaves it with open cylinder. The drilling then can be continued with less small bit through the open cylinder. Weatherford is one of the companies that provide this bit.

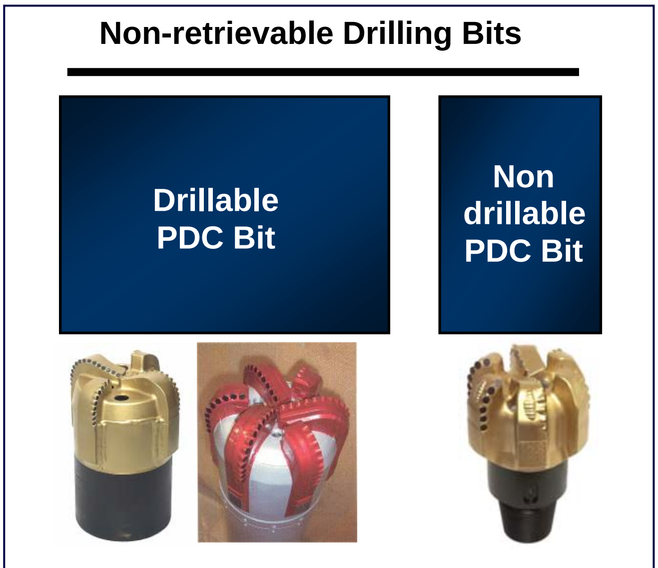


**Figure 2.5-Non-retrievable drilling bit [10]**

A non-drillable bit is made from hard steel and can be used to drill through the hard formation. When using the non-drillable bit, one disconnects and lets it fall into the rat-hole that had been drilled before and on the next drilling step, one steers a new curvature to avoid the bit in the rat hole.

**Retrievable system**


**Figure 2.6-Retrievable drilling bit [10]**

The retrievable system has a retrievable bit (figure 2.6), a wireline retrievable BHA box and pin. The bit is made from hard steel and cutting material; therefore it can be used to drill in the hard formation. When the casing depth is reached, one run a wireline inside the casing to disconnect and retrieve the bit.

The bit is pulled out through inside of the casing, leaving open hole cylinder in the bottom. Then the next smaller bit can be run in with the smaller casing inside the previous casing.

**Wireline retrieve BHA (Box)**

Located on the drilling end of the casing is the Wireline Retrievable Bottom Hole Assembly (BHA) Box (figure 2.7). This profile receives the wireline BHA, where it is both torsionally and axially locked into place. Another seal assembly on the BHA seals it into the bottom joint so that mud pump down the casing must pass through the BHA and any pressure in the well cannot pass between the Landing and Lock profile and the BHA. Hence, all fluid movement into or out of the casing must pass through the BHA just as in a conventional drilling operation.

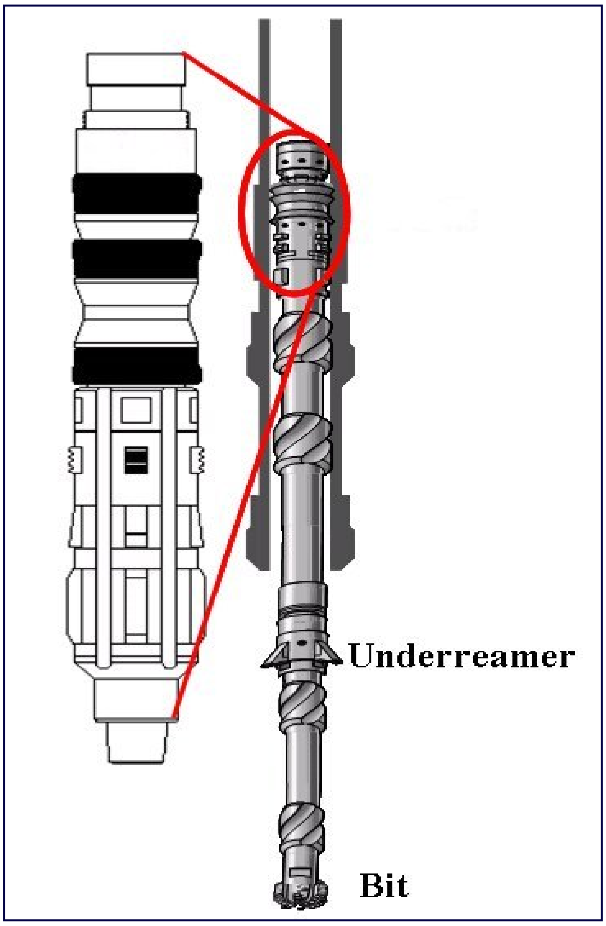


**Figure 2.7-Retrievable Box assembly [14]**

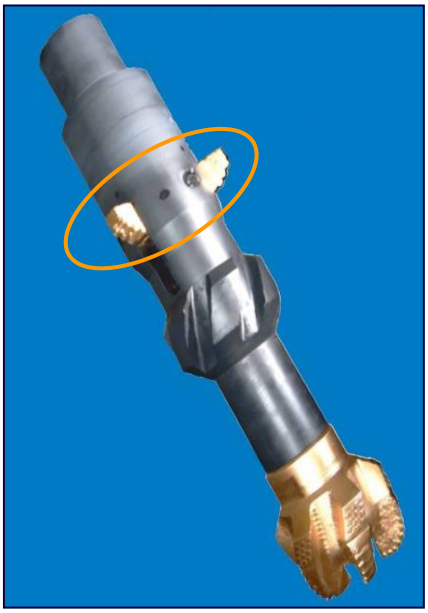

**Figure 2.8-Wing underreamer and bit [9]**

Since the entire BHA must small enough to pass through the drift diameter of the casing being used, the hole drilled with the bit alone would be smaller than the casing diameter. To enlarge the drilled hole, a under-reamer is run behind the bit to enlarge the hole enough for casing passage and to allow for cementing (figure 2.8). This under-reamer uses PDC cutters on the retractable arms to enlarge the hole. The use of PDC type cutters restricts the use of this tool to formations that can normally be drilling using PDC type bits.

High compressive strength rocks that require roller cone or diamond type bits may not be drillable with this type of under-reamer. This is one of the limitations of using the retrievable BHA assembly.

**Wireline Retrieve BHA (Pin)**

The BHA retrieval pin (figure 2.9) is a wireline run device used to grapple the BHA so it can be pulled to the surface for bit changes, under-reamer replacement or prior to cementing operations. The Retrieval tool can be pumped to bottom if for some reason it refuses to fall under its own weight. The tool is centralized in the casing and grapples a neck that is located on the BHA assembly.

**Figure 2.9-Retrievable Pin assembly [9]**

Once grappled, weight is placed on the BHA to release it and a straight pull then brings it to the surface. The retrieval procedure can also be accomplished with drillpipe if the well depth is shallow (1,000 ft to 2,000 ft). At these depths, retrieval with drillpipe can be quicker than with wireline due to rig-up time with the wireline.

### 2.1.2.2 Liner Drilling

Liner drilling differs from casing drilling mainly due to the length of the casing used in the system. Unlike casing drilling where the casing extends to the surface and it is gripped and rotated much like drillpipe, in liner drilling the casing is suspended and rotated using drillpipe. Many of the same liner running tools are used in liner drilling. These tools must be capable of withstanding the torque that will be transmitted to the liner and the setting tools must be designed to allow the pressures that will be seen during the drilling operations. In additional information, for Casing and Liner Drilling have almost the same bits.

### 2.1.3 CwD Engineering consideration

Considerations such as borehole stability, well control, casing setting depth, directional planning, and bit selection are treated much like they are conventional drilling. One significant difference is that the casing may be subjected to different stresses in CwD situation that it is for conventional uses. In additional, hydraulic power, lost circulation, cuttings transport, well cleaning, lateral vibration (whirl), torsional oscillation and directional control also become the main concern in drilling with casing due to the weight and bigger size of casing.

## 2.2 EXPANDABLE CASING THEORY

Two challenges facing on oil and gas industry are 1) accessing new reservoirs that currently cannot be reached economically, 2) maintaining profitable production from producing older field. Expandable steel technology, considered as one of the most exciting technologies that have emerged out of in the oilfield over the last ten years, may be crucial to meet this industry challenge.

### 2.2.1 Introduction

Well geometry is generally split into two main types: monobore and conventional geometry. Conventional wells are lined with production casing which is cemented in place. Hydrocarbons from the producing zones are brought to the surface in a separate, smaller piping system (tubing) that is installed inside the production casing.

In monobore wells, the production casing is cemented in the ground in a similar fashion as in conventional wells, however, the one size (mono) casing, is installed. The well has the same inside diameter from top to bottom. This pipe system is also used as the producing conduit. No tubing is run in these wells. See figure 2.10

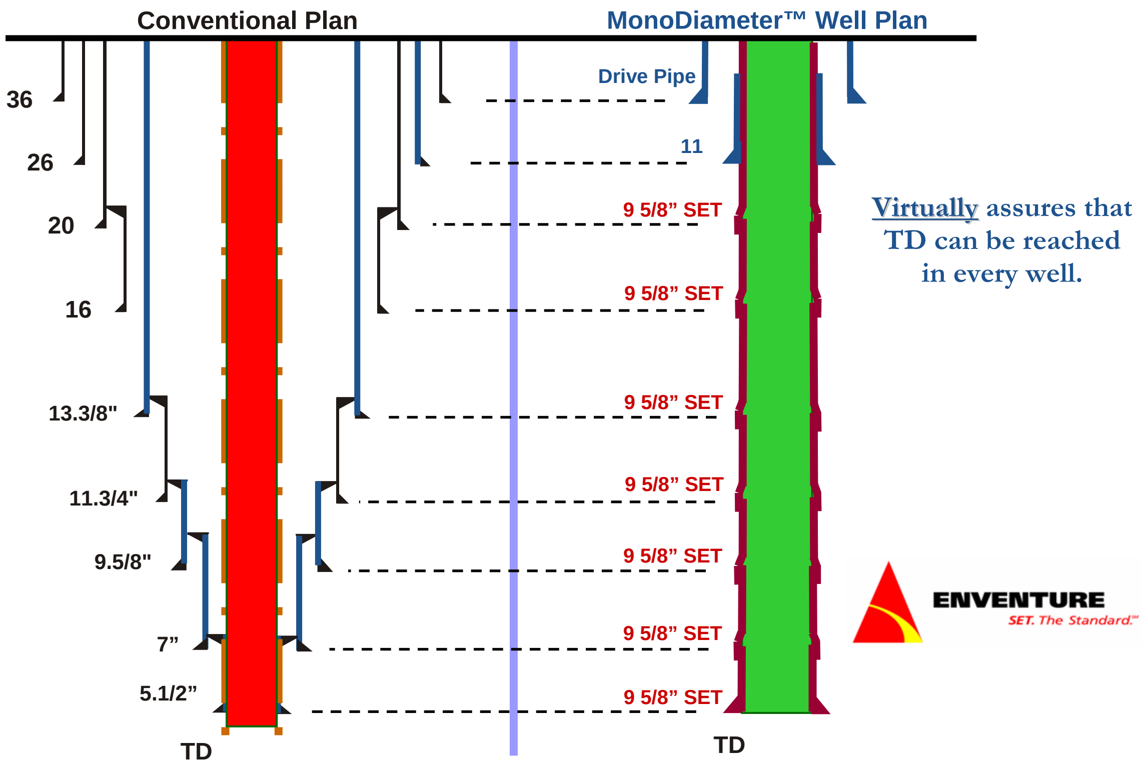


**Figure 2.10-Well schematic for conventional and monobore [20]**

Monobore wells are defined as wells with long monodiameter sections. Multiclad wells are defined as wells where the casing is expanded to the inner diameter of the previous casing, so the hole size reduction is only double the wall thickness of the casing.

Why monobore is important?

Nowadays, higher oil price and world demands on oil and gas supplies, has allowed the company to produce more oil from the same field. For a number of years, the exploration and production industry has sought to prove the feasibility of monobore as an advantageous solution to conventional casing designs. Monobore will allow higher production rate and reach deeper depth with possibilities to do sidetrack or multilateral well. In other word monobore will become solution to bring more profit for the oil company.

Ideally in High-pressure high temperature (HPHT) or deep water well, we need to have higher flow rates to compensate the expensive investment. The additional goals of both monobore and multiclad wells besides to achieve the higher production rate are:

- to reduce casing configuration (less steel consumption and cost for installation)
- to allow the use of smaller risers on offshore rigs and smaller surface equipment capacity/BOP.

All of these goals will significantly increase the cost saving.

We can obtain a monobore shape with three concepts, which are:

1. We drill with the same size of casing to the TD. This concept is impossible due to the limitation on surface power, forces and loading.
2. We use solid expandable tubular (SET) to get bigger diameter. This method could be applied for casing or liner.
3. We can continuously drill with the smaller casing and maintain the same ID, which in other word uses the better quality of material. This concept is still impossible due to today material technologies.

From these three concepts, the expandable technology is the most feasible one to obtain monobore. However, it is a cost expensive technology with technical challenges for E&P business. The monobore is still a dream for oil companies. There is no exclusively monobore well that yet has been implemented.

If we assume, we have the same well condition and reserve, we can make rough comparison between the two well geometries. Show on table 2.1.

**Table 2.1–Comparison Monobore and conventional**

| Shapes | Monobore | Conventional |
|---|---|---|
| **Positive** | • Bigger ID<br>• Higher flow rate<br>• Reach deeper reservoir<br>• More possibility to do multilateral.<br>• Easier in installing the completion<br>• Less steel consumption | • Cheaper<br>• Higher flexibility in modifying the completion.<br>• More experience in operation<br>• Stronger in steel properties |
| **Negative** | • More expensive<br>• Lower flexibility in modifying the completion.<br>• Lower experiences in operation (new technology)<br>• Weaker in steel properties | • Smaller ID<br>• Lower flow rate<br>• Reach shallower reservoir.<br>• Less possibility to do multilateral.<br>• More steel consumption |

Today technologies still cannot expand the casing from rig to target depth. The main limitation is the weakness of material properties. When the steel got expanded, the collapse and burst rating will be significantly reducing almost 60 – 70 percent.

The conventional design also becomes not economical enough to be installed today, especially for very deep well. The steel consumption and its configuration will bring a lot of disadvantages for Oil Company. The casing configuration will also end up with very small size (5 ½” or 3 ½”).

Therefore in this thesis, the author tries to propose the applications for this method and also the best well candidate. The design depends primarily on the formation, expected production rates and the expected production life of each individual well.

## 2.2.2 Material overview [21]

How can the steel be expanded?

In the material engineering, deformation is a change in shape due to an applied force. This can be a result of tensile (pulling) forces, compressive (pressing forces), shear, bending or torsion (twisting). Deformation is often described in term of strain.

In the figure 2.11 can be seen that the compressive loading (indicated by the arrow) has caused deformation in the cylinder so that the original shape (dashed lines) has changed (deformed) into one with bulging sides. The sides bulge because the material, although strong enough to not crack or otherwise fail, is not strong enough to support the load without change, thus the material is forced out laterally. Deformation may be temporary, as a spring returns to its original length when tension is removed, or permanent as when an object is irreversibly bent or broken.

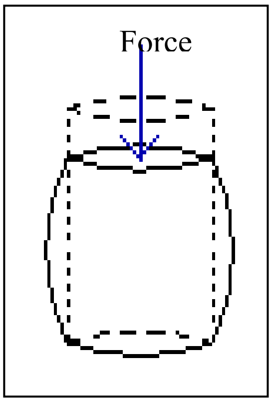


**Figure 2.11-Force acting on material** [21]

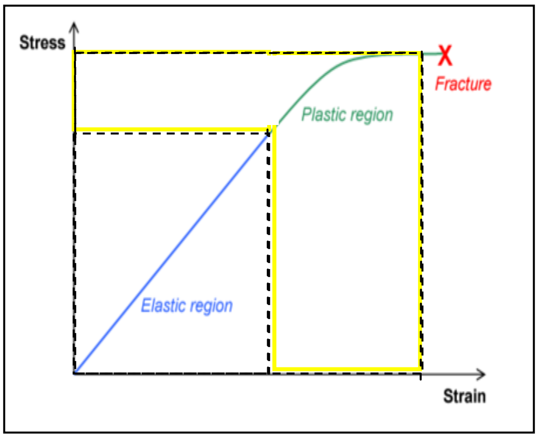


**Figure 2.12-Stress-Strain relationship** [21]

All steel can be expanded. In expandable casing, the expansion varies around the plastic area, between the end of elastic and before the fracture point, all the variation is in irreversible (permanent) deform.

On figure 2.12, the shaded area is the plastic region. On this zone the expandable process takes place.

Diagram of a stress-strain curve showing the relationship between stress (force applied) and strain (deformation) of a ductile metal.

Types of deformation

Depending on the type of material, size and geometry of the object, and the forces applied, various types of deformation may result. Here is listed the types od deformation from beginning of the deformation to the fracture.

*Elastic deformation*

This type of deformation is reversible. Once the forces are no longer applied, the object returns to its original shape. The elastic (rubber) has a rather large elastic deformation range. Soft thermoplastics*) and metals have moderate elastic deformation ranges while ceramics, crystals and hard thermosetting plastic**) undergo almost no elastic deformation.

*Metal fatigue*

Metal fatigue occurs primarily in ductile metals. It was originally thought that a material deformed only within the elastic range returned completely to its origin state once the force is removed. However, faults are introduced at the molecular level with each deformation. After many deformations, cracks will begin to appear, followed fract soon directly, with no apparent plastic deformation in between. Depending on the material, shape and how close to the elastic limit it is deformed; failure may require thousands of deformations.

*Plastic deformation*

This type of deformation is not reversible. However, an object in the plastic deformation range will first have undergone elastic deformation, which is reversible, so the object will return part way to its original shape. Soft thermoplastics have a rather large plastic deformation range as do ductile metals such as copper; silver and gold, steel do but iron.
Steel is used in SET process; actually it has the same properties with drillpipe or casing. It is deformed and changed it elasticity when the stress is applied in the plastic region (piston force by the cone).

*Fracture*

This type of deformation is also not reversible. A break occurs after the material has reached the end of the elastic and then plastic, deformation ranges. At this point forces accumulate until they are sufficient to cause a fracture. All materials will eventually fracture, if sufficient forces are applied.

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**) thermoplastic is a material that is plastic or deformable, melts to a liquid when heated and freezes to a brittle, glassy state when cooled sufficiently*

***) thermosetting plastic are polymer materials that cure, through the additional of energy to a stronger form) undergo almost no elastic deformation.*

On today technology, there are 2 main applications of expandable material in oil and gas industry which are Solid Expandable Tubular (SET) and Expandable Sand Screen.

Expanded casing applications concentrate on reducing the telescopic profile of well designs through a downhole tube expansion process. Wider applications of the technology exist for example water shut off and casing repairs in old wells. Figure 2.13 shows expanded tubular.

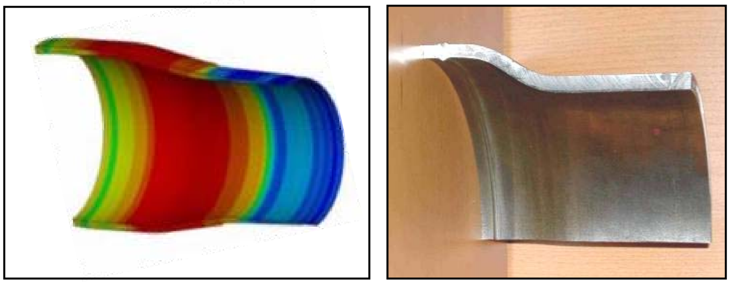


**Figure 2.13-Expandable material [20]**

To reduce the loss of diameter each time a new casing string or liner is set, a cold working process has been developed whereby the casing or liner can be expanded by up to 20% in diameter after being run down-hole. Figure 2.14 shows the process when the cone expands the casing.

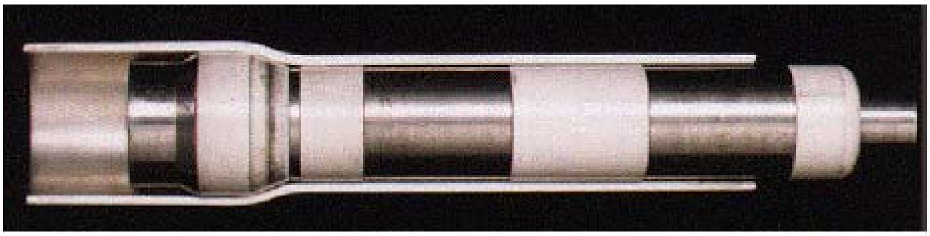


**Figure 2.14-Expandable tubing and cone [6]**

### 2.2.3 Industry overview [6]

As an industry overview, each of the three service providers is reviewed (Enventure, Weatherford, and Baker). The various expansion applications are described below.

- Enventure Data

  Enventure did almost 257 installations from both open hole and cased hole. For Chevron (CVX) to date, Enventure has already installed ten wells. (This system uses hydraulic pressure to push an expansion mandrel up through the casing – expanding the pipe as it goes from the bottom up.)

- Baker Data

  Baker Hughes has installed approximately twelve cased hole installations (This system uses a five foot jack system to push the expansion mandrel down through the pipe. The jacking system is similar to the original Homco Patch –weatherford system.)

- Weatherford Data

  Weatherford did approximately six cased hole installations (This system uses a rotary tool. The expansion starts at the top and goes downward.). However there is a new technology that is developed. This technology is almost similar to Enventure system (expansion from bottom to top), and has the expandable cone. The Homco Patch is used for cased hole and this expandable cone is used for open hole expansion.

Open hole SET should be used in the following situations, according to Chevron [6]:

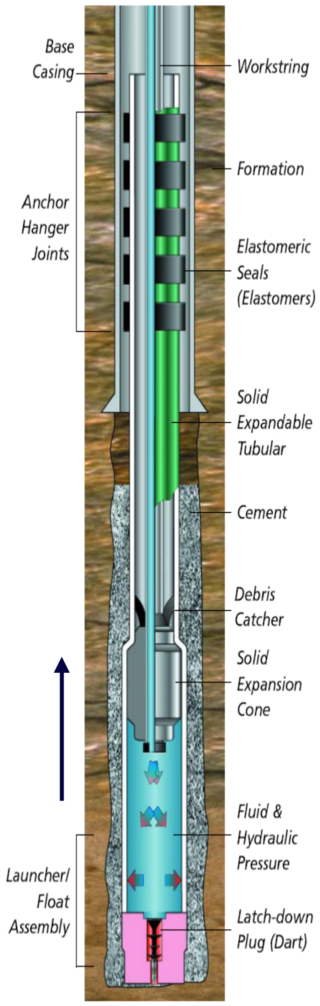
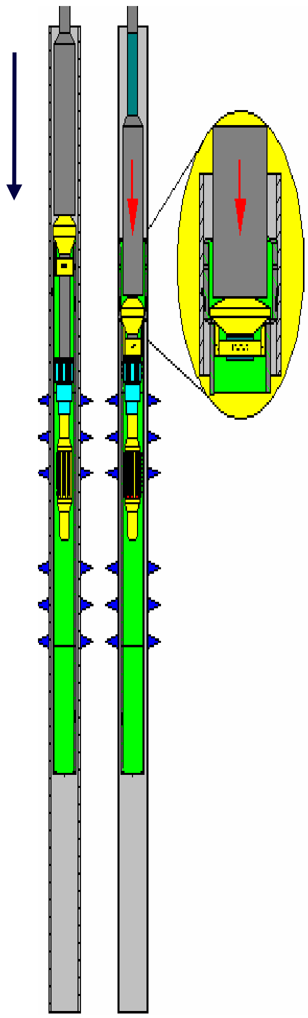
- No acceptable conventional alternative.
- A tolerance for higher operational risk and possible failure wells.
- No requirement for high burst or collapse rating.
- The best fit for expand is 500 – 1500 foot in under-reamed or bi-centered open hole and at least 1" above the drift of the base casing.
- Minimum hole angle with no doglegs
- A stable open hole section that will allow a six foot full drift OD plug container to easily reach TD without problems – losses, gains, doglegs, ledges, or sloughing.
- Minimal rotating hours in the next section of hole.
- The next casing string can easily be lapped back up and hung off in a conventional way to fully cover the expandable liner.
- Cementing is not critical in the SET liner interval – a good liner lap test and shoe test are the main objectives.
- The additional ID gained from using SET will yield a major economic benefit to offset the additional rig time and high cost of the service.

The lists above may sound like it eliminates every possibility. It does not. A short, planned, drilling liner is the best SET application. The first application of SET in West Cameron, West Africa in 1999 was a short planned drilling liner. SET works best when run before hole problems are encountered. Expandable casing needs to be used in a stable, bi-centered hole that can easily pass the six-foot, full drift, plug container. The benefit is an additional short drilling liner, used to avoid problems, while starting and finishing the well with conventional casing sizes. This type of application fits development or delineation wells much more than exploration. SET may help to solve differential problems that are sometimes encountered in wells drilled late in the life of a field development. However, the current success ratio in CVX operations discourages this type of application. Both cost and risk will keep SET from being used in most wells.

**Industry expandable methodology**

The clear leader in the solid expandable tubulars (SET) is Enventure. They have run more than 250 field applications where as Baker and Weatherford have only twelve and six respectively at midyear 2004. Enventure is the only company with a field proven open hole liner. However Weatherford has developed a new bottom–top expandable technology which seems could have a promising future application. Baker focused their business in expandable sand screen technology than SET.

Here is a side-by-side comparison of the expansion techniques:

| Enventure | Baker EX Patch | Weatherford |
|---|---|---|
| • Fixed cone, bottom to top, pressurizes.<br><br> | • Flex cone, top to bottom, drillpipe piston<br> | • Fixed cone, bottom to top, pressurizes.<br>**<u>for open hole</u>**<br> <br>Relax position expand position<br>**<u>for cased hole</u>**<br>• Flex roller, top to bottom, rotary and weight forces<br><br>**Homco Patch** |

Below is more detail on each manufacturer review:

**1. Enventure:**

There are 2 major operations, open hole and cased hole, which provide different application. Open hole expansion is used for getting bigger diameter and cased hole expansion is used for multiclad or repairing casing leaking operation.

**Open hole** – *operation sequences*

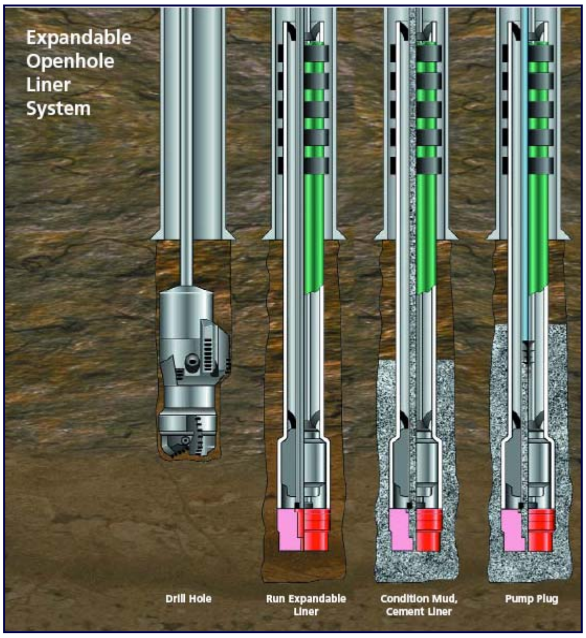
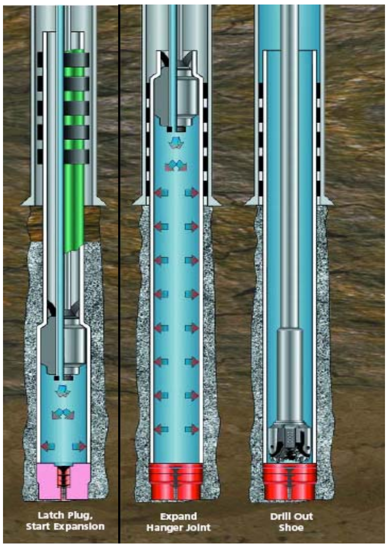



Figure 2.15-Enventure Open Hole sequences [15]

(1) *Drill hole* - Drill an oversized open hole interval. Enventure use bushing bit to underream the hole. (However it makes a lot of string vibration)

(2) *Runs Expandable Liner* - Pick up the expandable liner, expansion assembly and launcher.

(3) *Condition Mud, cement liner* - Run to the planned depth and perform cementing operation and pump plug.




(4) *Latch plug, start expansion* - seat the latch the plug and initiate expansion by expanding through the launcher.

(5) *Expand hanger joint* - expand the liner including the anchor hanger joint in the overlap between the SET and the base casing. Expand out of the top of the liner.

(6) *Drill out shoe* - Continue next drilling operation.

The improvement has been done for reducing the string vibration when underreaming. They install balancing weight in the bushing.

**Cased Hole** – *operation sequences*

(1) *Clean Out Casing* - Prepare the wellbore for the installation using mills or scrapers, if necessary.

(2) *Run and Position Expandable Liner* - Run the expandable CHL System in the well. Space out and position the liner over the interval to be repaired or reinforced.

(3) *Pump Dart, Start Expansion* - Seat the latch-down plug and initiate expansion by expanding through the launcher.

(4) *Expand Liner* - Pressurize workstring and pump expansion cone while pulling upon workstring.

(5) *Expand Anchor Hanger Joint* - Continue expansion until the cone exits the top of the liner and pressure test the installation.

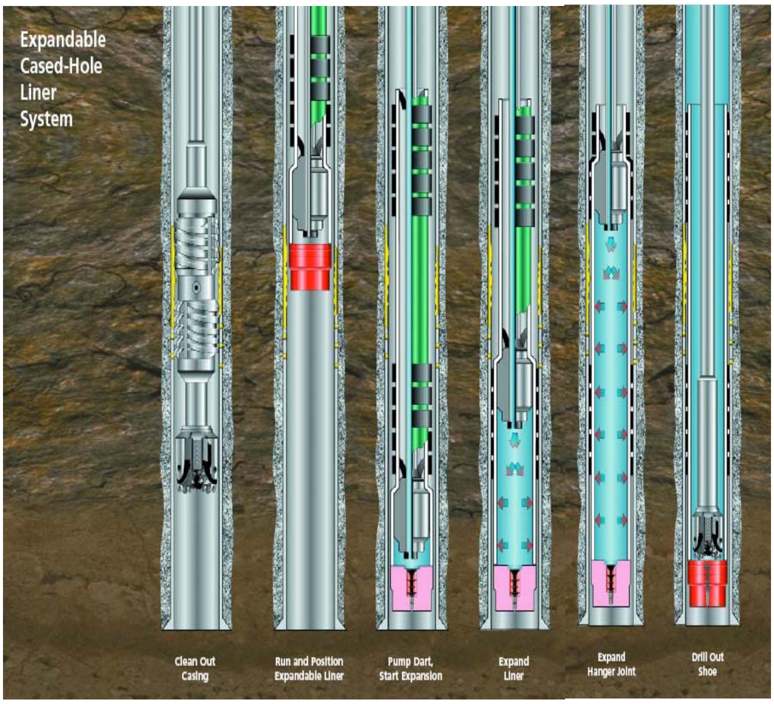



**Figure 2.16-Cased hole Enventure sequences [15]**

(6) *Drill Out Shoe* - Prepare the well for further completion or production operations.

Enventure uses pressure under an expansion cone to help on expanding the pipe. The cone is unseated as each connection is broken coming out of the hole. Open hole installations have ranged from 300 ft to 3400 ft, and cased hole applications from 20 ft to 6100 ft.

**2. Baker Hughes:**

Methods of expansion vary with applications and products. Baker Oil Tools preferred methodology is a top-down expansion process that uses hydraulic pressure fed into a piston. Hydraulic pressure anchors the system in place and opens the piston, which progressively pushes an expansion cone through the completion assembly, setting the liner hanger, expanding the blank pipe, setting the isolation packer and expanding the screen. After the expansion process is complete, the expansion tool is retrieved from the well. Using this system, thousands of feet of tubulars can be expanded in a single trip. Becauce the system does not rely on pushing or pulling energy from the drillstring, it can be activated easily in highly deviated wells. Baker Hughes is more concentrate in cased hole completion than open hole.

## Cased Hole

Expandable solid pipe is lowered into place and expanded inside corroded or damaged pipe. The expansion "clads" the two pipes into one, giving the well a new liner with minimal reduction in the internal diameter of the original, damaged pipe. The system can be used to block off unexpected problem drill sections or as part of the initial well design. Expandable liner hangers enable slimhole wellbore construction that is becoming increasingly important in deep water and extended-reach applications.

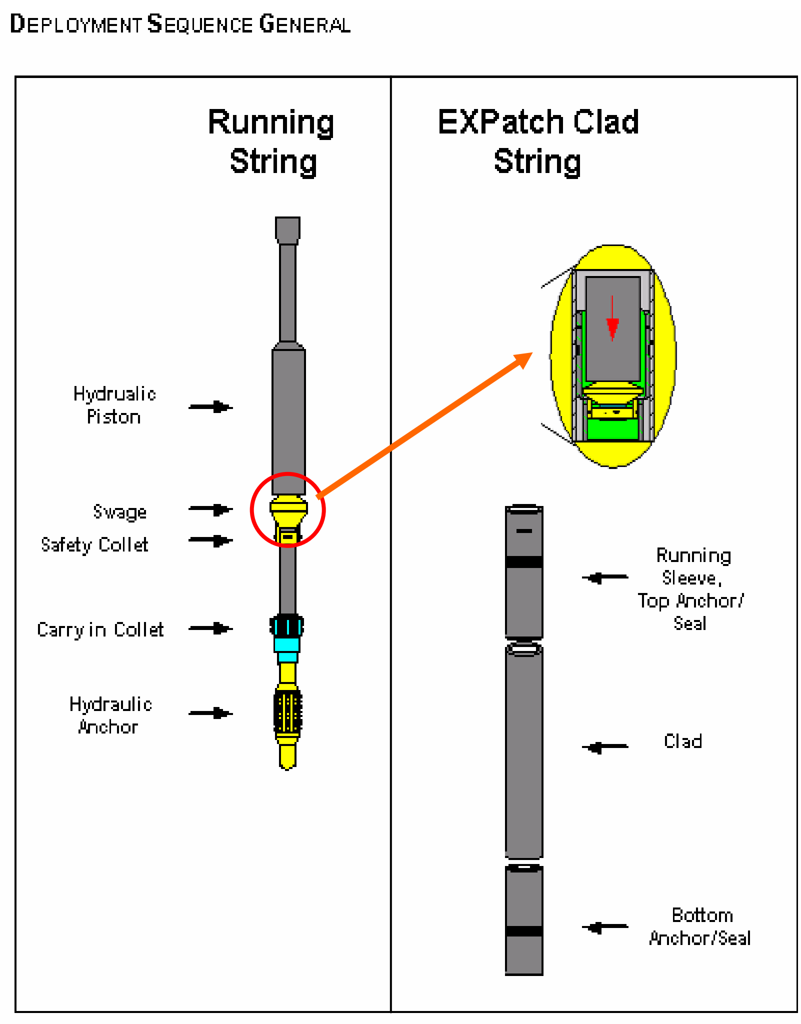



**Figure 2.17-Baker expandable** [6]

These are the basic components of the EXPatch cased hole system. The expansion process is a series of 5 ft downward strokes of the piston and anchor system until the cone exits the bottom of the expanded pipe. The process steps are shown below:

*Sequences:*

*(1)* Run clad to setting depth.

*(2)* Pressure up to activate tool and begin expansion process.

*(3)* After cycle, set down on drillstring to reset tool.

*(4)* Pressure up to reactive tool and continue expansion process.

*(5)* Continue cycle step 3-4 until entire length.

*(6)* POOH with running or expansion tools.

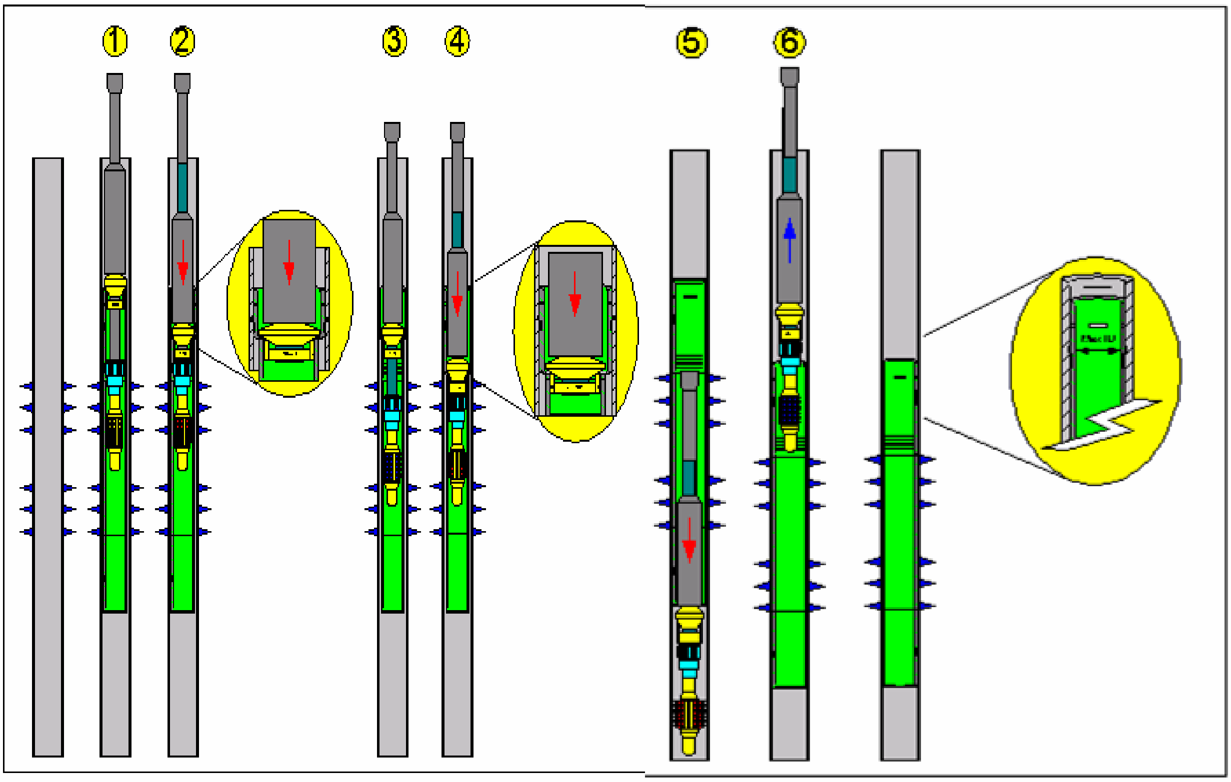



**Figure 2.18-Baker expansion sequences [6]**

Baker also has an open hole system that uses a recessed overlap which is run at the base of the previous casing string. In open-hole environments, the cladding can be used with expandable openhole packers to reduce or shut off water inflow. Used together with an expandable screen system in sand control completions, it can create a definitive mechanical fluid flow barrier that allows selective wellbore section shut-off. It is not included here because it has not been field proven.

Baker and Weatherford have flexible methods of expansion (split cone, flex – rollers) that can handle unexpected restrictions. However, this means non-uniform ID, wall thickness, and properties (burst, collapse). Casing patches do get enhanced properties from the base pipe. The burst is almost additive if the base casing is only perforated. The collapse is enhanced because the patch is constrained from becoming oval which is an early stage of collapse. Testing could be done to quantify the additional strength gained if needed for a specific application.

### 3. Weatherford

There are 2 major operation, open hole and cased hole, which provide different applications.

#### Open hole

**Figure 2.19-Corrugated casing [17]**

The Weatherford open hole expandable technology has almost the same method as Enventure. However they have a different kind of BHA and cone. On open hole expansion, it uses expandable cone which can be expanded by shear the drillstring. To provide a cone a space for expansion, they installed the corrugated casing in the bottom of expandable casing ("star shape" figure 2.18). This casing can be expanded using pressure, provide a chamber for cone to expand. To release the cone from the bottom anchor, after cementing, they rotate the BHA. The operation is activated by a dropping ball.

*Operation sequences:*

(1) *Run in Hole the expansion assembly*

(2) *Expand the chamber* - After reached the TD, the first ball is dropped to open the valve and continue pressurize the annulus to expand the corrugated casing to form a chamber for the cone to expand. After the chamber is open, compress the drillstring to shear the cone. Shearing will expand the cone. The ball will fall into a ball catcher when it sheared beyond its limit.

(3) *Cementing* - When keeping the string on compression we pump and fill the casing annulus with cement.

(4) *Release operation* – To release the cone, need to rotate the drillstring until the pin that connected with the box in the bottom will release.

(5) *Expansion process* – By pulling the drillstring out the hole the expansion will start from bottom to top. However we need to keep pressurize the pipe to keep the drillstring in compression and the cone in expansion form.

(6) *Drill out or milling job* – After the liner hanger had been expanded, then we need to run the bit or the mill assembly to drill out the shoe.

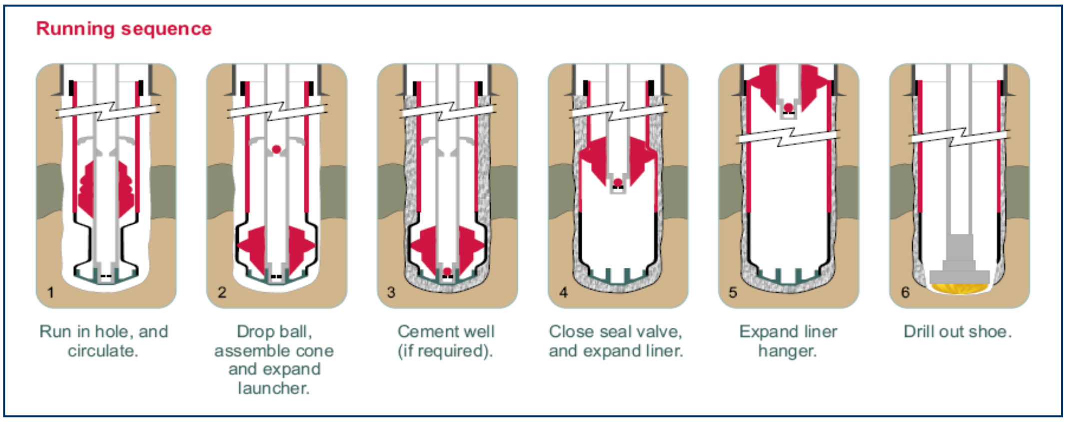
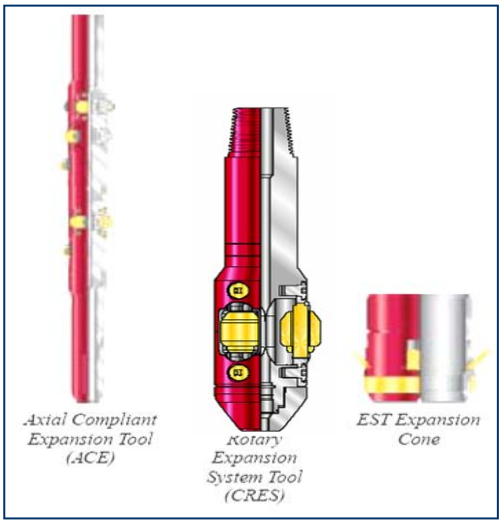



**Figure 2.20-Weatherford open hole, expansion sequence[17]**

### Cased hole

The cased hole expansion is used to repair the casing system. Weatherford has a rotary expansion cone. This tool has circumferentially mounted rollers in pressure-activated pistons. The expansion of the solid tubing is carried out by a combination of backpressure, created by circulating fluid through a nozzle in the tool and drillstring rotation. Each roller acts independently, expanding the solid tubular to fit any anomalies of the parent casing. Benefit of using this cone is low axial loads, has durable components (mean cheap) and fit through unexpanded tubular for easy retrieval. However the disadvantages of this cone are the expanded casing could have varied inside diameter. In other word, Weatherford fits tighter to the base casing but may not have uniform wall thickness.




Rotary compliant expansion:

- Metal to metal contact
- Maximum casing collapse and burst
- Tolerant to casing anomalies
- Top-down expansion

**Figure 2.21-Weatherford compliant cone [6]**

- Low rolling expansion
- Low axial load
- Retrievable system

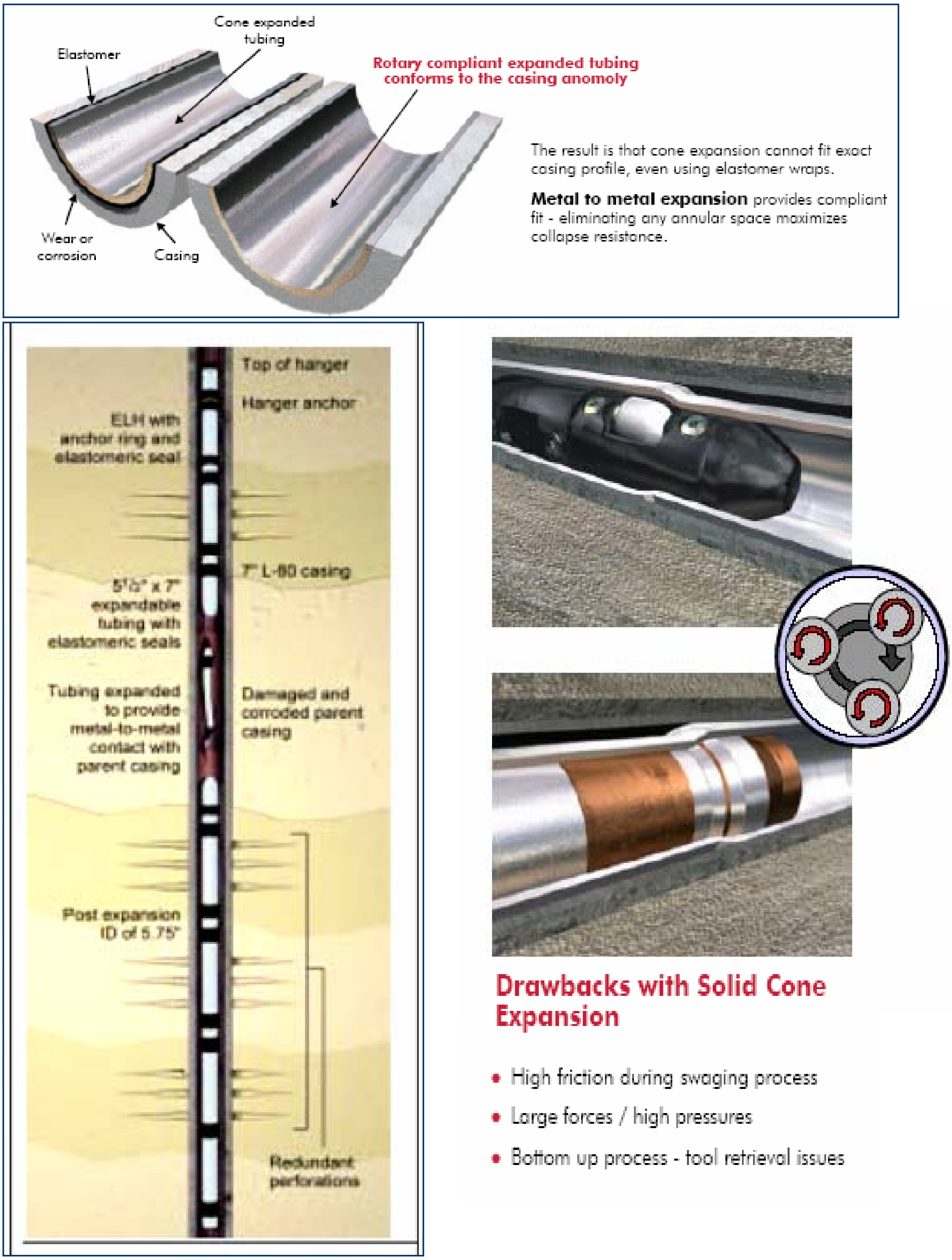



**Figure 2.22-Weatherford expandable technologies – additional information [6]**

## 2.3 COMBINATION OF DRILLING WITH EXPANDABLE CASING THEORY

There has not been any significant advancement of this technology. More issues and technical challenges have been raised that cast even more doubt on the feasibility of a commercially attractive product ever being developed. There are two areas that are causing the greatest concern; technically how to combine both technology and poor post expansion properties.

There are no case studies from this combine technology. Since both technology consists of almost the same operation procedures therefore we could combine it. Practically, our concept is tried to drill and case the hole with the expandable casing. Based on this concept, one first drill through unstable zone (lost circulation) with the expandable casing, then change the drilling BHA into expandable BHA, pump the cement and continue to expand the casing to get bigger diameter. Ideally the operation is done in one or two times trips.

Both advantages which are to obtain a bigger production casing size and to solve the lost circulation could be achieved in the same time. Bigger production casing size will let a higher production rate which will compensate the operation cost. Problem due to lost circulation can also be cut off. In the future, by increasing crew experiences, we expect saving on rig time aslo can be achived.

However there are many technical challenges such as dillema of having weak connection for drilling with casing and weak post expansion casing properties are becoming our main concern. In expandable casing we need to have weak connections, in order to expand the casing with the lower forces and in the mean time, we also need strong connections for drilling purposes to avoid failure. The weak post expansion casing properties make the operation limited just on special cases. It is important to understand that combine both technologies mean combines its disadvantages and limitation as well. The cost and operation risk are the most crucial and the most reasonable issue since the cost and risk of each technologies already high.

The visibility and technical studies is being done by service companies however it has not been commercialized yet. The progress to find the best solution is on going. The possibilities of the best drill-expand performance methodology is still on-study.

# CHAPTER III
# ANALYSIS AND RESULT

There are a few questions that the author will investigate. Answering those questions could help us conclude the feasibility study of this combine technology. The questions consist of mostly technical part and one economic part. These are the questions:

- How can this combined method works?
- Are the expandable casing connections strong enough for drilling with casing?
- How does the expandable casing perform after being used for drilling?
- What are the expandable casing properties that need to be considered?
- Is the cost competitive?
- Are there any limitations on this process?

To answer these questions the author needs to discuss with the expandable technology and drilling with casing experts.

## 3.1 ANALYSIS OF THE "DRILLING – EXPANSION" METHODOLOGY

***Question: How can this combined method works?***

***Analysis:***

To find mechanical and technical possible methods that could be implemented with the current technologies, the author visited the companies and gathered the information. After learning and observing, we believe there could be two methods that can be proposed. Here we presented a conceptual method and in the discussion part we will preview the industry product supporting this concept. The two methods that being conceptually considered feasible are:

<u>Method 1: drill and expand method</u>

In this method, first drill the formation with the casing until the casing shoe reaches the expected depth. Then change the drilling bottom hole assembly with the expansion bottom hole assembly. The expansion cone is run into the hole with the drillpipe to bottom of the casing. Before expansion process, pump cement through the drillpipe out to annulus of casing and afterward start expansion from bottom to top.

Another alternative that could be possible for saving tripping time is to run the top-bottom expansion method. However one has to mill the cement out and clean the well before continues with the expansion process. The top-bottom expansion method has more challenges on additional cleaning operation than bottom-top method; therefore the top-bottom method prefers to be run on the clad system where the cement does not need to be pumped through the expandable casing. Isolating the leak casing and trouble zone is the suitable jobs for top-bottom expansion method. There are two different operations that need to be considered on changing the drilling to expandable bottom hole assembly which actually depend on the BHA types. If the BHA is:

- Retrievable

  First, one runs the wireline or drillpipe inside the casing, and land the PIN (figure 3.1) that is attached on the end of wireline or drillpipe to the BOX (figure 3.2) on the top of retrievable casing drilling BHA. locks and pulls the drilling assembly out of hole and then run expansion BHA

**Figure 3.1-PIN of retrieve tool** [9]

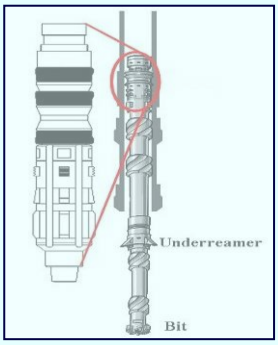



**Figure 3.2-BOX of retrieve tool** [9]

- Non-retrievable

  Ones drill with the drillable bit using the casing as drillstring until the casing shoe reaches the expected depth. Drop the ball to shear and open the bit that will leave the drilling BHA with the open cylinder shape. Then run the expandable cone through inner section of the casing and bit. However if one decides to drill with the non-drillable bit, then one needs to run wireline through inside of the casing and disconnect the bit. Let it fall into the rat hole (the hole that we had drilled previously) and pull the wireline out of hole. Leave the bottom with open annulus casing and continue running the expansion cone with drillpipe. Until the expandable cone reaches the casing shoe, then the bottom-top expansion can be proceed. On the next drilling well path, kick off or steer the new bit to avoid the old bit that felt on the rat hole.

Method 2: Drill with concentrate pipes

Concentrate pipes means pipe inside pipe, in this way is a drillpipe inside the casing. The method is to drill with a bit which is attached on drill pipe inside the casing; so practically we continuously casing the hole when we drilling. The drillpipe must be equipped with wing underreamer (figure 3.3). Operate on the wing-open position when drilling, we provide a bigger hole for the casing to be able to be run. After the bit reached the expected target, the drillpipe is pulled out hole with wing-closed position. Continue running the expansion BHA to the bottom of the casing shoe, so we can expand the casing from the bottom to top after pumping cement. The top-bottom expansion after milled out the cement, also possible to be run. These concepts allow the combine method can be performed.

**Figure 3.3-Wing underreamer [9]**

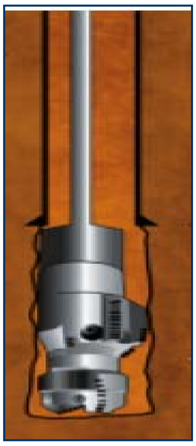


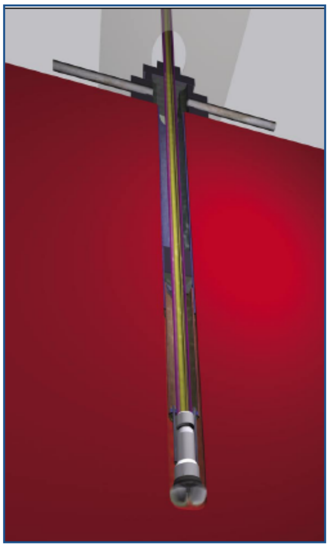
**Figure 3.4-Bushing bit [15]**

In stead of using wing underreamer, other technique to get a bigger open hole diameter which is provided by Enventure is presented here. They use bushing bit (figure 3.4). While drilling, the drillpipe that attached to the bit and bit bushing is rotated. The rotation makes the bushing bit scraped the hole to get a bigger ID. However the scraping brings the negative effect, which we call "bushing effect". This effect makes the lateral vibration on the drillstring that could result on a fatigue system. The development is on going. One of the solutions by putting a weighting bar on the other side of bush bit to compensate and balance the lateral force is being observed.

Additional method: Use a new drilling hydraulic concept (additional information)

Reelwell under develops the concept. The concept has no real application in the field yet; the testing will be started on May 2007. Here we present the concept briefly. The method is almost similar with the concentrate pipe method (figure 3.5). The casing is run outside the pipe and the bit is attached on the drillpipe. Having an upper BHA and a bottom BHA is the main concept of this method. The purpose is to give a piston force to push the bit while drilling (figure 3.6). Therefore one of the targets of this method is to reduce the weight on bit. Therefore, a smaller surface equipment and facility could be used to drill a long horizontal section. For the system specification we can see on table 3.1.

The unique method about this concept is the fluid circulation flow on the system. The system has two BHA (upper and lower), which is attached on the drillpipe. Besides pumping the fluid like on a conventional drilling, we also pump the drilling fluid into the casing annulus to push the upper BHA for providing piston axial force on drill bit. However this method still has a lot of consideration on well control, flow insurance and cutting transport because plugging on the regulator (bottom BHA) could risk the whole operation.



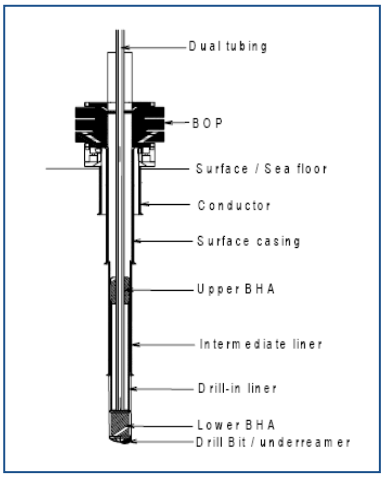



Figure 3.5-Reelwell system configuration [18]

| *Item or parameter* | *Value* |
|---|---|
| Outer tubing OD [in]<br>- wall thickness [in] | 4.5"<br>0.27" |
| Inner tubing OD [in]<br>- wall thickness [in] | 2 3/8"<br>0.15" |
| Length of reeled dual tubing [km] | 3 |
| Hole diameter [in] | 8.5" |
| Pore pressure at TD [bar] | 320 |
| Mud density to balance pore pressure [kg/l] | 1.3 |
| Assumed circulation fluid density [kg/l] | 1.1 |
| True vertical depth for the bit [m] | 2500 |
| Max. shut in pressure in return conduit [bar] | 50 |
| Return choke pressure while drilling [bar] | 1 |
| Circulation fluid pump pressure [bar] | 250 |
| Circulation fluid flow rate [lpm] | 330 |
| Pressure loss in inner tubing [bar] | 50 |
| Pressure loss in tubing annulus [bar] | 20 |
| Pressure available for bit and motor [bar] | >180 |
| Hydraulic power available for motor [kW] | 90 |
| Average ROP in typical formation [m/h] | 21 |
| Cuttings concentration in return [% vol.] | 3.9 % |

**Table 3.1-Rellwell Specification [18]**

**Figure 3.6-Reelwell concept drawing [18]**

Form these 3 conceptual methods, which are described briefly; we can see that there are possibilities that the drilling with expandable casing method could be implemented. Successful similar test has been achieved and plenty of money has been financed for the researches. Therefore the temporary answer from this question can be drawn as below:

***Result:***

- Conceptually with present technology, drilling with expandable casing is possible.
- Since we do not need to mill out the cement and clean the inside wall interface of casing, the bottom to top expansion is recommended for drilling with expandable casing method.

## 3.2 ANALYSIS OF THE CASING CONNECTIONS

***Question: Are the expandable casing connections strong enough for drilling with casing?***

***Analysis:***

As we know in drilling operation, the connection is the weakest part from the stress and loading. The connections are weaker in torsion, tension and easy to leak due to high inside pressure on expansion process compare to drillstring body. This strength of connections will be reduced by the wear of drilling when transmitting drilling forces. There are two major types of connection joint, flush joint (figure 3.7) and coupling joint (figure 3.8). Each type of the connection has its own properties and limitation. The choosing for the appropriate drilling operation is required on design. Below shows the lateral cut view of the joint.


**Figure 3.7-The casing connection type – flush joint** [16


**Figure 3.8-The casing connection type – coupling joint** [16]

**Differences between**

| **Flush joint** | **Coupling joint** |
|---|---|
| • The OD of the connection is the same with the pipe body.<br>• Lower in strength; tension, torsion and bending stress.<br>• Has been used on expansion process. | • The OD of the connection is bigger than the pipe body.<br>• Higher in strength; tension, torsion and bending stress.<br>• Has not been used on expansion process |

Note: In the expandable casing, the flush joint is widely being used because of its lower strength properties. It will allow a lower expansion force to reform it. Both joints can be used for conventional drilling. The joint could have different design and strength depends on the provider.

Below is the common expandable connection property that is provided by Enventure (table 3.2). This connection is for 9 ⅝" XPC #36 (36 lbs/ft), with flush joint connection type.

**Table 3.2-Enventure Connection properties [15]**

| 9 ⅝ XPC #36, N-80 flush joint (enventure)-CONNECTION | |
|---|---|
| • **Connection joint strength** | **533,900 lbf (2375 KN)** |
| • Compressive load rating | 427,100 lbf (1900 KN) |
| • Min parting load | 634,000 lbf (2820 KN) |
| • Max pure bend rating | $19,8^0$/100 ft |
| • Torque | |
| Mimimum final torque | 2500 ft.lbf (3.4 KN.m) |
| Optimum final torque | 2800 ft.lbf (3.8 KN.m) |
| Maximum final torque | 3100 ft.lbf (4.2 KN.m) |
| **Maximum Yield torque** | **6200 ft.lbf** (8.5 KN.m) |

Our challenge is to analyse if this connection can be used for a simple drilling operation. Therefore we have to make a simple-general well plan and calculate the stress; tension and torque, which we will compare it with the connection properties. If the connection has a stronger strength than the drilling stress, then we can conclude that it is adequate to be used in this specific drilling case. Since different case will show different stresses, the acceptance determination of this connection will vary.

It is important to make a general-representative case. Here, we present a simple model of torque and tension on drilling with casing operation, compare with the connection properties. Case example:

**Table 3.3-Case well parameter**

| **Input parameters** | | |
|---|---|---|
| Kick-off-depth | 1500.00 | m |
| Inclination of sail/hold section | 60.00 | deg |
| Build radius | 500.0 | m |
| Length of Bottom-hole-assembly (BHA) | 200.00 | m |
| Mud weight | 1.56 | s.g. |
| Length of sail/hold section | 2200.00 | m |
| Tool joint radius (select meters or inches) | 0.251 | m |
| Friction coefficient | 0.30 | |
| Bit force (kN or tonnes) | 2.00 | tonnes |
| Bit torque | 6 | kN/m |
| Unit weight of drill pipe (in air) | 0.30 | kN/m |
| Unit weight of BHA (in air) | 3.00 | kN/m |
| | | |
| **Output values** | | |
| Buoyancy factor | **0.8** | |
| Horizontal reach of well | **2155** | m |
| Vertical depth of well | **3033** | mTVD |
| Measured well depth | **4224** | mMD |
| Dogleg severity of build section | **3.4** | deg/30m |

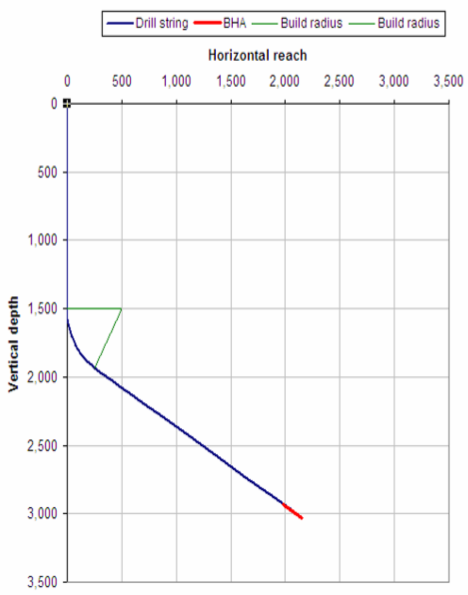



**Figure 3.9 Case well profile**

Tension and drag profile for case example.

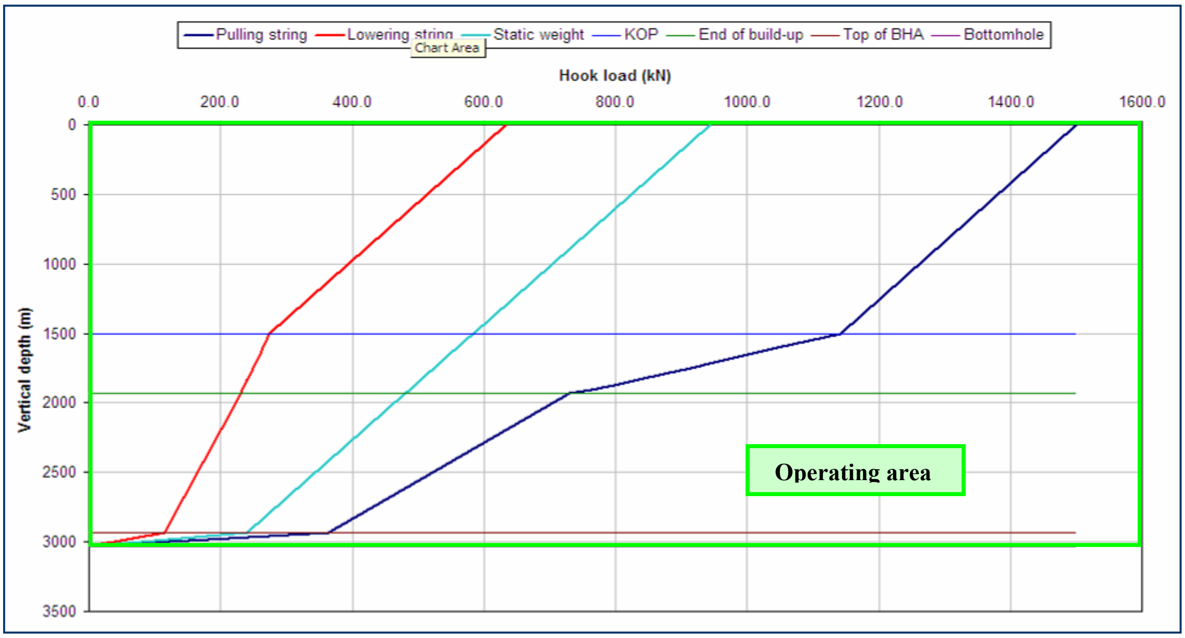



**Figure 3.10-Hook load profile for case example**

As we see in the connection properties (table 3.2), this expandable connection has a tension limit of 2375 KN and a compression limit of 1900 KN. If we plot it on the figure 3.10 we will be in a safe operation area (bigger than the forces) where operation maximum tension is 1500 KN. Therefore practical speaking, the connections tension and compression are adequate to be used for this case. The next figure 3.11 shows the torsion strength of the drilling compare with the torque limit of the connection.

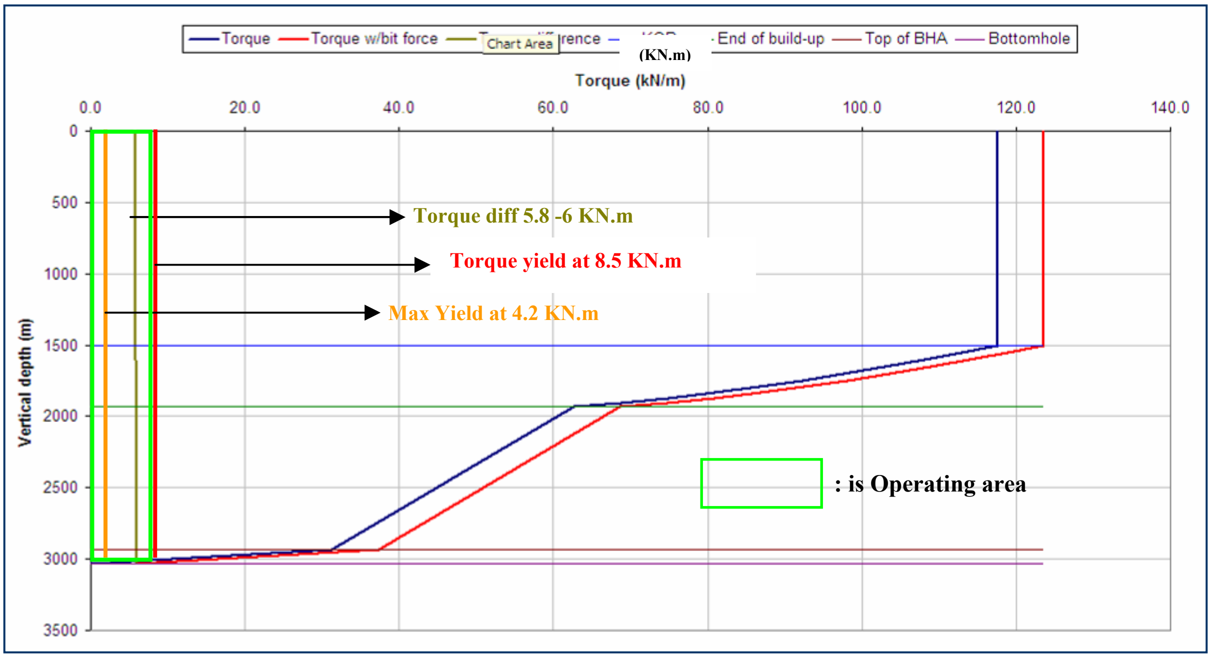



**Figure 3.11-Torque profile for case example**

We can see obviously that the connection is not strong enough in torsion for drilling operation. Therefore the connection cannot be used because it will tear apart when we rotate the drillstring. Therefore the drilling with expandable casing cannot be done since the connection is too weak. The proposed solution will be presented in the discussion chapter IV. This case is made with a very common well profile, the higher torque and tension will happen in a deep well or in a long horizontal section well. Design and simulation is unique for every well. The conclusion for the answer from the connection's analysis is represented as below

***Results:***

The torque limit of market connections for expandable casing available in the market is not strong enough for drilling operations. The torque rating is the most critical properties for expandable connections. Improvements and modifications should be made to meet the drilling purposes. Each type of connection and well profile will show a different result. Therefore, engineering approach for design should be carried out for each specific case.

## 3.3 ANALYSIS OF THE EXPANSION PERFORMANCE POST-DRILLING

***Question: How does the expandable casing perform after being used for drilling?***

***Analysis:***

When we used casing as the drillstring, it will be exposed to loading stress (compression, tension, torsion and bending stress). Moreover, the outside walls of the casing will also be exposed to scratch and wear. To analyze the expandable performance after being used for drilling, we have to know what the criteria for the perfect expansion process are, and what are the drilling effects that need to be taken into account to meet those criteria.

The proper conditions for expandable casing to ensure good expansion are:

- Clean and uniform inside wall interface of the casing.
- Minimum hole angle with no dogleg (no significant tortuosity).
- The casing coupling and connection are strong enough for expansion process.

There are 3 considerations we should analyze and assure on drilling operation to obtain the adequate expansion conditions.

The effects on drilling which are considered important to achieve a proper expansion are:

- The well can not suffer from any debris and junks after drilling operation.
- The casing has no big dogleg and tortuosity profiles.
- The well has no lateral vibration and whirl during the drilling operation.

***Analysis 1***: The well can not suffer from any debris and junks after drilling operation.

Before, this consideration was not taken into account for the expandable casing, because the casing was run on a separate operation from drilling operation. The cleanness and the uniformity of the casing inside wall pre-expansion are assured. However, if we used the expandable casing for drilling, after cementing, cements could stick on the inside wall of the expandable casing. Besides when we use a retrievable bit, pulling the bit out the hole could scratch the casing inside wall. These are risky for the expansion cone to pass and also for expansion pressuring process. Therefore the additional operation for well cleaning with brush and scraper is recommended (figure 3.12).

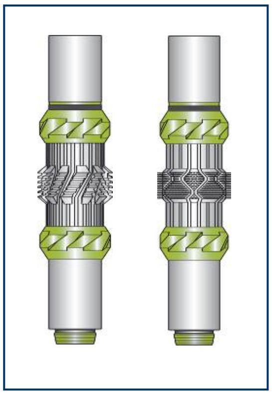


**Figure 3.12-Casing scraper and brush [19]**

To assure we have the uniform inside diameter of expandable casing, we can make up a mill bit on the end of drillstring when we run cleaning operation. The mill bit should have an outside diameter (gauge diameter) as big as the inside diameter (drift diameter) of casing. This mill bit will mill any substandard casing wall thickness to the size of mill OD. Therefore we can obtain a uniform ID wall.

***Analysis 2***: The well has no big dogleg and tortuosity.

The well path is specified by directional surveys from either a real or planned well. The inclination and azimuth at discrete points along the path define the survey stations and a smooth cylinder are delineates the well path between survey points (see figure 3.13). A Tortuosity is defined as the amount of curvature between stations, typically shown as deg/100ft. The dogleg and tortuosity will make casing on bending and waving shape. This shape will make the expansion cone could not distribute the lateral expansion force uniformly. The un-uniform casing thickness will provide a spot, which will become the weakest part of the casing due to the stress.

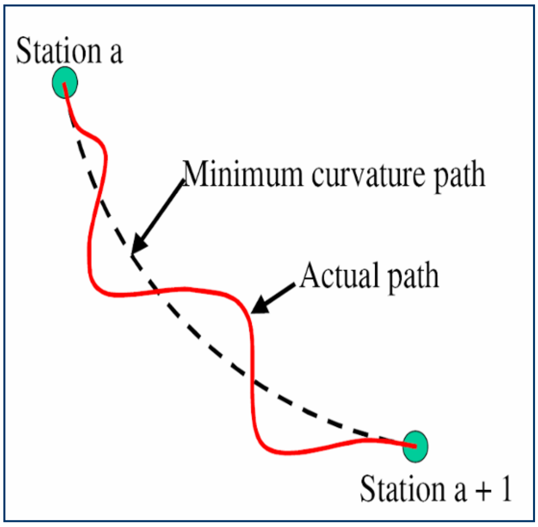



**Figure 3.13-Different between actual and survey well path [2]**

To reduce tortuisity, we can install stabilizers. The lower most stabilizers consist of a conventional near bit stabilizer that also serves as a float sub and crossover from the rotary connection on the bit to the casing connection. The upper two spiral-blade stabilizers are rigid body centralizer subs with full gauge hard faced blades. (For example, near bit stabilizer to string stabilizer is 1/3L and distance between string stabilizers is 2/3L and L is the length of BHA).

By installing stabilizers we could reduce the dogleg on the well profile. This condition will help us to provide a better pre-expandable condition. Figure 3.14 shows the inclination surveys. Even though the maximum inclination observed in the well was no more than 4º, the well can have smaller dogleg by installing the stabilizers. Wells 1, 2, 3 have no stabilizers and wells 4, 5, 6 and 7 have stabilizers. Stabilizers could reduce almost a quarter of the dogleg inclination.

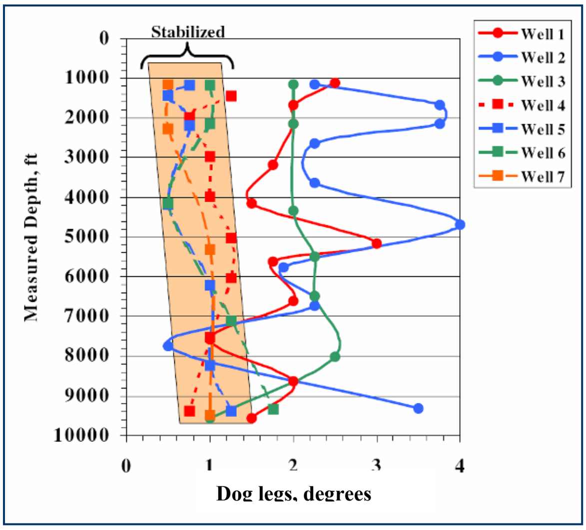



**Figure 3.14-Inclination survey drilled with 4½" and 5"casing and full hole bits [2]**

Besides reducing the tortuisity (inclination variation), the stabilizer can also reduce torque. The reduction in rotating torque is significant. Figure 3.15 shows a plot of the "off bottom" torque for a well drilled with slick assembly. Using a typical open hole friction factor of 0.3 and cased hole friction of 0.2 the torque was predicted to be only about 800 ft-lbf at TD (dashed line). The actual measured torque was 3-4 times larger than the calculated torque. A tortuosity of 0.6 º/100 ft was required to match the actual measured torque.

By installing stabilizers, the torque was reduced dramatically as shown in figure 3.16. For this well, the torque is matched by using a tortuosity of 0.15º/100 ft. The clear conclusion is that the stabilizer assembly drilled a straighter and smoother hole, thus the torque was significantly less.

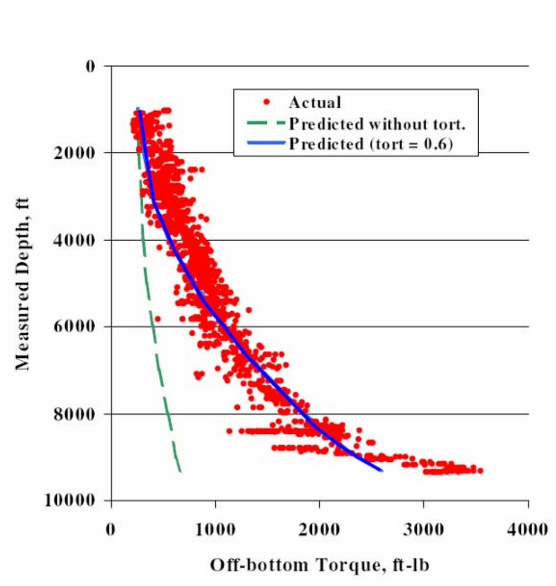



Figure 3.15-Off bottom torque without stabilizer [2]

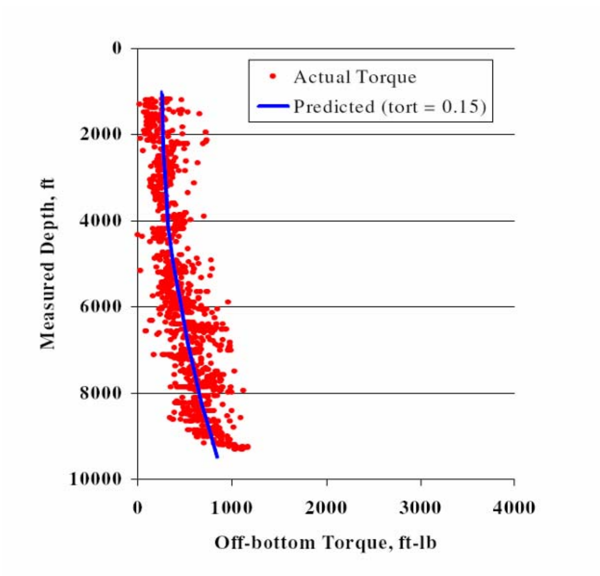



Figure 3.16-Off bottom torque with stabilizer [2]

Installing the stabilizers, one will make the expandable connection lose a lot of torque burdens. As we discuss before, the expandable casing connection has low torque strength, therefore besides reducing dogleg, stabilizers could make it more feasible to be accepted in drilling operation. The additional calculation and design should be run to determine the acceptance criteria.

***Analysis 3***: The well has no lateral vibration and whirl during the drilling operation.

Lateral vibration or whirl is the most damaging vibration in DwC. The vibration can lead to failure in casing coupling. The destructive lateral vibration can occur at any point along the drillstring. The vibration most often displays an interaction with the drillstring rotation as lateral displacement that orbits the borehole center (figure 3.17). This vibration often happens in smaller ID casing. As the drillstring rotates, the initially small lateral force causes friction, which produces a traction force that tends to cause the contact point to walk around the hole.

Lateral vibration and whirl can increase the torque on the system resulting in the connection not being sufficiently strong to be expanded. On the expansion process when the cone runs through the connection, the connection can leak due to de-rate strength.

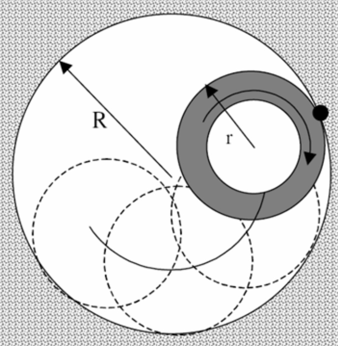



**Figure 3.17-Schematic of Whirl [2]**

This precession of string around the hole, generates a centrifugal force that increases the contact force. Whirl is less likely to be initiated at low rotation speeds, but once it is initiated, the increase in contact force causes the whirl to be self-sustaining and make it continue, even if the rotary speed is reduced.

What is the indication that lateral vibration occurs? When there is an interaction between torque and rpm (torque high, rpm high and vice versa) then downhole lateral vibration is indicated to happen. To detect the whirl, we need to monitor torque and compare it with torque and drag model prediction.

Torque also increased when we increase the WOB or when we drill through or into soft formation, which makes the ROP high. Steps to determine whirl:

1. Note the on-bottom drilling torque, and then pick the bit off-bottom without reducing the rotary speed.
2. Record the torque and slowly reduce the RPM to zero.
3. Re-establish the rotary at 30 RPM and record the torque.
4. If the torque remains high when the bit is picked up and gradually decreases as the RPM is reduced, and return to a considerably lower value when rotation is re-established, then whirl is happened.

What can lateral vibration cause? The connection of casing can be fallen apart. Besides, increasing the wear in casing coupling due to increase of contact force, it can caused increasing in the number of effective rotation.

How to eliminate the whirl? First reduce the RPM to zero and start drilling with lower RPM, or change the mud with better lubricator or we can use mud motor. By minimizing the effect of lateral vibration (whirl) then we could assure that our connections do not have additional torque loading. Since the expandable casing is weak on torque, so when we used it on drilling we should drill with low RPM, use a better lubricator mud or we can used mud motor. Using a mud motor is a good solution because we could keep the drill bit RPM high but not the drill pipe. Rotation on drillpipe is just for wellbore cleaning and cutting transport purposes.

From the analysis we could conclude the answer of the question. There is a possibility the expandable could be performed optimally if we have a good control and consideration during drilling operation. However, the expansion casing could be de-rated on its strength due to post drilling operation.

***Result :***

Expandable casing could become de-rated post the drilling operations. Therefore, there are some drilling considerations:

- To assure we have a clean interface on the inside wall of the casing we should do a cleaning operation before the expansion process. To assure we have a uniform inside diameter, a mill should be installed on the drillstring during the cleaning operation.
- To avoid exceeding torsion on the expandable casing connectors due to tortuosity and dogleg, stabilizers should be installed.
- To minimize the whirl that can lead to the connection becoming fatigued, we should use a better lubricator and drill with low RPM, alternatively high RPM using a mud motor.

## 3.4 ANALYSIS OF THE CASING PROPERTIES POST-EXPANSION

***Question: What are the expandable casing properties that need to be considered?***

***Analysis:***

The main concern of the expansion material properties after the expansion process is the low collapse rating. It will be shown in the discussion how the collapse influences well design. This effect happens because the expansion process will reduce the wall thickness. Based on the collapse pressure formula, reduction on wall thickness and yield strength is the two effects that will reduce the collapse rating. Below it is shown the formula for calculate the collapse rating.

- For two dimensional stress (uni-axial stress) formula by Ballow. (This equation is neglected axial stress). [7]

$$P_{collape} = 2\sigma y \frac{\left(\frac{do}{t}\right) - 1}{\left(\frac{do}{t}\right)^2}$$

for plastic deformation

- For three dimensional stress (tri-axial stress) formula by Bernt Åadnøy and Jan Åarsen [7]

$$P_{collape} = \frac{Pi\,(2\beta - 1) - \sigma z + \sqrt{4\sigma y^2 - 3(Pi + \sigma z)^2}}{2\beta}$$

$$\text{where} \qquad \beta = \frac{\left(\frac{do}{t}\right)^2}{2\left(\left(\frac{do}{t}\right) - 1\right)}$$

Where: σy = limit of yield stress    do = outside diameter

σz = axial stress    t = wall thickness

Pi = inside pressure

It is agreed in both formulas, the parameter that controls the collapse pressure is the ratio between outside diameter and wall thickness (do/t). For post expansion casing, we will get bigger outside diameter and thinner wall thickness. In other word, the ratio will be higher than non-expanded pipe. Raising the ratio, will significantly reducing the collapse pressure.

**Table 3.4-Comparisons between connections with body**

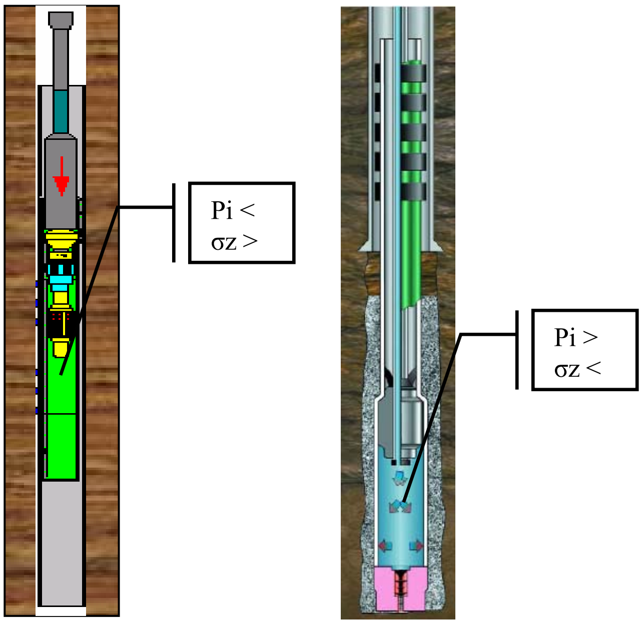
| **Connection 9 ⅝ XPC #36, N-80 flush joint (Enventure)** | | **Pipe Body 9 ⅝ #36, N-80 (Hydril)** | | **comparison** |
|---|---|---|---|---|
| • Connection joint strength | 533,900 lbf | • Body yield strength | 820,000 lbf | 1.54 times stronger |
| • Minimum Yield strength | 4,550 psi | • Minimum Yield strength | 80,000 psi | 17.6 times stronger |

As shown in table 3.4 the body is much stronger than the connection. Therefore, as considered previously, the weakest part of the system is the connection. The stress on the pipe body then can be neglected, except for the bending stress. Bending is a critical issue due to cracking of the pipe body.

In the expansion process, we try to reform the pipe structure by forcing the cone to push the casing. The cone applies lateral and axial forces to the inside wall. The consideration about expansion performance is then more in the inner wall than outside wall. However the crack or scar on the outside wall will reduce the casing resistance due to high internal pressure on expansion process.

The 3-dimensional collapse rating formula considers the tri-axial stresses. Besides increasing the outside diameter and wall thickness ratio (do/t), the collapse rating will reduce if internal pressure (Pi) reduces and the axial pressure increases (σz). Therefore during the expansion process, On figure 3.18 shows that on;

- Bottom to top expansion, the internal pressure will increase and the axial stress will decrease.
- Top to bottom expansion, the internal pressure will decrease and the axial stress will increase.




Having a low internal pressure and high axial stress according to triaxial collapse pressure formula is the worst combination.

Therefore the proper expansion should be from bottom to top to avoid low collapse rating slightly after expansion

**Figure 3.18-Comparison of expansion methods**

The table 3.5 below will show us the properties of expandable casing pre and post expansion. Data is provided by Enventure. It is shown obviously that the post expansion collapse rating is very low.

## Table 3.5-Pre and Post expansion-casing properties (Data is provided by Enventure) [15]

| System Size | Base Casing | | | | Solid Expandable Tubular System | | | | | | | | | API | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SET x Base Casing | OD (in.) | Weight (lb/ft) | ID (in.) | Drift (in.) | Pre-Expansion | | | Initial Wall (in.) | Launcher OD (in.) | Post-Expansion | | | Exp. Ratio (ID) | Yield (psi) | Collapse (psi) |
| | | | | | OD (in.) | ID (in.) | Wt (lb/ft) | | | OD (in.) | ID (in.) | Drift (in.) | | | |
| 13.375 54.5 lb/ft x 16.000 109.0 lb/ft | 16.000 | 109.0 | 14.688 | 14.500 | 13.375 | 12.615 | 54.5 | 0.380 | 14.500 | 14.505 | 13.770 | 13.632 | 9.2% | 3,650 | 800 |
| 13.375 54.5 lb/ft x 16.000 97.0 lb/ft | 16.000 | 97.0 | 14.850 | 14.662 | 13.375 | 12.615 | 54.5 | 0.380 | 14.570 | 14.681 | 13.950 | 13.811 | 10.6% | 3,590 | 760 |
| 13.375 54.5 lb/ft x 16.000 95.0 lb/ft | 16.000 | 95.0 | 14.868 | 14.680 | 13.375 | 12.615 | 54.5 | 0.380 | 14.570 | 14.681 | 13.950 | 13.811 | 10.6% | 3,590 | 760 |
| 13.375 54.5 lb/ft x 16.000 84.0 lb/ft | 16.000 | 84.0 | 15.010 | 14.822 | 13.375 | 12.615 | 54.5 | 0.380 | 14.750 | 14.827 | 14.100 | 13.959 | 11.8% | 3,540 | 730 |
| 13.375 54.5 lb/ft x 16.000 75.0 lb/ft | 16.000 | 75.0 | 15.124 | 14.936 | 13.375 | 12.615 | 54.5 | 0.380 | 14.822 | 14.925 | 14.200 | 14.058 | 12.6% | 3,500 | 710 |
| 11.750 47.0 lb/ft x 14.500 77.9 lb/ft | 14.500 | 77.9 | 13.455 | 13.299 | 11.750 | 11.000 | 47.0 | 0.375 | 13.200 | 13.348 | 12.640 | 12.514 | 14.9% | 3,8[illegible] | 920 |
| 11.750 47.0 lb/ft x 14.000 112.8 lb/ft | 14.000 | 112.8 | 12.400 | 12.250 | 11.750 | 11.000 | 47.0 | 0.375 | 12.191 | 12.238 | 11.500 | 11.385 | 4.5% | 4,350 | 1,[illegible]70 |
| 11.750 47.0 lb/ft x 13.625 88.2 lb/ft | 13.625 | 88.2 | 12.375 | 12.219 | 11.750 | 11.000 | 47.0 | 0.375 | 12.191 | 12.140 | 11.400 | 11.286 | 3.6% | 4,390 | 1,410 |
| 11.750 47.0 lb/ft x 13.375 72.0 lb/ft | 13.375 | 72.0 | 12.347 | 12.191 | 11.750 | 11.000 | 47.0 | 0.375 | 12.191 | 12.140 | 11.400 | 11.286 | 3.6% | 4,390 | 1,410 |
| 11.750 47.0 lb/ft x 13.375 68.0 lb/ft | 13.375 | 68.0 | 12.415 | 12.259 | 11.750 | 11.000 | 47.0 | 0.375 | 12.191 | 12.238 | 11.500 | 11.385 | 4.5% | 4,350 | 1,370 |
| 9.625 36.0 lb/ft x 11.875 71.8 lb/ft | 11.875 | 71.8 | 10.711 | 10.625 * | 9.625 | 8.921 | 36.0 | 0.352 | 10.616 | 10.653 | 9.980 | 9.880 | 11.[illegible]% | 4,550 | 1,570 |
| 9.625 36.0 lb/ft x 11.750 65.0 lb/ft | 11.750 | 65.0 | 10.682 | 10.625 * | 9.625 | 8.921 | 36.0 | 0.352 | 10.616 | 10.624 | 9.950 | 9.851 | 11.[illegible]% | 4,570 | 1,590 |
| 9.625 36.0 lb/ft x 11.750 60.0 lb/ft | 11.750 | 60.0 | 10.772 | 10.616 | 9.625 | 8.921 | 36.0 | 0.352 | 10.616 | 10.653 | 9.980 | 9.880 | 11.9% | 4,550 | 1,570 |
| 8.625 32.0 lb/ft x 10.750 65.7 lb/ft | 10.750 | 65.7 | 9.560 | 9.404 | 8.625 | 7.921 | 32.0 | 0.352 | 9.404 | 9.402 | 8.724 | 8.637 | 10.1% | 5,200 | 2,2[illegible] |
| 8.625 32.0 lb/ft x 10.750 60.7 lb/ft | 10.750 | 60.7 | 9.660 | 9.504 | 8.625 | 7.921 | 32.0 | 0.352 | 9.404 | 9.485 | 8.810 | 8.722 | 11.2% | 5,1[illegible] | 2,150 |
| 8.625 32.0 lb/ft x 10.750 55.5 lb/ft | 10.750 | 55.5 | 9.760 | 9.604 | 8.625 | 7.921 | 32.0 | 0.352 | 9.404 | 9.524 | 8.850 | 8.762 | 11.7% | 5,100 | 2,120 |
| 7.625 29.7 lb/ft x 9.875 67.5 lb/ft | 9.875 | 67.5 | 8.519 | 8.500 * | 7.625 | 6.875 | 29.7 | 0.375 | 8.379 | 8.417 | 7.700 | 7.623 | 12.0% | 6,140 | 3,150 |
| 7.625 29.7 lb/ft x 9.875 62.8 lb/ft | 9.875 | 62.8 | 8.625 | 8.469 | 7.625 | 6.875 | 29.7 | 0.375 | 8.379 | 8.417 | 7.700 | 7.623 | 12.0% | 6,140 | 3,150 |
| 7.625 29.7 lb/ft x 9.625 53.5 lb/ft | 9.625 | 53.5 | 8.535 | 8.379 | 7.625 | 6.875 | 29.7 | 0.375 | 8.379 | 8.417 | 7.700 | 7.623 | 12.0% | 6,140 | 3,150 |
| 7.625 29.7 lb/ft x 9.625 47.0 lb/ft | 9.625 | 47.0 | 8.681 | 8.525 | 7.625 | 6.875 | 29.7 | 0.375 | 8.180 | 8.340 | 7.620 | 7.544 | 10.8% | 6,220 | 3,230 |
| 7.625 29.7 lb/ft x 9.625 47.0 lb/ft | 9.625 | 47.0 | 8.681 | 8.525 | 7.625 | 6.875 | 29.7 | 0.375 | 8.379 | 8.503 | 7.790 | 7.712 | 13.3% | 6,050 | 3,050 |
| 7.625 29.7 lb/ft x 9.625 43.5 lb/ft | 9.625 | 43.5 | 8.755 | 8.599 | 7.625 | 6.875 | 29.7 | 0.375 | 8.599 | 8.609 | 7.900 | 7.821 | 14.9% | 5,940 | 2,950 |
| 7.625 29.7 lb/ft x 9.625 40.0 lb/ft | 9.625 | 40.0 | 8.835 | 8.679 | 7.625 | 6.875 | 29.7 | 0.375 | 8.599 | 8.609 | 7.900 | 7.821 | 14.9% | 5,940 | 2,950 |
| 7.625 29.7 lb/ft x 9.375 39.0 lb/ft | 9.375 | 39.0 | 8.575 | 8.500 * | 7.625 | 6.875 | 29.7 | 0.375 | 8.379 | 8.417 | 7.700 | 7.623 | 12.0% | 6,140 | 3,150 |
| 6.000 18.6 lb/ft x 7.750 46.1 lb/ft | 7.750 | 46.1 | 6.560 | 6.435 | 6.000 | 5.390 | 18.6 | 0.305 | 6.370 | 6.445 | 5.854 | 5.795 | 8.6% | 6,610 | 3,820 |
| 5.500 17.0 lb/ft x 7.750 46.1 lb/ft | 7.750 | 46.1 | 6.560 | 6.435 | 5.500 | 4.892 | 17.0 | 0.304 | 6.151 | 6.252 | 5.680 | 5.621 | 16.1% | 6,600 | 3,800 |
| 5.500 17.0 lb/ft x 7.625 47.1 lb/ft | 7.625 | 47.1 | 6.375 | 6.250 | 5.500 | 4.892 | 17.0 | 0.304 | 6.151 | 6.156 | 5.580 | 5.521 | 14.1% | 6,750 | 4,030 |
| 6.000 18.6 lb/ft x 7.625 39.0 lb/ft | 7.625 | 39.0 | 6.625 | 6.500 | 6.000 | 5.390 | 18.6 | 0.305 | 6.500 | 6.489 | 5.900 | 5.841 | 9.5% | 6,540 | 3,720 |
| 6.000 18.6 lb/ft x 7.625 33.7 lb/ft | 7.625 | 33.7 | 6.765 | 6.640 | 6.000 | 5.390 | 18.6 | 0.305 | 6.640 | 6.623 | 6.040 | 5.981 | 12.1% | 6,350 | 3,420 |
| 6.000 18.6 lb/ft x 7.625 29.7 lb/ft | 7.625 | 29.7 | 6.875 | 6.750 | 6.000 | 5.390 | 18.6 | 0.305 | 6.640 | 6.767 | 6.190 | 6.131 | 14.8% | 6,150 | 3,150 |
| | Ver 9.0 September 10, 2004 | | | | * Special Drift | | | | | | | | | | |

ADDITIONAL BASE CASING SIZES AND WEIGHTS, AS WELL AS A COMBINATION OF CASING WEIGHTS, COULD BE ACCOMMODATED BUT NEED TO BE REVIEWED ON A CASE-BY-CASE BASIS. CONTACT ENVENTURE FOR THESE SITUATIONS.

## Table 3.5-continue [15]

| System Size | Base Casing | | | | Solid Expandable Tubular System | | | | | | | | | API | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SET x Base Casing | OD (in.) | Weight (lb/ft) | ID (in.) | Drift (in.) | Pre-Expansion OD (in.) | Pre-Expansion ID (in.) | Pre-Expansion Wt (lb/ft) | Initial Wall (in.) | Launcher OD (in.) | Post-Expansion OD (in.) | Post-Expansion ID (in.) | Post-Expansion Drift (in.) | Exp. Ratio (ID) | Yield (psi) | Collapse (psi) |
| 5.500 17.0 lb/ft x 7.000 38.0 lb/ft | 7.000 | 38.0 | 5.920 | 5.795 | 5.500 | 4.892 | 17.0 | 0.304 | 5.800 | 5.785 | 5.190 | 5.131 | 6.1% | 7,420 | 5,050 |
| 5.500 17.0 lb/ft x 7.000 35.0 lb/ft | 7.000 | 35.0 | 6.004 | 5.897 | 5.500 | 4.892 | 17.0 | 0.304 | 5.800 | 5.842 | 5.250 | 5.191 | 7.3% | 7,310 | 4,880 |
| 5.500 17.0 lb/ft x 7.000 32.0 lb/ft | 7.000 | 32.0 | 6.094 | 5.969 | 5.500 | 4.892 | 17.0 | 0.304 | 5.969 | 5.918 | 5.330 | 5.271 | 9.0% | 7,160 | 4,660 |
| 5.500 17.0 lb/ft x 7.000 29.0 lb/ft | 7.000 | 29.0 | 6.184 | 6.059 | 5.500 | 4.892 | 17.0 | 0.304 | 5.969 | 5.995 | 5.410 | 5.351 | 10.6% | 7,040 | 4,470 |
| 5.500 17.0 lb/ft x 7.000 29.0 lb/ft | 7.000 | 29.0 | 6.184 | 6.059 | 5.500 | 4.892 | 17.0 | 0.304 | 6.059 | 6.109 | 5.530 | 5.471 | 13.0% | 6,830 | 4,160 |
| 5.500 17.0 lb/ft x 7.000 26.0 lb/ft | 7.000 | 26.0 | 6.276 | 6.151 | 5.500 | 4.892 | 17.0 | 0.304 | 6.151 | 6.109 | 5.530 | 5.471 | 13.0% | 6,830 | 4,160 |
| 5.500 17.0 lb/ft x 7.000 23.0 lb/ft | 7.000 | 23.0 | 6.366 | 6.241 | 5.500 | 4.892 | 17.0 | 0.304 | 6.151 | 6.214 | 5.640 | 5.581 | 15.3% | 6,660 | 3,900 |
| 5.500 17.0 lb/ft x 7.000 20.0 lb/ft | 7.000 | 20.0 | 6.456 | 6.331 | 5.500 | 4.892 | 17.0 | 0.304 | 6.151 | 6.252 | 5.680 | 5.621 | 16.1% | 6,600 | 3,800 |
| 4.250 10.7 lb/ft x 5.500 23.0 lb/ft | 5.500 | 23.0 | 4.670 | 4.545 | 4.250 | 3.750 | 10.7 | 0.250 | 4.545 | 4.526 | 4.040 | 3.981 | 7.7% | 7,740 | 5,540 |
| 4.250 10.7 lb/ft x 5.500 20.0 lb/ft | 5.500 | 20.0 | 4.778 | 4.653 | 4.250 | 3.750 | 10.7 | 0.250 | 4.545 | 4.597 | 4.115 | 4.056 | 9.7% | 7,560 | 5,260 |
| 4.250 10.7 lb/ft x 5.500 17.0 lb/ft | 5.500 | 17.0 | 4.892 | 4.767 | 4.250 | 3.750 | 10.7 | 0.250 | 4.767 | 4.763 | 4.290 | 4.231 | 14.4% | 7,160 | 4,660 |
| 4.250 10.7 lb/ft x 5.500 15.5 lb/ft | 5.500 | 15.5 | 4.950 | 4.825 | 4.250 | 3.750 | 10.7 | 0.250 | 4.767 | 4.819 | 4.349 | 4.290 | 16.0% | 7,030 | 4,460 |
| 4.250 10.7 lb/ft x 5.500 14.0 lb/ft | 5.500 | 14.0 | 5.012 | 4.887 | 4.250 | 3.750 | 10.7 | 0.250 | 4.767 | 4.819 | 4.349 | 4.290 | 16.0% | 7,030 | 4,460 |

ADDITIONAL BASE CASING SIZES AND WEIGHTS, AS WELL AS A COMBINATION OF CASING WEIGHTS, COULD BE ACCOMMODATED BUT NEED TO BE REVIEWED ON A CASE-BY-CASE BASIS. CONTACT ENVENTURE FOR THESE SITUATIONS.

**Nested Systems ****

| System Size | Base Casing | | | | Solid Expandable Tubular System | | | | | | | | | API | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SET x Base Casing | OD (in.) | Weight (lb/ft) | ID (in.) | Drift (in.) | Pre-Expansion OD (in.) | Pre-Expansion ID (in.) | Pre-Expansion Wt (lb/ft) | Initial Wall (in.) | Launcher OD (in.) | Post-Expansion OD (in.) | Post-Expansion ID (in.) | Post-Expansion Drift (in.) | Exp. Ratio (ID) | Yield (psi) | Collapse (psi) |
| 11.750 47.0 lb/ft x 13.375 68.0 lb/ft | 13.375 | 68.0 | 12.415 | 12.259 | 11.750 | 11.000 | 47.0 | 0.375 | 12.191 | 12.140 | 11.400 | 11.286 | 3.6% | 4,390 | 1,410 |
| 9.625 36.0 lb/ft x 11.750 Expanded | 12.140 | 46.5 | 11.400 | 11.286 | 9.625 | 8.921 | 36.0 | 0.352 | 11.030 | 11.012 | 10.350 | 10.247 | 16.0% | 4,330 | 1,360 |
| 9.625 36.0 lb/ft x 11.750 65.0 lb/ft | 11.750 | 65.0 | 10.682 | 10.625 * | 9.625 | 8.921 | 36.0 | 0.352 | 10.616 | 10.478 | 9.800 | 9.702 | 9.9% | 4,670 | 1,680 |
| 8.625 32.0 lb/ft x 9.625 Expanded | 10.480 | 36.8 | 9.800 | 9.702 | 8.625 | 7.921 | 32.0 | 0.352 | 9.404 | 9.524 | 8.850 | 8.762 | 11.7% | 5,100 | 2,120 |
| 7.625 29.7 lb/ft x 8.625 Expanded | 9.524 | 33.1 | 8.850 | 8.762 | 7.625 | 6.875 | 29.7 | 0.375 | 8.662 | 8.730 | 8.026 | 7.946 | 16.7% | 5,810 | 2,820 |
| 8.625 32.0 lb/ft x 10.750 60.7 lb/ft | 10.750 | 60.7 | 9.660 | 9.504 | 8.625 | 7.921 | 32.0 | 0.352 | 9.404 | 9.524 | 8.850 | 8.762 | 11.7% | 5,100 | 2,120 |
| 7.625 29.7 lb/ft x 8.625 Expanded | 9.524 | 33.1 | 8.850 | 8.762 | 7.625 | 6.875 | 29.7 | 0.375 | 8.662 | 8.730 | 8.026 | 7.946 | 16.7% | 5,810 | 2,820 |
| 6.000 18.6 lb/ft x 7.625 29.7 lb/ft | 7.625 | 29.7 | 6.875 | 6.750 | 6.000 | 5.390 | 18.6 | 0.305 | 6.640 | 6.744 | 6.166 | 6.107 | 14.4% | 6,180 | 3,190 |
| 5.500 17.0 lb/ft x 6.000 Expanded | 6.744 | 20.0 | 6.166 | 6.107 | 5.500 | 4.892 | 17.0 | 0.304 | 5.969 | 5.995 | 5.410 | 5.351 | 10.6% | 7,040 | 4,470 |
| | Ver 9.0 September 10, 2004 | | | | * Special Drift | | | | | | | | | | |

** ADDITIONAL BASE CASING SIZES AND WEIGHTS FOR NESTED SYSTEMS, COULD BE ACCOMMODATED BUT NEED TO BE REVIEWED ON A CASE-BY-CASE BASIS. CONTACT ENVENTURE FOR THESE SITUATIONS.

Here is shown the example, of comparison burst and collapse rating between post expansion casing and non-expanded casing.

**Table 3.6-Comparison of Burst and collapse for pre-post expansion casing**

| SET and Base casing | Post expansion* | | Base casing** | |
|---|---|---|---|---|
| | P.burst (psi) | P.coll (psi) | P.burst (psi) | P.coll (psi) |
| 13.375" #54.5 | 3500 | **710** | 3980 | **1140** |
| 11.750" #47.0 | 4350 | **1370** | 4470 | **1630** |
| 9.625" #36.0 | 4550 | **1570** | 5120 | **2370** |
| 7.625" #29.0 | 6220 | **3230** | 6890 | **4790** |
| 5.500" #17.0 | 6600 | **3800** | 7740 | **6290** |

*note : for comparison, the base casing use the hydril common casing grade (L-80)*

**) data from Enventure*

***) data from Hydril*

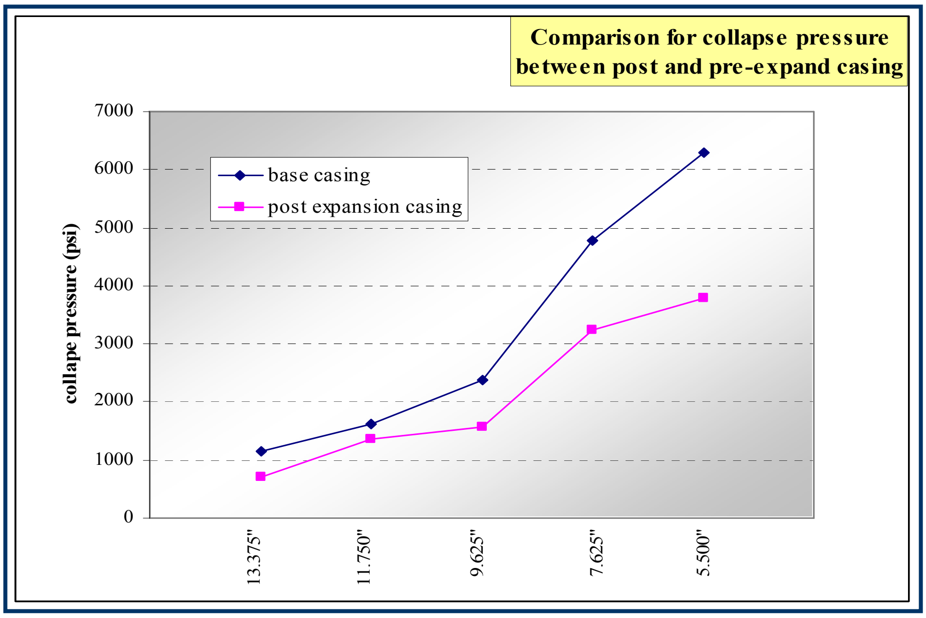



**Figure 3.19-Graphical represent for collapse rating between pre-post expansions**

So based on the collapse pressure formula and the expandable casing properties provided by industry, definitely we could see that the post expandable casing properties is low on collapse rating. Therefore the casing properties that need the most concern is its low collapse rating.

***Results:*** The post expansion casing has a lower collapse rating. This effect should be our main consideration.

## 3.5 ANALYSIS OF THE COST

***Question : Is the cost competitive?***

***Analysis :***

Nowadays, there is still no commercial service for drilling with expandable casing method. Therefore to predict the cost for combine method we have to add the cost from drilling with casing and expandable casing separately. Only the service companies can give their cost prediction. The technology is new and the vendors are limited, the companies monopolize the market.

There are no price lists. Each job is priced by the Business Development group for the company involved. For expandable technology service only, according to Enventure, they will charge $ 175 - $ 200 per feet of expansion. This price does not include the casing tools, the casing crews, the cementing head, the cement and pumping charges.

Cost for DwC is almost comparable with conventional drilling. However since DwC faster on the rate of penetration (500 – 750 ft/day) which saves a lot of money on rig expenses makes the cost more feasible. Table 3.7 and 3.8 show cost estimation for drilling with casing included equipment and operation. (Source: Casing while drilling March 2004 conference, World oil)

**Table 3.7-Costs for conventional rig and equipments [12]**

| Conversion Item | Estimated Cost |
|---|---|
| 1. Casing Drilling Wireline Winch | $ 500,000.00 |
| 2. Split Crown Blocks | $ 150,000.00 |
| 3. Split Traveling Blocks | $ 150,000.00 |
| 4. Wireline BOPs | $ 50,000.00 |
| 5. Solids Control Equipment | $ 85,000.00 |
| 6. Modify Mast for Top Drive | $ 20,000.00 |
| 7. Rig Day rate (Land rig) | $ 10,000.00 |
| **Total =** | **$ 965,000.00** |

**Table 3.8-Costs for Drilling with casing operations** [12]

| Operation | Per Well Cost |
|---|---|
| Rig Move Days | $ 36,000.00 |
| Top Drive Rig Up | $ 24,000.00 |
| Top Drive Rental | $ 25,000.00 |
| Location Construction | $10,000.00 |
| Automated Catwalk | $12,000.00 |
| Casing Drive Assembly | $ 20,000.00 |
| Total = | **$ 127,000/well** |

Table 3.9 show cost estimation for expandable casing included equipment and operation. (Source: SPE/IADC 102011)

**Table 3.9-Costs for Expandable casing operations** [22]

**Tied-back Expandable Liner vs. Openhole Clad Drilling Liner**

Time & Cost Comparison

*Spread Rate for Rig is $110,000 per day* — $4,583 per hour

| Event | Conventional Solid Expandable Drilling Liner | Time (Hrs.) | Cost ($000) | Event | Expandable Full-bore Drilling Liner | Time (Hrs.) | Cost ($000) |
|---|---|---|---|---|---|---|---|
| 1 | Time to Under Ream Hole Section (ROP = 100 ft/hr.) (Length to Under Ream = 3000 feet) | 30.00 | $137,500 | 1 | Under Ream Hole Section (ROP = 100 ft/hr. plus 12 hrs. trip time) (Length to Under Ream = 100 feet) | 13.00 | $59,583 |
| 2 | Prepare and Pick-up BHA | 1.00 | $4,583 | 2 | Prepare and Pick-up BHA | 1.00 | $4,583 |
| 3 | Time to pick-up and make-up each joint of Expandable Casing (3300' including overlap) (20 min./joint) (Number of Joints Required = 87 joints) | 29.00 | $132,917 | 3 | Time to pick-up and make-up each joint of Expandable Casing (100' - No overlap Required) (20 min./joint) (Number of Joints Required = 3 joints) | 1.00 | $4,583 |
| 4 | Time to Rig-up False Floor to enable the Running of the Work String (45 minutes) | 0.75 | $3,438 | 4 | Time to Rig-up False Floor to enable the Running of the Work String (45 minutes) | 0.75 | $3,438 |
| 5 | Time to Run to Depth the Expandable Liner w/Launcher (1000'/hour to 10,000 feet) | 10.00 | $45,833 | 5 | Time to Run to Depth the Expandable Liner w/Launcher (2000'/hour to 13,000 feet) | 6.50 | $29,792 |
| 6 | Time Pump Cement to Cement "tied-back" Expandable Drilling Liner (Estimate of 6 Hours) | 6.00 | $27,500 | 6 | Time Pump Cement to Cement Full-bore Expandable Drilling Liner (Zero - No Cementing Required) | | |
| 7 | Cost of Cementing Job | | $80,000 | 7 | Cost of Cementing Job (None Required) | | N/A |
| 8 | Time to Expand "tied-back" Expandable Drilling Liner (Ave 20 minutes/stand of 90 foot dirl pipe. Expanding 37 stands) | 12.21 | $55,963 | 8 | Time to Expand "tied-back" Expandable Drilling Liner (Ave 20 minutes/stand of 90 foot dirl pipe. Expanding 1.25 stands) | 0.41 | $1,891 |
| 9 | Drill-out Shoe of "tied-back" Expandable Drilling Liner | 2.00 | $9,167 | 9 | Drill-out Shoe of Full-bore Expandable Drilling Liner | 2.00 | $9,167 |
| | **Total (Cost of Assoc. Well Costs Only - "tied-back" System)** | **90.96** | **$496,900** | | **Total (Cost of Assoc. Well Costs Only - Full-bore System)** | **24.66** | **$113,036** |

In the discussion, the author will present a Chevron cost prediction for running a separate drilling with casing and expandable casing operation. In that case, they drilled with casing and then in the next hole section conventional drilling was performed and continue with running and expanding the expandable casing. This cost is compared with the conventional drilling through trouble zone. The author would also provide the cost prediction if run the

9-5/8” monobore hole from top to bottom as the comparison case. However this cost predictions neglect the additional cost because of failure and risks.

The well candidate that could have a reasonable cost to run this combine method is the wells with:

- No acceptable conventional alternative.
- There is a significant drill through trouble zone – losses, gains, ledges, or sloughing.
- A tolerance for higher operational risk and possible failure wells.
- No requirement for high burst or collapse rating.
- Minimum hole angle with no doglegs
- The additional ID gained from using SET will yield a major economic benefit to offset the additional rig time and high cost of the service.

Because of very limited information about the costs for the combined technology, the author will predict the cost based on each support technologies. Using this case study, the author will try to provide cost estimation for combine method that will be shown in next chapter. The answer for the cost of this combine method, temporary can be concluded as below.

***Result:***

It is possible to save costs because running this combined method will reduce the rig time used. However, well candidates should be carefully considered prior to using this method.

## 3.6 ANALYSIS OF THE OPERATIONAL LIMITATIONS AND RISKS

***Question : Are there any limitations and risks on this process?***

***Analysis :***

Combining those technologies means we also combine both technologies limitations.

The limitations of drilling with casing

One of the challenging operations, which could become a limitation in drilling with casing, is to land the casing hanger into the wellhead. The casing hanger should not be rotated when seated on the wellhead, because the sealing and landing profile is weak due to deformation.

The damage of the casing hanger will let the additional repair operation. Casing hanger profile is shown on figure 3.24.

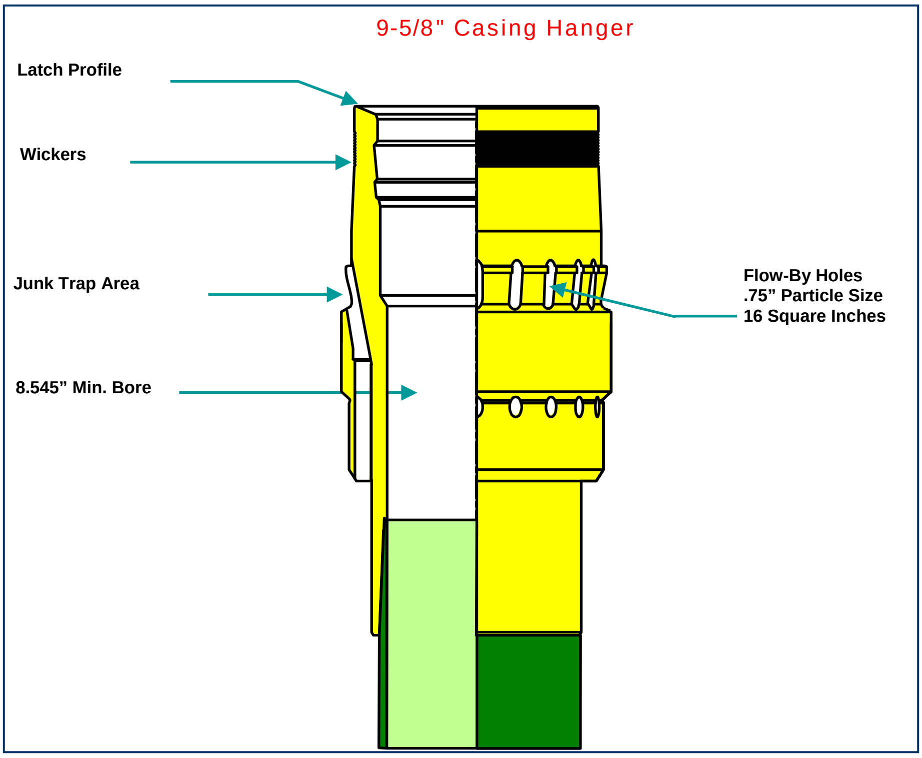



**Figure 3.20-General Casing hanger design** [9]

<u>The limitations of SET are:</u>

Interviews with Chevron staff have disclosed that the limitations of expandable casing are:

- The casing does not have a high collapse rating post expansion and that it will not withstand high external pressure. Therefore the expandable casing only accepted to be run on the formation with low pressure.
- Wells should have minimum hole angle with no dogleg. The inside wall of pre-expansion casing should be clean in order to achieve to get a good uniform expansion and no leakage.
- Since the expandable casing connection is low strength, a good liner lap test and shoe test must be performed carefully.

<u>The limitations of combined method:</u>

From the limitations of both of these technologies, we can conclude that drilling with expandable casing will have even more limitations. Moreover, the expandable casing has more limitation than drilling with casing itself. These limitations contribute significantly to the combined method.

After analyzed, technically, there are two major limitations within this method, which are:

- The expandable casing connection has a low torque rating. Minimum hole angle and whirl with no big torsion should be achieved to avoid the expandable connection falling apart when drilling or expanding.
- The casing is very low on the collapse rating. Tendency to collapse is high especially when the formation pressure is high and the pipe on tension.

***Risk analysis of combined method***

In order to do risk analysis, there are two outcomes of this technology that become our concern:

- Health, Safety and Environment (HSE) outcomes
- Time delay and economical outcomes

These two outcomes will be applied and analyzed as the impact when the combined method fails. The results of the analysis will be presented both in its probability (frequency it occurs) and consequence (impact if it happens). The probability will be arranged and valued from very low probable, less probable, probable, high probability to very high probability. The consequences will be arranged and valued from minor, significant, severe, and major to catastrophic. This value will be assessed by author belief and will be plotted on risk matrix. Based on its limitations, the boundaries are;

1. The expandable casing connection has a low torque rating. Minimum hole angle and whirl with no big torsion should be achieved to avoid the expandable connection falling apart when drilling or expanding. The impact on:

    a. Health, Safety and Environment (HSE) are:
    If the connection fails when drilling or expanding, the drillstring will disconnect. The lost circulation or the kick could happen depend on how high the formation pressure compares to pipe internal pressure.
    Kick could blow out to the surface if the barriers fail. The integrity of the rig and the safety and lives of the crews will be in danger. Besides, the kick could bring uncontrolled volumes of formation fluid up to the surface, which will contaminate the environment around the rig site.

In the event of the lost circulation, there will not be a high risk to the crews' lives and surface environment.

***The author's assessment is High probability and Major consequence***

b. Time delay and economical outcomes are:

If the drillstring disconnects, the kick or the lost circulation will have significant effects on additional operation time which will impact on the cost.

Since the well control technology quite advances now, we could detect the kick faster or solve it safer. However a kick may not so severe, but an extreme kick is a blowout which will indeed lead to a long time delay.

The lost circulation needs time to be solved. One has to stop the whole operation and make a new fluid which will add to a lot of time delay. Besides, the fluid which is lost into the formation will increase the operational cost.

***The author's assessment is High probability and Severe consequence.***

2. The casing is very low on the collapse rating. Tendency to collapse is high especially when the formation pressure is high and the pipe is on tension. The impact on:

a. Health, Safety and Environment (HSE) are:

If collapse happens, the casing will reduce in size (the inside diameter gets smaller). It prevents the next string of casing to be run. Therefore the operation may have to be stopped. If there is no leaking, the pressure will be in a static condition. The safety and the environment will be ensured.

However if there is a leak, lost circulation or kick could happen. The risk could be significant. However from a collapse to the leak phase, it is a progressive process therefore it will be detected and handled earlier. Barriers will be activated to prevent the blow out.

***The author's assessment is Probable and Significant consequence.***

b. Time delay and economical outcomes are:

If collapse occurs, the casing ID will significantly reduce in size (its inside diameter gets smaller). To be able to run the next casing or drillpipe, further analysis should be conducted. We may run a log to map the ID geometry; we also may run a mill to make the size uniform. Many alternative operations could be studied before the final decision to continue or abandon is chosen. However the major impact, it will bring a lot of time delay which will increase the operational cost.

***The author's assessment is Probable and Severe consequence.***

For additional information, this assessment is a subjective quotation. If the assessments are plotted in the risk matrix, it will show as below. The risk matrix has consequences on its axis and probability on its coordinate (figure 3.21).

| ***Risk analysis*** | ***Consequences*** | | | | |
|---|---|---|---|---|---|
| ***Probability*** | Minor | Significant | Severe | Major | Catastrophic |
| Very high Probability | | | | | |
| High Probability | | | 1.b | 1.a | |
| Probable | | 2.a | 2.b | | |
| Less Probable | | | | | |
| Very low Probable | | | | | |

ACCEPTABLE SHOULD BE IMPROVED UNACCEPTABLE

**Figure 3.21-Risk matrix for combined method**

Based on our analysis of combined method limitations and risks we can conclude as shown below.

***Result:***

There are a lot of technical limitations and risks of drilling with expandable casing especially due to the fact that expandable casing has low post-expansion material properties and its connection has low limitation on the torsion ratings. However a good engineering approach and improvements in technology can hopefully overcome these limitations and risks.

## CHAPTER IV
## DISCUSSION

Here we will discuss our analysis from chapter 3. To simplify, before the discussion we will refresh the results from our analysis on each sub-chapter. This chapter will present the challenge, proposed solution or discussion.

### 4.1 DISCUSSION OF THE DRILLING – EXPANSION METHODOLOGY

| ***Challenge: How can this combined method works?*** |
| --- |
| ***Result:***<br>• Conceptually with present technology, drilling with expandable casing is possible.<br>• Since we do not need to mill out the cement and clean the inside wall interface of casing, the bottom to top expansion is recommended for drilling with expandable casing method. |

***Discussion***

<u>**Discussion 1:** Conceptually with present technology, drilling with expandable casing is possible.</u>

We first use drilling with casing system, which is provided by Tesco Corp, the expandable casing is used as the drillstring for transmitting the drilling forces. The expandable casing could be provided by Enventure or Weatherford, depending on which expansion method we are going to use.

The drilling with casing could use non-retrievable or retrievable bottom hole assembly. For example, if we use:

- Non-retrievable BHA with drillable bit.
  When the drill bit reached the expected depth, drop a ball to stop the circulation, pump the cement and pressurize the cylinder to shear the bit. After the bit is sheared, with annulus remaining open, run the "modified" expandable casing BHA to the casing shoe

and start expansion from bottom to top. Modified expandable BHA supposedly has an expandable cone and uses the same expansion method. The chamber for the cone to expand should be provided and can be attached to the open cylinder annulus.

- Non-retrievable BHA with non-drillable bit

  When the drill bit reaches the expected depth, disconnect and drop the bit using wireline. The bit will fall into the rat hole that had been previously drilled. With open annulus remaining open, then we run the “modified” expandable casing BHA to the casing shoe and start expansion from bottom to top. On the next drilling operation, the bit should be steered to avoid the rat hole.

- Retrievable BHA and bit

  When the drill bit reaches the expected depth, run the wireline to retrieve the BHA and bit. When the wireline retrievable pin sits on the wireline retrievable box and latch, we can disconnect the bit and BHA from the drillstring. By tripping out the wireline we can receive our bit. On the casing shoe that remains an open annulus, then we run the “modified” expandable casing BHA to the casing shoe and start expansion from bottom to top.

If we would like to use top to bottom expansion, after the drill bit reached the expected depth, drop the ball to stop the circulation, pump the cement and pressurize the cylinder to shear the bit. After the bit is sheared, remaining with the drilling assembly, we then run mill bit, brush and scraper to clean the inside interface wall of expandable casing. After this requirement is met, we continue to drop the plug to close the open annulus. Then the Modified Baker or Weatherford top-bottom expansion cone can be run to expand the casing.

There is an additional conceptual plan that combines drilling and expanding bottom hole assembly into one package drilling-expanding BHA. The purpose of installing this BHA is to reduce additional operation for changing the BHA. The BHA conceptually might look like the expandable BHA attached on the top of drilling BHA. When the drilling reaches the expected depth we drop a ball to close the annulus in the bit. Then we can start the expansion process from bottom to top (Enventure or Weatherford). Then the remaining drilling BHA can be handled many different ways depending on whether a retrievable or non-retrievable system had been used. This combined BHA can reduce the wireline tripping or BHA changing times. In other word, it can save costs due to operation and rig times. However the reliability of expansion assembly after being used for drilling operation should be studied further. The conceptual design presented on above just shown as the overview to convince that there are technical possibilities to combine both methods. Additional each technology is discussed below:

**Drilling with casing Technology**

Tesco is a company that specializes in drilling with casing technology. Besides having drilled a test well with 29,000 ft, they have drilled 125 commercial wells. Figure 4.1 shows the Tesco drilling footage activities. In this figure you can see there is a significant increase in the drilling depth using casing. Besides providing drilling with casing services, Tesco and Weatherford also provide drilling with casing rig and support equipment.

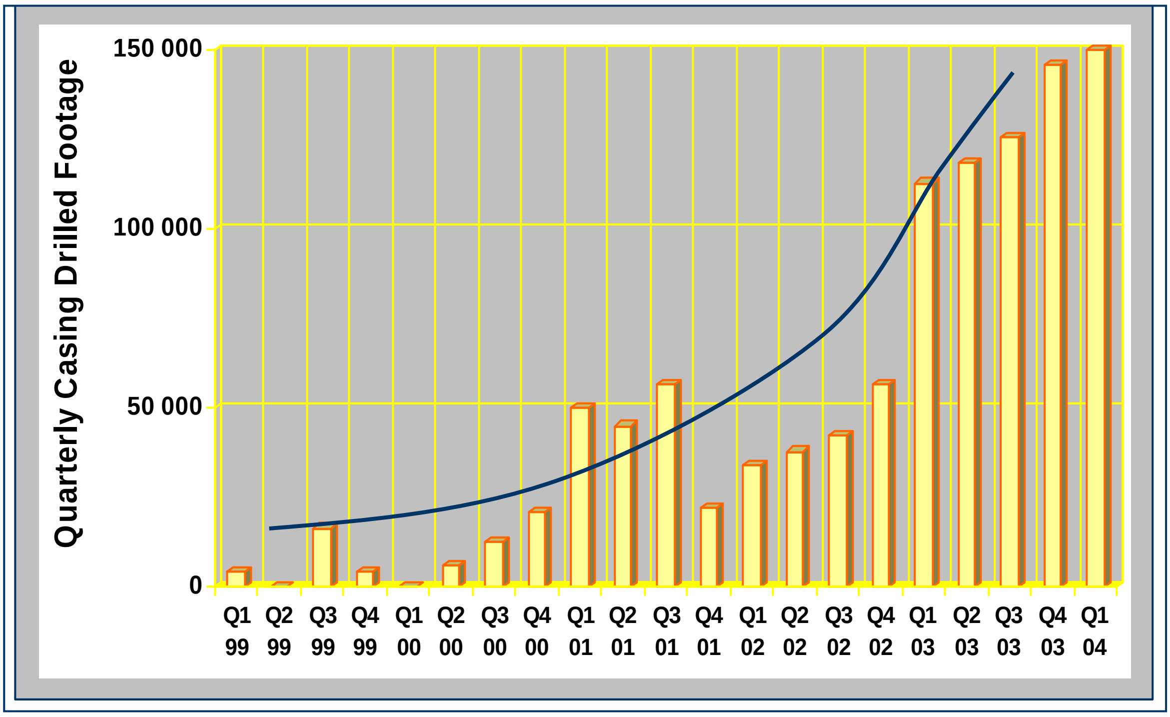



**Figure 4.1-Casing drilling footage [14]**

Drilling with casing justification:

- Faster process
- Reduces trouble time
- Increased reserves
  - More wells
  - Better production rate
- Integrated rig solution

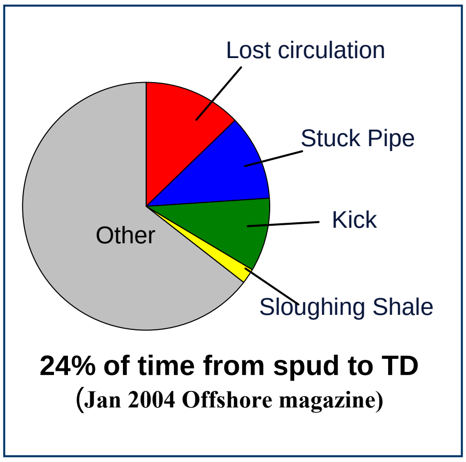



**Figure 4.2-Comparison of trouble zone on DwC [14]**

In some cases it is difficult to run the casing after the conventional drillstring is tripped out because of poor borehole quality. Some of these difficulties can be reduced by using casing for drilling. There is no full explanation for this, but the well stability could be improved with casing drilling operations. Not knowing about the smear effect at the time, during DwC operation, the operator raised the mud weight as needed on the first few wells and noted that they could TD a hole section with ½ to 1 ppg less mud weight without experiencing the losses they had worried about. It is predicted that this happened because they drilled with the bigger OD and therefore they had bigger surface area between rock and the metal. Figure 4.3 shows the smear effect. Below the Smear effect experiment and analysis by drilling with casing experts is presented. (*Source information: World oil conference for DwC*) [13]

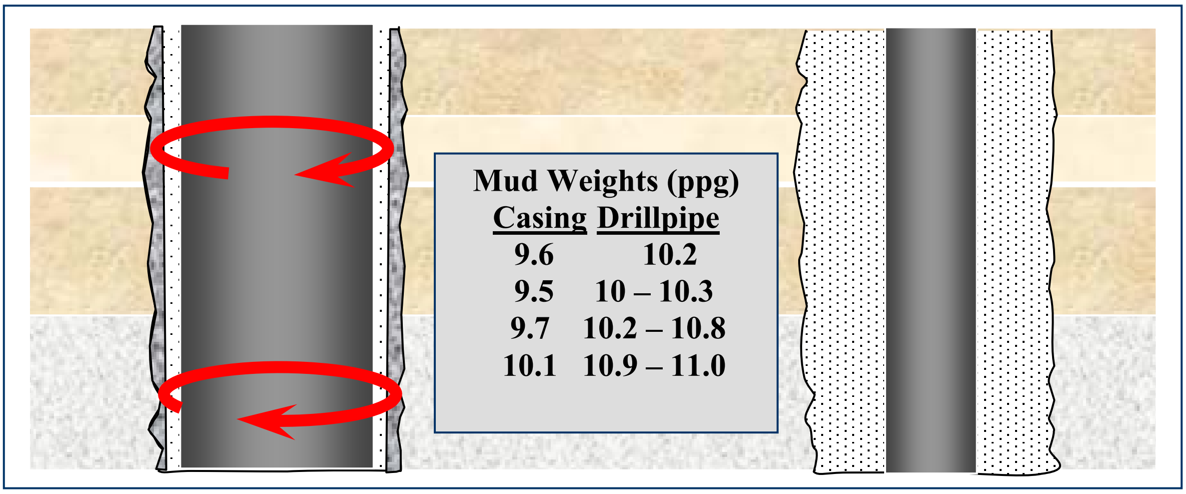



**Figure 4.3-Smear effect profiles** [13]

They also noted the difference in the cuttings that came from the well (figure 4.4) compared with conventional drilling. The time they hypothesized that they were smearing or plastering


**Figure 4.4-Cutting comparison between DwC and conventional drilling** [13]

the wellbore wall with cuttings and creating a super touch filter super impermeable filter cake. This phenomenon is termed the smear effect.

They tested this theory by drilling a well in an area near three wellbores which had all suffered from severe lost returns problems. Two of the wells required not only cement plugs to stop the losses but eventually a liner as well. The third well was stuck and sidetracked due to open hole problems including losses. The casing drilling well was drilled in the middle of these three wells and did not experience any losses or stuck pipe trouble.

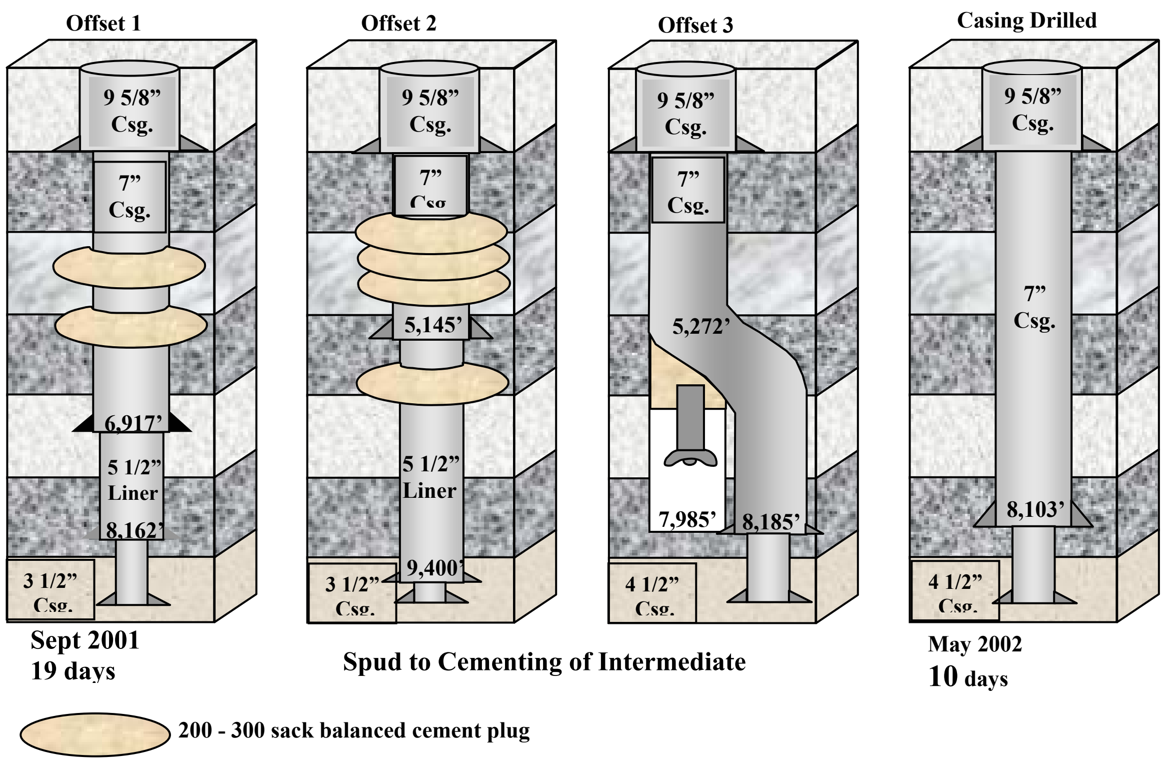



**Figure 4.5-Smear effect experiment on testing wells [13]**

Following this success they moved to a well that had been conventionally drilled with severe losses. After three attempts to stop the losses with cement plugs the well was abandoned. They moved one of the casing drilling rigs on to this wellhead and successfully drilled the well down with little trouble.

They did have losses when they reamed out the cement plugs however after drilling 100 ft of new hole the losses slowed significantly and were minimal after 500 feet. This proved that the smear effect did indeed exist and was extremely beneficial in preventing losses in weak or fractured formation.

They really wanted to understand this phenomenon and embarked on several study paths. They wanted to understand if this event was damaging the formation or was it preventing damage by limiting the amount of filtrate that entered the pores. They cored both conventional wells and casing drilling wells in some of the middle Wilcox sands and compared the cores, if there was a difference in the core damage or invasion depth it was too small to denote. Not seeing the expected difference here they turned their attention to the mud and solids in the system.

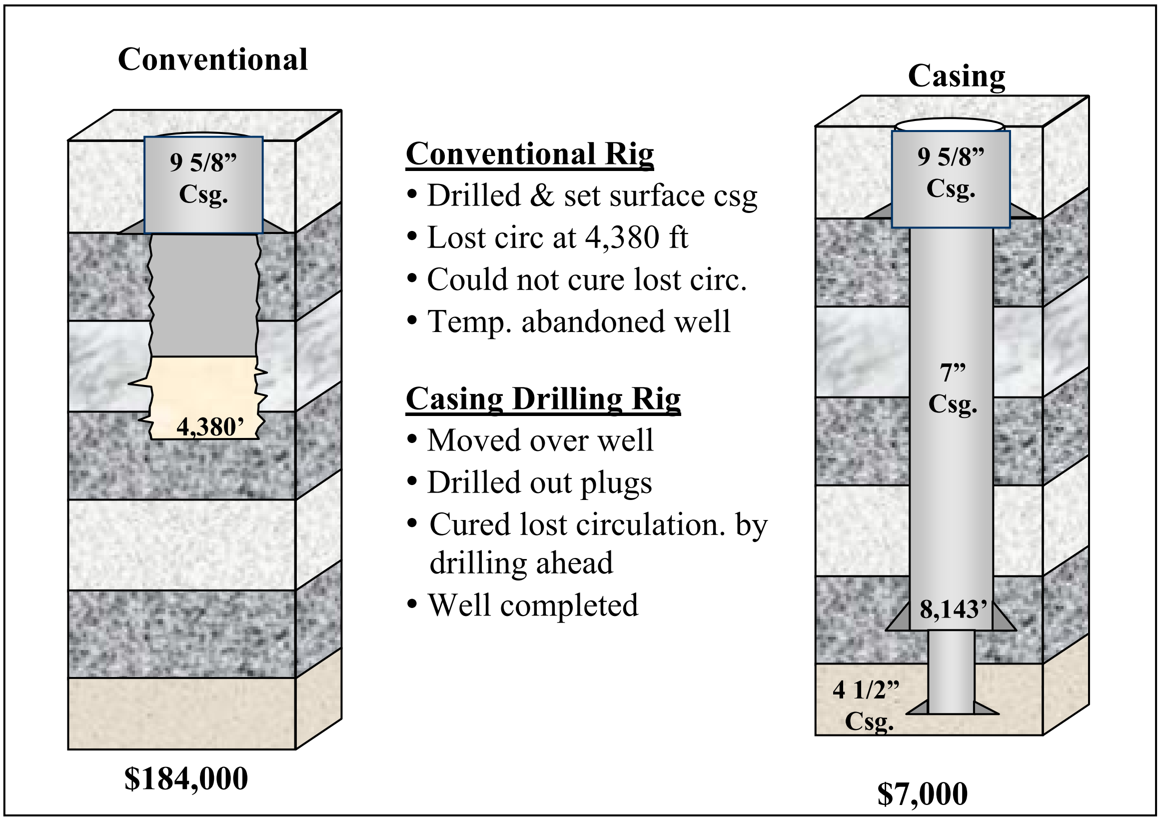



**Figure 4.6-Comparison between DwC and conventional drilling based on drill test [13]**

It should also be noted that the cost for casing drilling operations were less than conventional drilling. See figure 4.6 to compare the cost.

**Expandable technology [6]**

In open hole applications, Enventure is the only field proven technology at this time according to Chevron expandable expert (REF). However, on cased hole applications, Baker and Weatherford may be a better alternative. On a cased hole application, Baker is available for 5 ½”, 7”, and 7 5/8” base casing repairs only. The Weatherford system is only available for 6 5/8” and 7” (9 5/8” also designed). There are no price lists. Each job is priced by the Business Development group for the company involved. This service is expensive –The pipe is listed in the range of $150 - 200 / foot on the quotes.

Weatherford and Baker have re-usable tools which means they could be cheaper and do not require drilling out at the end of the expansion. Enventure does a pressure test on the liner as it is placed, but the aluminum shoe must be drilled out at the end of the expansion with a full gauge bit or mill. The wall thickness on most Enventure pipe is ± 0.375” where Baker uses ± 0.25” wall. Clearance and strength vary accordingly. The Weatherford rotary technique uses a metal-to-metal contact which can cause variation in wall thickness. Burst and collapse properties of the patch are enhanced by the base pipe. Burst can be calculated and estimated, but collapse if critical may require testing.

The Baker and Weatherford tools are “compliant” and will pass through a restriction in the casing. The Enventure tool is solid and will assure a full gauge, round hole. The Enventure system will not tolerate any debris between the patch and the base casing.

The top down expansion systems of Baker and Weatherford allow easy access and replacement of the expansion mandrel, if a problem occurs. The bottom up Enventure system requires backing out of the safety joint, pulling the inner drill pipe string, cutting and recovering the unexpanded patch, and finally, recovering the solid mandrel. The lower section of expanded patch must then be milled up unless there is room to start again above that point.

The correct system to be used in a cased hole operation will depend on the specific objectives of the application (pressure integrity, clearance, cost, size, operability, availability, deliverability, etc.). All three systems should be evaluated.

The generic cost estimate for a short 40' patch for 5 ½" casing from Baker is approximately $44,000. This estimate shows that the costs are very reasonable. This could be a solution to shallow casing leaks where squeezes are often repeated without success. The cost is lower because of the re-useable expansion tools. An additional benefit is that no drill out would be required after expansion. However, note that the cost for additional length is between $150 and $175 per foot.

The Weatherford rotary system and the Baker drill pipe piston system do not require drill out like the Enventure pressure expansion system does. The expansion tools are also re-useable unlike the Enventure fixed cone. The Weatherford rotary system is dependant on bearing life which is 300 ft. Sizes are also very limited for Baker and Weatherford.

Weatherford has also obtained the patent right to solid cone pressure expansion from Shell but they do not have a commercial product at this time. They also offer the original Homco patch and own that technology as well. Weatherford is in the development stage on multiple SET concepts.

An industry SET users group was formed in April of 2003 in Houston. The group was organized by Unocal with strong BP support. Early in 2004 several service companies sponsored an industry survey of the operators to evaluate the potential market demand for expandable tubular products. The Rock Mechanic consulting group conducted the survey and shared the results with those that participated. The survey is an objective, non-technical, optimistic view of the expandable market. Some of the study conclusions were:

- The very high reliability of expandable sand screens and solid expandable tubular technology
- That the future of Slim Well-type wells is finally here (i.e. the use of multiple expendables to reduce or slim the casing profile of a well
- That the future of monodiameter wells is soon.

In this business, there are many things involved such as patent right, economy strategy and companies political issues. Regarding the industry overview showed above, to be able to apply drilling and expanding method, we will study the application of the conceptual example using industry practice. Here we present our conceptual plan application using industry technology.

**Discussion 2 :** Since we do not need to mill out the cement and clean the inside wall interface of casing, the bottom to top expansion is recommended for drilling with the expandable casing method.

The top-bottom expansion method needs to mill out the cement before running expansion operation. In the expansion process the debris on the inside wall cannot be tolerated. The cement and swarf exist in the ID of casing can risk the expansion process therefore this method is not recommended. The well cleaning operation should be done and will add to the operation and rig time. Technically it can be done but has more challenges than the bottom-top method. In addition, if we recall the 3D collapse pressure equation, it shows that the top-bottom expansion can also reduce the collapse rating slightly after the expansion.

For 3 dimension stress (tri-axial stress) formula by Bernt Aadnøy [7]

$$P_{collape} = \frac{Pi(2\beta - 1) - \sigma z + \sqrt{4\sigma y^2 - 3(Pi + \sigma z)^2}}{2\beta}$$

$$where \quad \beta = \frac{\left(\frac{do}{t}\right)^2}{2\left(\left(\frac{do}{t}\right) - 1\right)}$$

Where σy = limit of yield stress

σz = axial stress

Pi = inside pressure

do = outside diameter

t = wall thickness

The expansion from top-bottom will increase the axial stress (σz) and have low internal pressure below the cone that will reduce collapse pressure slightly post expansion. On this phase a moment after expansion, the material is still in stable condition and the reduce stress (hoop stress) still remains on the casing. This hoop stress can govern the collapse of the casing a moment after expansion cone passes through it.

## 4.2 DISCUSSION OF THE CASING CONNECTIONS

| ***Challenge: Are the expandable casing connections strong enough for DwC?*** |
|---|
| ***Results:*** The torque limit of market connections for expandable casing available in the market is not strong enough for drilling operations. The torque rating is the most critical properties for expandable connections. Improvements and modifications should be made to meet the drilling purposes. Each type of connection and well profile will show a different result. Therefore, engineering approach for design should be carried out for each specific case. |

***Discussion***

The author explored the possible flush joint connections in the market today from different vendors. The connection properties that are provided by Enventure this is a connection for 9 ⅝" XPC #36 (36 lbs/ft), flush joint type connection.

For comparison the author will list a connection with the same specification that shows stronger properties. Hydril provides this connection for conventional drilling. From table 4.1, obviously we can see that the Hydril connection is stronger than the Enventure connections. There is a large reduction in the casing connection strength after being used in drilling. Therefore in anticipation of failure, the stronger connection is always preferred and also has wider operation limitations. The development for expandable connection is in progress; industries have seen this limitation and have spend a lot of money for research and development to overcome the challenges. Below are the properties of both connections.

**Table 4.1–Comparison Enventure and Hydril connection** [16]

| **9 ⅝ XPC #36, N-80 flush joint (Enventure)** | | **9 ⅝ 511 #36, N-80, flush joint (Hydril)** | | **comparison** |
|---|---|---|---|---|
| • Connection joint strength | 533,900 lbf | • Connection joint strength | 684,000 lbf | 1.28 x stronger |
| • Compressive load rating | 427,100 lbf | • Compressive load rating | 686,000 lbf | 1.60 x stronger |
| • Min parting load | 634,000 lbf | • Min parting load | 684,100 lbf | 1.08 x stronger |
| • Max pure bend rating | $19{,}8^0/100$ ft | • Max pure bend rating | $26^0/100$ ft | 1.32 x stronger |
| • Torque | | • Torque | | |
| Mimimum final torque | 2500 ft.lbf | Mimimum final torque | 9200 ft.lbf | 3.68 x stronger |
| Optimum final torque | 2800 ft.lbf | Optimum final torque | 11,000 ft.lbf | 3.93 x stronger |
| Maximum final torque | 3100 ft.lbf | Maximum final torque | - N/A - | - N/A - |
| Maximum Yield torque | 6200 ft.lbf | Maximum Yield torque | 88,000 ft lbf | 14.2 x stronger |

The criteria for connection properties to assure the successful operation are:

- Make up torque of connection must be bigger than torsion in drilling operation
- Connection joint strength must be higher than tension or hook load in drilling operation.
- Compressive load rating must be bigger than string weight in the mud.
- Maximum bending rating must be bigger than the dogleg in well profile.

The connector provides discontinuities that may be the weakest point for fatigue. The main fatigue in connection is because the casing connector geometry may create stress riser where local stresses are higher than expected. Alternating stress is higher in the connection than the body which means the connection is weaker.

When the connector is made up on the surface, the torque is acting through the threads to produce a screw jack effect. This effect places compression on the torque shoulder and high tension in the coupling wall. The magnitude of this tensile stress depends on the make up torque, the thread design, coupling wall thickness, joint compound friction coefficient and the amount of interference from the thread. The fatigue life and ultimate torque rating must be balanced.

Expandable joint yield torque is approximately 93 % lower than usual casing connection. In other words, the expandable connection is 14 times weaker than usual connections. This property is unacceptable for drilling operation. It is not strong enough on torsion for drilling operation as proved in the chapter three.

Since it is stronger, the Hydrill connection could be used for expandable and DwC applications. However, according to the expandable designer and developer for Weatherford, modification of Hydril 511 connection should be made. The groove should be cut and an elastomer that allows the connection to seal during expansion and post-expansion process needs to be added. It should be kept in mind that the stronger connection needs more lateral expansion force to be able to expand properly.

We also can use bottom hole motor; so the upper string doesn't suffer from big torsion. The rotation in the upper string is for hole cleaning purposes. Below the industry updates about casing connection technology are shown in order to show that improvements are on going and show promising results.

Additional information 1 [8]

A paper was presented this year about Connection Qualification for casing-Drilling application (SPE/IADC 105432). In this paper they presented the method for testing and inspecting the connection of 9 5/8”, 53.5lb, P-110 DWC/C-SR connection.

This coupled connection utilizes a thread seal and resilient seal ring to enhance the pressure containability (see figure 4.1). The design employs an API buttress thread with abutting pin noses as the torque shoulder to improve the torque capacity and fatigue performance. Depending on application, there are two options for the seal rings (100% virgin Teflon or 25% glass filled Teflon). The glass filled version was used for this project.

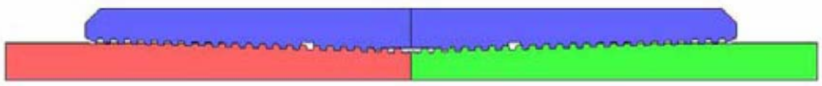


**Figure 4-1 DWC/C-SR connection**

The result of this test confirms that the connection has passed the test without leaking or mechanical failure. The test for qualification is accepted. Chevron and Grantprideco cooperated together on this project. In the future this qualification tests should be run for the modified connection for DwC and expandable purposes, such as a modified Hydril 511 connection.

Additional information 2 [4]

Here is the updated information from the service company about the Join Industry Project (JIP) coordinates by Noble. This project is focusing on technologies exchange between services companies and also field testing in Houston. One of the purposes is to test and modify the Hydril’s connection that has also included as a participant of JIP.

Hydril’s task is to cut 723 expandable wedge threads at its normal premium thread prices. Hydril will provide these connections at its normal premium connection prices and will assist in running the expandable casing in the field to ensure that the threaded connections are inspected and run properly.

Problems with existing weak connections are:

1. Major cause of solid expandable failures
2. Limit ability to expand strong casing (P110)
3. Limit amount that casing can be expanded
4. Reduce burst and collapse strength
5. Pull apart during expansion
6. Require special “drawn-over-mandrel” casing
7. Cannot tolerate casing “dings” and blemishes
8. Require outer sleeve reinforcement
9. Thread leakage prevents expansion
10. Prevent expanding Monobore overlaps in one step

Hydril 723 Expandable Wedge Thread is:

1. Stronger threads critical to SET success
2. Hydril 723 wedge thread 30 to 60% stronger
3. Wedge design holds threads together during expansion
4. Use off-the-shelf casing with normal “dings” and defects
5. Eliminates special handling of casing
6. Increases reliability & reduces cost
7. Gives Noble a major competitive advantage

Kind of Hydril 723 Expandable Wedge Thread testing

New or modified expandable tools and new threaded connectors will be tested at TIW’s Houston facility prior to being run in Participant monobore wells. These tests will be conducted in TIW’s test frame pump facility, test laboratory and shallow test well in Houston. These tests will include:

1. Cone force measurements
2. Threaded connection tests
3. Burst and collapse tests
4. Pumping tests
5. Shallow well tests
6. Monobore overlap expansion tests
7. Liner hanger tests
8. Packer expansion tests

The conclusion of JIP is confidential to the sponsor and service companies. All intellectual property (IP) developed during this JIP will belong to the companies that develop it (e.g., Noble Drilling, TIW, Hydril, TAM, Smith International, Houston Engineers, CSI Technologies, CCSI, etc.) since these service companies are paying for the development of the tools used on this project and need to own the IP to successfully market their tools and services.

No IP rights will be granted to JIP Participants since Participants will receive their benefit from this JIP by using ET wells in their fields to reduce drilling costs and having first call on the use of Noble's ET tools for two years after Phase I is completed.

Both industry examples show the high-torque and no leaking due to expansion connection research and development is still on going. The development shows promising result for further operations.

## 4.3 DISCUSSION OF THE EXPANSION PERFORMANCE POST-DRILLING

***Challenge : How does the expandable casing perform after being used for drilling?***

***Result :***

Expandable casing could become de-rated post the drilling operations. Therefore, there are some drilling considerations:

- To assure we have a clean interface on the inside wall of the casing we should do a cleaning operation before the expansion process. To assure we have a uniform inside diameter, a mill should be installed on the drillstring during the cleaning operation.
- To avoid exceeding torsion on the expandable casing connectors due to tortuosity and dogleg, stabilizers should be installed.
- To minimize the whirl that can lead to the connection becoming fatigued, we should use a better lubricator and drill with low RPM, alternatively high RPM using a mud motor.

***Discussion:***

**Discussion 1**: To assure we have a clean interface on the inside wall of the casing we should do a cleaning operation before the expansion process. To assure we have a uniform inside diameter, a mill should be installed on the drillstring during the cleaning operation.

Based on the dynamics of the well debris can stay in the bottom of hole, in the drillstring wall and suspended in drilling fluid in annulus. Debris can be classified as "Solid", "Gunk" or "Junk": [19]

- Solids includes
  - Mill scale rust from poorly prepared tubular
  - Swarf from milling operation
  - Solid fallout from drilling fluids e.g. Barite
  - Cutting formation and cement
- Gunk includes
  - Viscous drilling fluid such as synthetic mud at low temperature
  - Gelling of OBM on contact with water
  - Thread compound (pipe drop)
- Junk includes
  - Materials generated during cement plug or float equipment drill out
  - Metal generated after float or completion equipment drill out
  - Elastomers/seal remain after milling as packer
  - Debris by product of perforation operation
  - Any other foreign material introduced from surface

Source of debris [19]

- Drill pipe & casing wear due to tripping in & out of hole
- P&A plugs (cement & drillable packers)
- Tie-back float equipment (wiper plug, collar & cement)
- Failure to bump the plug while cementing (cement, wiper plugs)
- Unconditioned mud (barite/solids fall-out due to poor/reduced suspension properties)
- Surface equipment (drill floor, hydraulics & hoisting systems)
- Mud emulsions
- Any tool run through the rotary
- Miscellaneous unknown

Determination of Well Cleanliness

- Nephelometric Turbidity Units (NTU)

  The determination of well cleanliness is usually based on the cleanliness of fluid returning from the wellbore. The most common measures are Nephelometric Turbidity Units (NTU) and solids content. The higher the NTU number, the lower the well cleanness. Usually if the NTU < 100 the well is defined as a clean well, however this is also depend on company demand.
- Drag and Toque (additional)

  Other indicators of a clean well are torque and drag (related to the friction coefficient of fluid coating the casing walls) and cleanliness of the string when was pulled back.

Mechanical Wellbore Cleaning Tools

Basically, based on the working method and which debris are being cleaned, we can group the tools into:

- Casing scrapers to remove cement and casing burrs
- Casing brushes to remove gunk, cement and scale
- Magnetic tools to retrieve ferrous debris

Best wellbore cleaning conditions are:

- High annular velocity

  The higher the annular velocity, the cleaner the well will be. In a highly deviated well, flow rate is the most critical parameter affecting hole cleaning efficiency. An increase in annular velocity improves hole cleaning, regardless of the flow regime. Therefore, we need a circulating device to boost the low annular velocity.
- Turbulent flow

  Turbulent flow is a chaotic flow characterised by intense mixing caused by eddies. Turbulence is deliberately initiated to help displace the mud cake from the walls to the hole.
- Good concentric flow profile

  The best carrying capacity is produced when the drillpipe is concentric within the annulus. This provides a uniform annular profile throughout the annular cross section. In horizontal wells the concentric profile can be achieved by introducing a stabilizer. As additional information the casing scraper can also acts as a stabilizer.

- Mud Rheology

  The relationships between mud rheology and hole cleaning vary, depending on the annular flow regime. Viscosity provides the mechanism by which fluid energy is transferred to the cutting. Gel strength also provides suspension under static conditions, such as when the flow stops due to the pumps being turned off.

Therefore to assure the casing inside diameter is clean and uniform before expansion operation, it is recommended for the well cleaning operation to be run before the expansion process. The debris can be accumulated on the inside wall of the casing when casing is used for drilling operation. Mud, cement, chemicals substances and fluids are circulated through the inside of the casing. All of these effects should be taken into account. We do not want to take a risk of casing failure or casing leak during the expansion process. Any cement junk and swarf that stacked on the wall and scar on the interface of the wall could jeopardize the expansion process. The cone could be stuck and cannot pull out of hole or the wall could not expand properly due to un-uniform diameter size.

**Discussion 2:** <u>To avoid exceeding torsion on the expandable casing connectors due to tortuosity and dogleg, stabilizers should be installed.</u>

Drillstring fatigue failures generally result from oscillating bending stress rather than axial or torsional loads. Fatigue is predominantly located in the lower portion of the drillstring, rather than the top where the static point is highest. In many cases, fatigue crack will result in a leak before the final rupture. The majority of wash outs that are found in drillstring are actually caused by the fatigue cracks. In order to fatigue, the part must be exposed to an alternating tensile stress. There are 2 common sources of cyclical tensile stresses, Bending stress that result from rotating the pipe and the vibration.

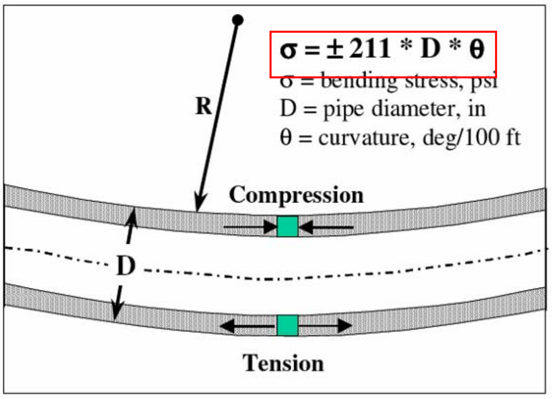



**Figure 4.8-Bending stress from pipe curvature** [2]

When the pipe is elastically deflected, the outside is tension and the inside is compression. Since the wall thickness is thin, the entire wall will suffer the same stresses. The outer fiber will be stressed slightly more than the inside (see figure 4.8).

The magnitude of the alternating bending stress is proportional to the pipe diameter and dogleg severity. This dictates that the larger casing must be limited to smaller curvature in order to prevent fatigue failures.

The bending will lead to the cone not giving uniform lateral expansion force. This effect results in the post expansion casing having an eclipse shape rather than a smooth circular shape. The eclipse shape of the post expansion casing will make the casing easier to collapse. The example of this case is on coiled tubing drilling, where it easy to collapse due to its eclipse shape.

To solve and reduce the bending stress we could do:

- Put more stabilizers on the casing, therefore the avoiding pipe body from big dogleg
- Increase the care of the pipe handling

This stress concentration factor is multiplied by the bending stress to obtain the alternating stress*) for fatigue life calculation. The higher the alternating stress, the lower the casing strength. The magnitude of the alternating bending stress is proportional to the pipe diameter and dog-leg severity. This dictates that the larger casing must be limited to smaller curvature in order to prevent fatigue failures. If curvature and the outside diameter are big the alternating stress will increase. In addition, the casing is subjected to axial stresses from the hanging weight and from internal pressure that can increase the mean stress level and also reduce the alternating stress 20-30% or more.

The maximum allowable operating stress for CwD situation depends on the number of the alternating stress cycles expected. The casing is likely to be subjected to a higher alternating stress than drillpipe in drilling the same hole size and inclination. This means the casing maximum allowable operating stress is higher than drillpipe. An example of alternating stress relationship with dogleg can be seen in figure 4.9.

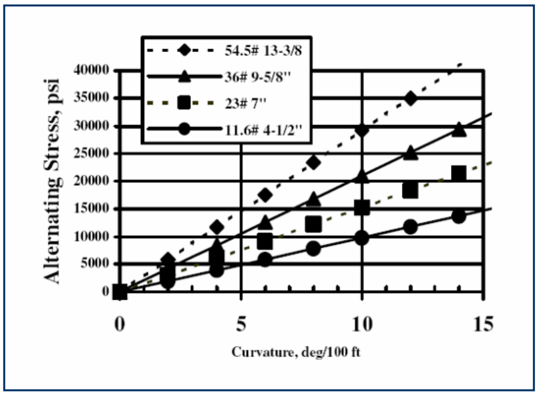



**Figure 4.9-Alternating stress for curve drillstring [2]**

The bigger the OD of casing the bigger the alternating stress worked on the same dogleg angle.

*Alternating stress: A stress produced in a material by forces that are such that each force alternately acts in opposite directions.*

**Discussion 3**: <u>To minimize the whirl that can lead to the connection becoming fatigued, we should use a better lubricator and drill with low RPM, alternatively high RPM using a mud motor.</u>

Fatigue failures are caused by cyclical loading at stresses well below the elastic strength of the part. Under repeated loading, a crack develops 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 friction factor used is generally assumed to be independent of velocity and the rotating torque (whirl) should be independent of rotary speed. Differences between DwC and conventional drilling are in average weight and diameter. Casing is much heavier than drill string with almost the same properties. Casing coupling is also bigger than DP tool joints. High inclination makes the torque and drag bigger.

Generally the curved section high in the well contributes more to torque and drag than the same curvature located deeper in the well. Tension is maximal in the vertical section and drag is maximal in the horizontal section. Therefore when drilling with casing, the casing OD is bigger, the OH is smaller and the RPM is high. Those are the best combination for whirl to occur.

The main points relating to casing whirl are listed below:

- Torque that increases when the rotary speed increases is often indicative of whirl
- Torque that remains high when the bit is picked up off bottom (at constant RPM) but returns to normal when the RPM is reduced to zero and restarted is proof of whirl
- Threshold WOB and rpm to initiate drillstring whirl
- Whirl can be reduced by reducing the RPM and WOB
- Whirl tends to happen when drilled through hard formation and abrasive
- Drillstring whirl is sometimes associated with buckling
- Whirl may also associate with lateral resonant frequencies; RPM should not pass the limit of this frequency
- Whirl is more likely in poor lubrication fluid
- Centralizer can increase the whirl if it is not smooth
- Design of Bit also can initiate whirl

- The tendency of whirl is happen when drilled the cement and damaging PDC cutter
- Accumulation of cutting can initiated whirl
- The torque measured with a hydraulic top drive should be corrected for fluid friction effect before using it to monitor the whirl

It is important that the casing is protected from slip and tong marking during handling and making up. A small mark would have a significant influence in the casing stress rate. Figure 4.10 shows the stress concentration factor reported for a die-mark on drillstring reported by Hossain (presenter of "Fatigue life Evaluation" IADC/SPE paper).[3]

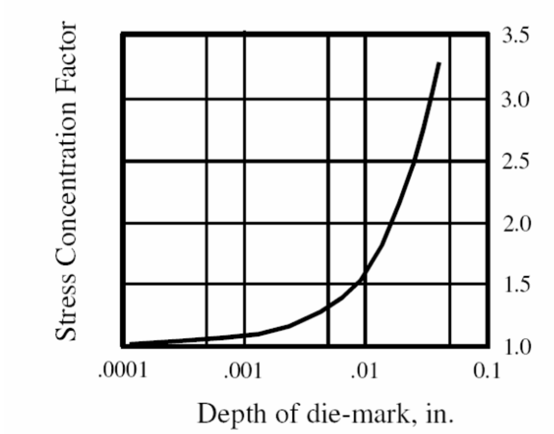



**Figure 4.10-Axial stress concentration factor for die [2]**

Monitoring the rotary speed may be more critical with DwC. Fatigue is direct accumulation of stress cycles from rotating. When not drilling, the rotating speed should be minimal. While drilling, the rotary speed should be no higher than a linear increase in the penetration rate. However material technology has improved, therefore in the coming year there may be a more friendly solution for pipe handling and material resistance to the stress.

Concluded from this discussion, we have to keep the torque in DwC as low as possible due to torsion limitation of connection properties. High torque caused by high dogleg and high alternating stress should be eliminated. The ways to eliminate those effects are to:

- Install an appropriate number of stabilizers on the drill string
- Use mud with good lubrication properties
- Use a drill motor to avoid high torsion on the drillstring
- The casing should be handled carefully to avoid a mark which can reduce the casing stress rate.

# 4.4 DISCUSSION OF THE CASING PROPERTIES POST-EXPANSION

| *Challenge: What are the expandable casing properties that need to be considered?* |
|---|
| ***Results:*** The post expansion casing has a lower collapse rating. This effect should be our main consideration. |

***Discussion***:

In the discussion the author will show a Chevron case study. In this case, the risk of running expandable casing is shown using Erskine field. The current success ratio for commercial applications is shown as 93% by Enventure. A detailed review of ChevronTexaco (CVX) applications shows a much lower probability of success. The CVX data yields success rates in the range of 30% to 66% depending on the application and the definition of "success" [6]. Here we will try to calculate the collapse and burst rating of the expandable liner due to completion.

***Analysis:*** [1]

Example:

The design parameters are as follows:

| | |
|---|---|
| Depth of casing | : 2365 m |
| Depth of Liner | : 2625 m |
| Depth to production packer | : 2580 m |
| Depth to seabed | : 225 m |
| Depth to sea level | : 25 m |
| Depth to top of cement | : 2300 m |
| Pore pressure gradient at 2365 m | : 1.55 s.g |
| at 2640 m | : 1.50 s.g |
| Formation fluid density | : 0.76 s.g |
| Design fracture gradient | : 1.87 s.g |
| Mud density | : 1.70 s.g |
| Cement density | : 1.90 s.g |
| Completion fluid density | : 1.10 s.g |

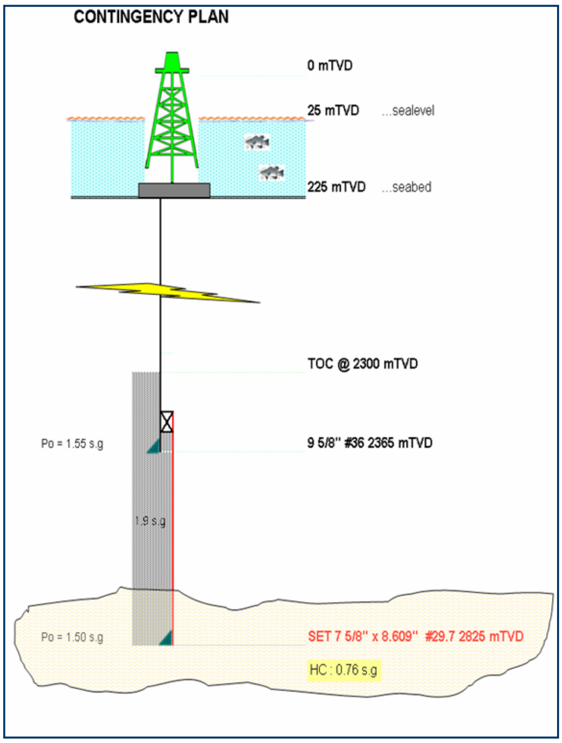



**Figure 4.11-Contingency Plan Profile**

The casing (expandable liner) data are:

<u>Pre-expansion</u>

$OD_1$ : 7.625"

$ID_1$ : 6.875"

Wall thickness ($t_1$) : 0.375"

Weight : 29.7 lbm/ft

<u>Post-expansion</u>

$OD_2$ : 8.609"

$ID_2$ : 7.900"

Wall thickness ($t_2$) : 0.3545"

Burst strength : 5940 psia = 405 bars

Collapse resistance : 2950 psia = 200 bars

<u>Case 1 – Collapse loading if the perforations get plugged</u> [1]

This post-drilling scenario assumes the formation pressure as external loading in the reservoir interval and formation fluid density inside.

The external pressure
at casing shoe is : 0.098 x 1.55 x 2365 = 359 bar
at liner shoe is : 0.098 x 1.50 x 2625 = 386 bar

The internal pressure of formation fluid
at casing shoe is : 0.098 x 0.76 x 2365 = 176 bar
at liner shoe is : 0.098 x 0.76 x 2625 = 196 bar

The resultant pressure
at casing shoe is : (359 – 176) bar = 183 bar @ 2365 mTVD
at liner shoe is : (386 – 196) bar = 190 bar @ 2625 mTVD

**) Design factor (Norsok D-010): ratio between the rated strength of the material over the estimate load*

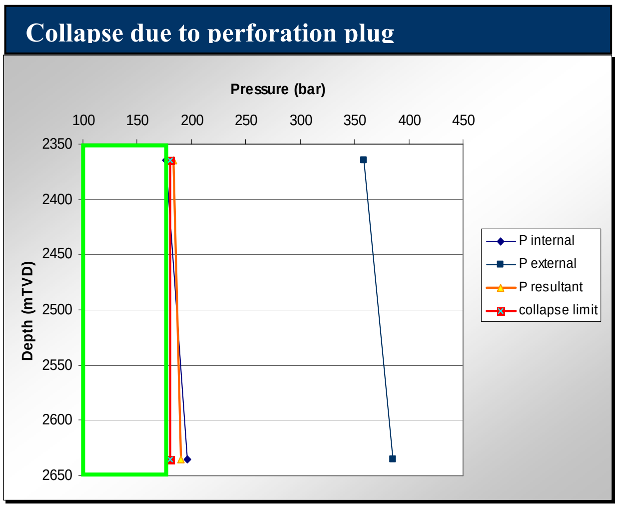



Figure 4.12 Comparison of collapse rating

Note: This calculation applies only at the reservoir level. There is no need to derate the collapse rating for biaxial stresses, as the axial load is small and the liner is cemented along its full length providing mechanical support. Also, there will be no drilling below the liner, so it is not necessary to adjust the collapse pressure for wear.

However since the liner is used for production, we have to consider 10% for corrosion. So the design factor*) using expandable casing in this case becomes (200x0.9)/190 = 0.95 (**unacceptable).**

This design factor is considered **unacceptable.** As comparison the Norwegian sector uses NORSOK D-010 as the standard,where the design factor for the collapse rating should be bigger than 1.0.

Case 2 – Burst during bull heading [1]

When pumping fluids into the formation, the perforation may plug off, resulting in a build-up of pressure across the casing wall. We assume that the production packer is set above the liner. Furthermore we assume that the bull heading fluid is formation fluid. The maximum pressure inside the liner is defined equal to the fracturing pressure of the formation behind the casing.

The internal pressure then becomes:

At casing shoe is : 0.098 x 1.87 x 2365 = 433 bar

At liner shoe is : 0.098 x 1.87 x 2625 = 481 bar

On the outside, we use the very conservative assumption that a sea water gradient exists behind the casing, giving a pressure of:

At casing shoe is : 0.098 x 1.03 x 2365 = 239 bar

At liner shoe is : 0.098 x 1.03 x 2625 = 265 bar

The resultant pressure is:

At casing shoe is : 433 – 239 = 194 bar @ 2365 mTVD

At liner shoe is : 481 – 265 = 216 bar @ 2640 mTVD

The burst rating needs to be derated 10 % for corrosion and wear of drilling process. Therefore the design factor = (405 x 0.9)/194 = 1.88 (acceptable)

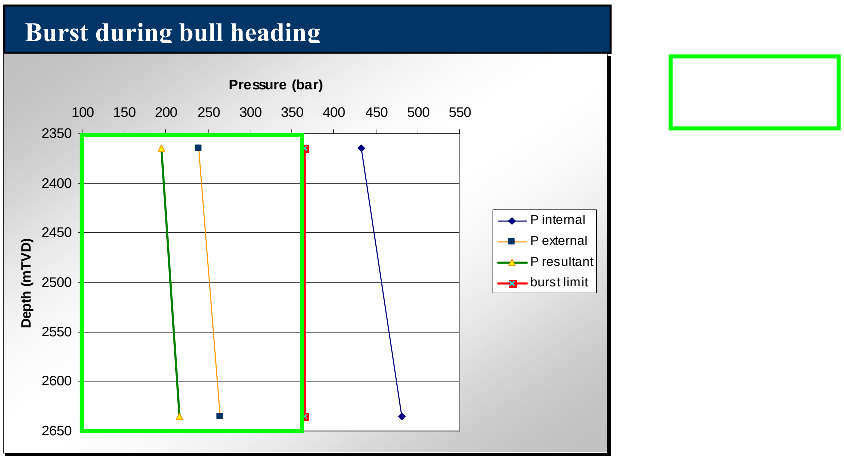



**Figure 4.13-Comparison of burst rating**

According to NORSOK D-010 the burst design is considered as **acceptable** if bigger than 1.1. So this design factor is acceptable.

<u>Case 3-Pipe tensional load design</u> [1]

The pipe body yield strength is: $P_{pipe\ yield} = \frac{405x10^5\ N/m^2}{(\pi/4(8.609^2 - 7.9^2)x0.000645)m^2} = 6.83.10^9\ N$

The pipe has very strong tensional load compare with its weight that is just 325 m (length of liner) therefore the design factor must be **acceptable**. Additional information from NORSOK the tri-axial design is acceptable if bigger than 1.25

Based on this simple well profile we could see that the collapse design does not pass the criteria (unacceptable). However, burst and tensional design is acceptable. So the expandable liner will collapse when we install completion. Different well profile will show different result. Therefore the engineering approach for design should be carried out on each case before we decide to install expandable casing.

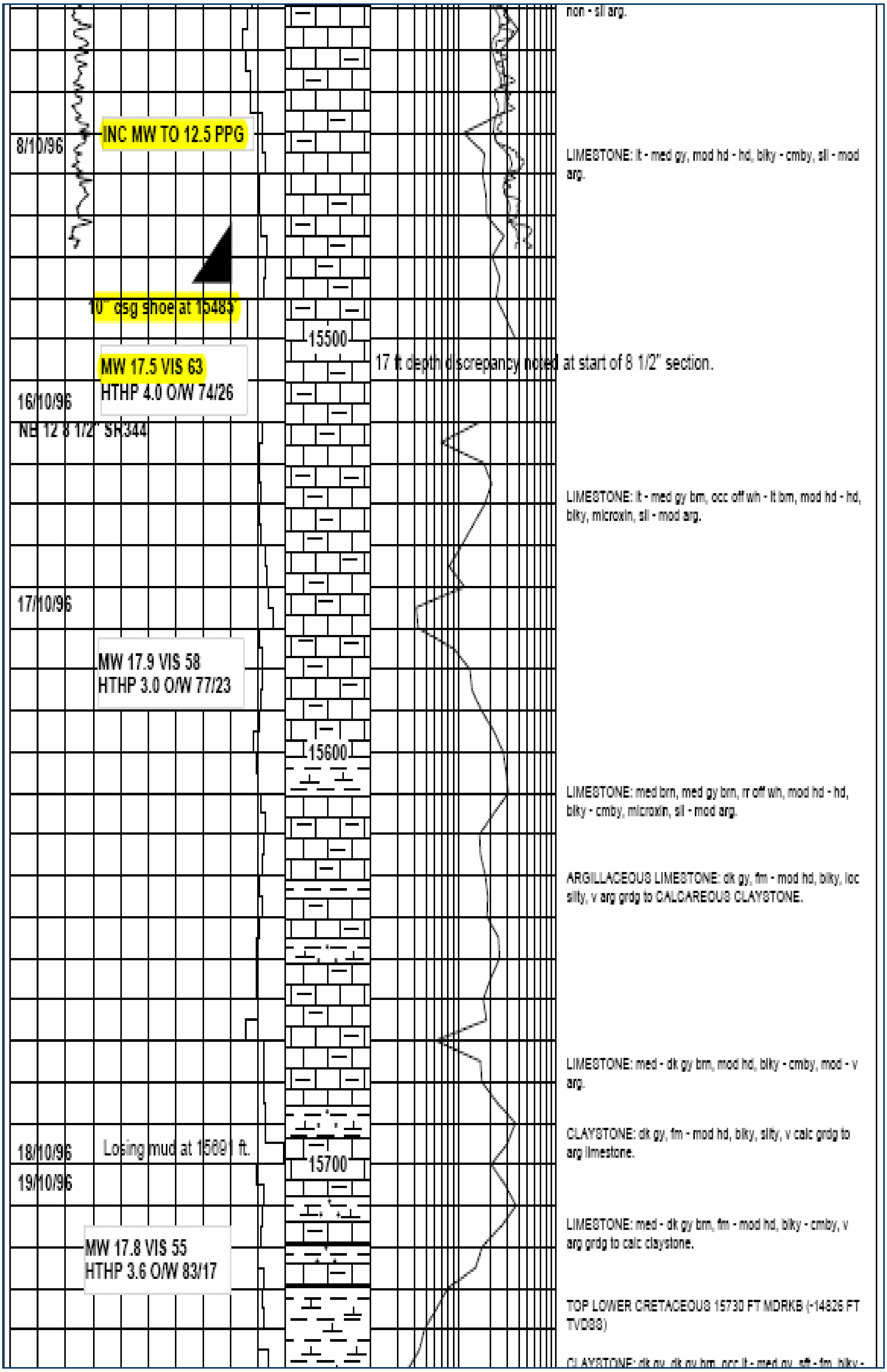
To avoid collapse when installing the completion we need to ensure that the differential pressure between the reservoir and completion fluid does not exceed the collapse rating of expandable casing. Technically said, we must design the completion fluid specific gravity to maintain high internal pressure. Upon the installation, we need to consider the collapse failure more than the burst failure and the tension failure. The design should be carried out for each specific installation.

***Case study: ERSKINE High Collapse of expandable casing*** [5]

Chevron Energy Technology Company (ETC) was asked to evaluate the feasibility of using a high collapse rating expandable casing in the upcoming drilling of the several depleted HPHT sands in the Erskine field (North Sea, UK sector). The request stated:

"Evaluate expandable liners as means of casing off virgin pressure shales above the reservoir to enable mud weight to be lowered to drill the depleted reservoir section. Review geology and quantify risks of this approach in achieving successful coverage of virgin pressured shales."

In the development drilling of the Erskine wells the intermediate casing was set in the limestone at around 15500 feet. This is 400 feet above the Erskine sandstone reservoir. The mud weight was increased from 12.5 ppg in the intermediate hole to17.6 ppg in the shales above the reservoir. Currently, the Erskine reservoir has been significantly depleted but the shales above the reservoir still require virgin mud weights. The proposed re-drill plan would be to use expandable casing to case off the high-pressure shales to allow a reduction in mud weight before drilling the depleted sand. The Erskine Field W-1 mud log is shown below on figure 4.14:


non - sil arg.
8/10/96
INC MW TO 12.5 PPG
LIMESTONE: lt - med gy, mod hd - hd, blky - crnby, sil - mod arg.
10" csg shoe at 15485
15500
MW 17.5 VIS 63
HTHP 4.0 O/W 74/26
17 ft depth discrepancy noted at start of 8 1/2" section.
16/10/96
NB 12 8 1/2" SR344
LIMESTONE: lt - med gy brn, occ off wh - lt brn, mod hd - hd, blky, microxln, sil - mod arg.
17/10/96
MW 17.9 VIS 58
HTHP 3.0 O/W 77/23
15600
LIMESTONE: med brn, med gy brn, rr off wh, mod hd - hd, blky - crnby, microxln, sil - mod arg.
ARGILLACEOUS LIMESTONE: dk gy, fm - mod hd, blky, loc silty, v arg grdg to CALCAREOUS CLAYSTONE.
LIMESTONE: med - dk gy brn, mod hd, blky - crnby, mod - v arg.
CLAYSTONE: dk gy, fm - mod hd, blky, silty, v calc grdg to arg limestone.
18/10/96
Losing mud at 15691 ft.
15700
19/10/96
LIMESTONE: med - dk gy brn, fm - mod hd, blky - crnby, v arg grdg to calc claystone.
MW 17.8 VIS 55
HTHP 3.6 O/W 83/17
TOP LOWER CRETACEOUS 15730 FT MDRKB (-14826 FT TVDSS)

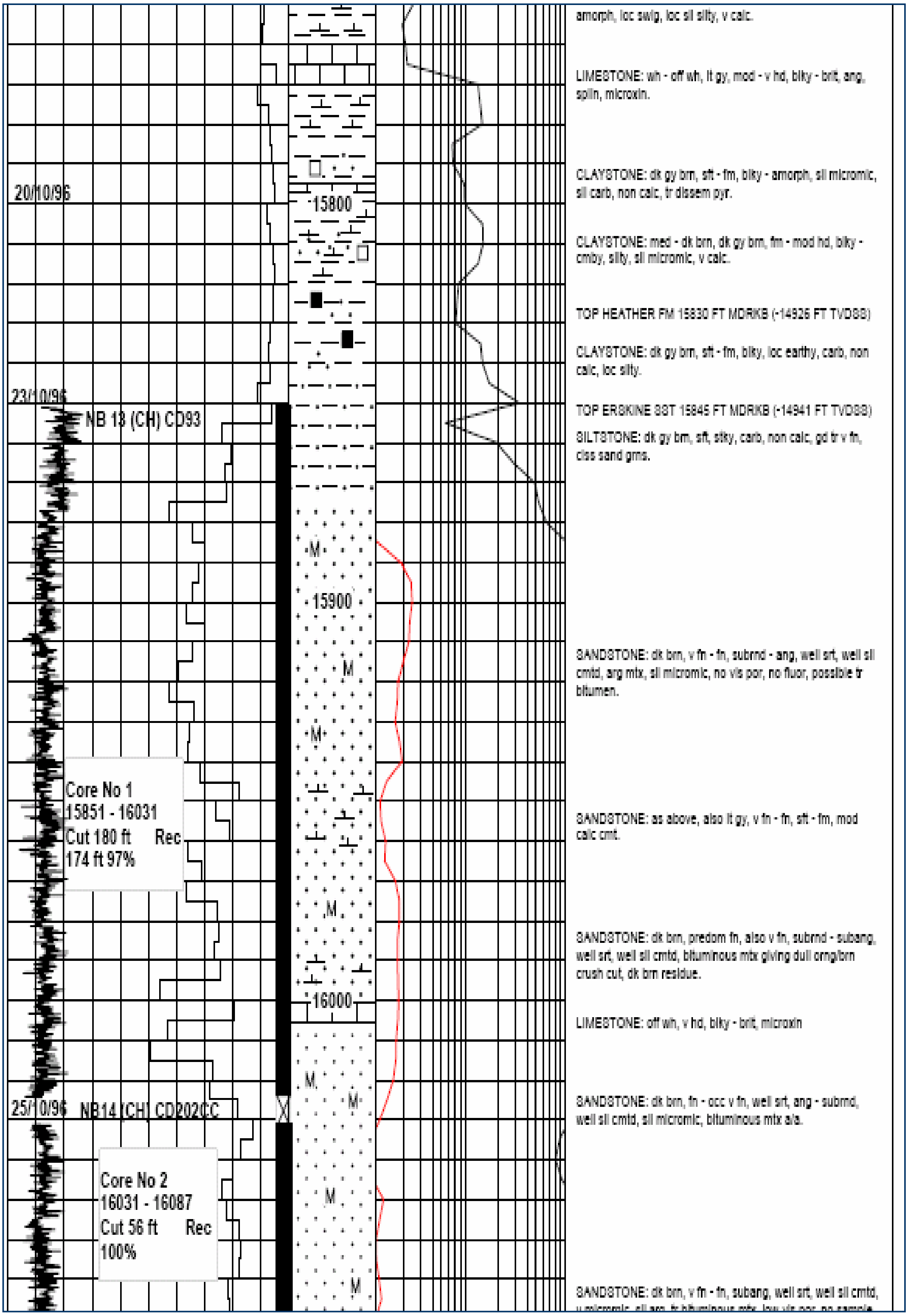



**Figure 4.14-Erskine Field W-1 mud log [5]**

The original bottom hole pressure of the Erskine sand was measured during a production test with the results (13883 psi, approximately 17.4 ppg) shown below:

**Table 4.2-Recorded BHP of Erskine** [5]

MXQ GAUGE COMPARISONS

| | Gauge MXQ-4400 | Gauge MXQ-4401 | Gauge MXQ-4405 |
|---|---|---|---|
| Depth (ft RKB) | 16398.84 | 16398.84 | 16398.84 |
| | | | |
| EVENT DATE & TIME | Psia Deg F | Psia Deg F | Psia Deg F |
| 20/01/98 11:00:02 Stable BHP after setting gauges | 13882.65 348.70 | 13883.72 345.54 | 13883.73 348.38 |
| 20/01/98 14:05:26 Prior to Opening Well | 13883.13 348.30 | 13884.63 345.18 | 13885.20 348.06 |
| 20/01/98 22:54:42 Last flowing pressure | 13728.43 348.54 | 13729.95 345.58 | 13730.89 348.26 |
| 22/01/98 12:54:46 End of buildup period | 13868.43 348.22 | 13869.79 345.12 | 13871.37 348.02 |

The current BHP is in the 5600 psi range. The Rock Mechanic Analysis Team at ETC did an evaluation of the effect of this depletion on the fracture gradient in the Erskine reservoir. There was also a mini-fracture breakdown test done on one of the wells as part of this evaluation. The conclusion was that as much as 0.91 psi of fracture gradient could be lost for every 1 psi drop in reservoir pressure. This means that a collapse load of 7200 psi could be exerted by the 17.4 ppg shales or the drilling fluid if circulation was lost while drilling the reservoir and dropped to the reduced fracture gradient.

The advantage offered by expandable casing is an increase in internal diameter that can allow additional casing strings to add to the well design. This requires more costly tolerance practices like flush joint casing and bi-center drilling. The casing walls must be minimized to allow an adequate passage for the next string. Strength in both the pipe body and the connections is sacrificed. The close tolerance annulus is a hazard in getting the pipe to depth, circulating, and cementing. These are common problems in expandable operations. If the current clearances are further reduced, it will be likely that these problems will be exacerbated.

The normal expandable casing offered for an 8.5" drift clearance is 7.625, 29.7#, 80 grade pipe with a 0.375 pre-expansion wall thickness. The post expansion wall thickness is 0.358", the drift is 7.623" and the collapse is 3150 psi. The next hole drilled below this casing could be 7.5 x 8.5" bi-center and 7" flush joint casing could be run. The clearance would be .31" verses the drift around the 7" flush joint casing. This is less than half of the normal clearance (.75") found in an 8.5" hole with a 7" flush joint liner.

For expandable casing to be useful in Erskine it needs significantly increased collapse resistance. The API collapse formulas are:

$$P_Y = 2\sigma_{py}\left(\frac{\left(D/t\right)-1}{\left(D/t\right)^2}\right), \text{ Yield}$$

$$P_P = \sigma_{py}\left(\frac{A}{D/t}-B\right)-C, \text{ Plastic}$$

$$P_T = \sigma_{py}\left(\frac{F}{D/t}-G\right), \text{ Transition}$$

$$P_E = \frac{46.95x10^6}{\left(D/t\right)\left(D/t-1\right)^2}, \text{ Elastic}$$

Collapse performance is calculated using the procedure recommended by API in (American Petroleum Institute, Latest Edition). Given the following input variables:

- Internal pressure (Pi)
- Axial stress (σz)
- Tube outside diameter (D)
- Tube wall thickness (t)

The key parameter in collapse is (D/t). To increase collapse, the wall thickness (t) can be increased or the diameter (D) can be decreased. The casing expansion process does exactly the opposite. Increasing the yield strength can also help  but D/t is the most effective change.

Any stress from tension in the pipe reduces the collapse strength. It appears that it is contributing to lower collapse strength. The collapse rating of expandable casing will be determined by conventional API casing calculations. A recent GOM well, experienced two collapse failures of expandable casing. The first occurred while going in the hole prior to expansion due to a plugged port. The second failure occurred while reducing the mud weight after the pipe had been expanded. The unexpanded pipe collapsed at 120% of the API rating, the expanded pipe failed at 100% of the Enventure collapse rating which is approximately 20% lower than API. While most casing is stronger in collapse than the API formulas indicate (as shown in figure 4.15) expanded casing is rated 20% lower than the API formulas indicate and it fails at these lower values.

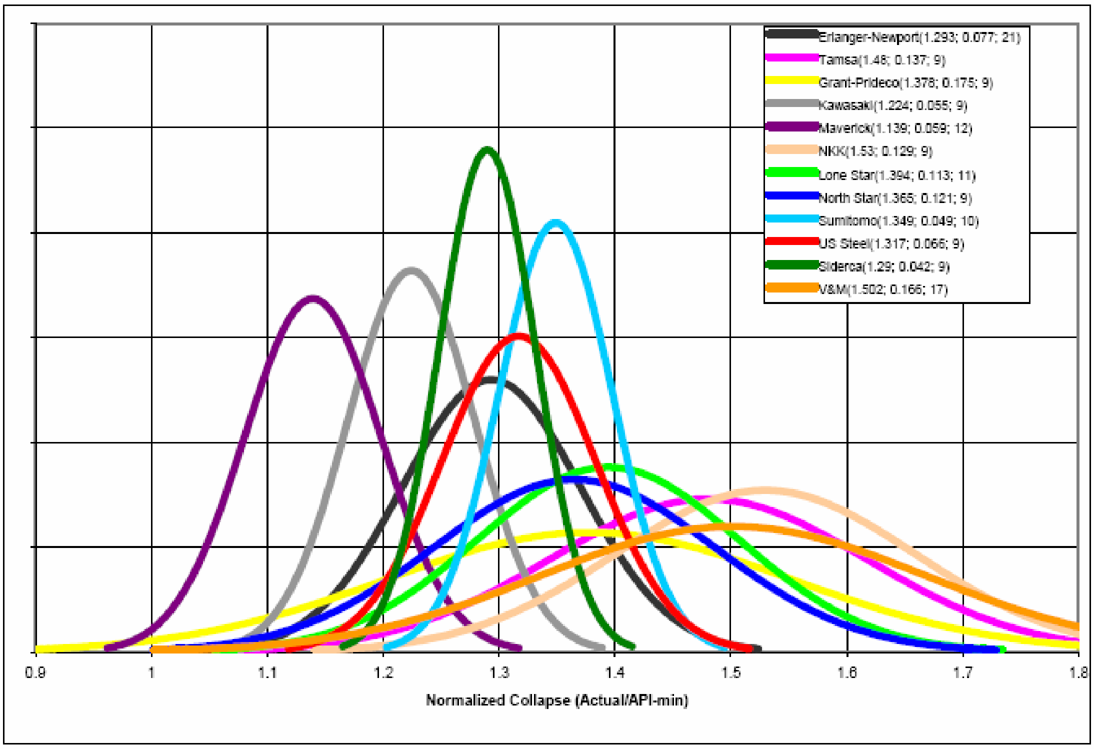



**Figure 4.15-Comparison of Normalized collapse from different casing [5]**

Any change in yield strength or increase in wall thickness will result in higher expansion pressure and increased risk of failure during the casing expansion process. The current success rate for worldwide Chevron expandable casing applications at conventional pressures is only 50%. Increasing wall thickness will also reduce the resulting clearance for the next hole section.

For the Erskine design, increasing the pre-expanded 7 5/8" pipe from 29.7 ppf to 39 ppf increases the initial wall thickness from 0.375" to 0.5". The post expansion collapse increases from 3150 psi to 5400 psi. However, the pressure required for expansion increases from 3800 psi to 4970 psi and the post expansion clearance drops from 0.31" to 0.21".

In order to get the appropriate collapse strength, the internal drift diameter will be reduced to a level that is no longer an advantage.

A recent application on a Unocal operation in the Gulf of Mexico demonstrated the type of failure that can occur if the collapse strength of expandable casing is challenged. The expandable drilling liner was set covering the open hole from 27,521 ft to 28,555 ft. The subsequent operations are described:

- TIH with 9 7/8"bit and 11" Rhino Reamer (3rd Bit)
- Started cutting mud weight to 12.0 ppg to reduce differential (over-balance)
  - Mud weight SET set in – 13.0 ppg
  - Collapse rating of SET – 1,580 psi (which is about equal 1 ppg differential @ 29,600' – mud cut to 12.0 ppg)
  - Looked at differential – Wrong assumption made that some bleed off to formation pressure (11.1 ppg) would have occurred
- Drilled from 29,623' to 29,639'. Cutting mud weight
- Pipe stuck. (Expandable casing collapse)
- Raised mud weight to 12.5, then 13.0 ppg. Pipe free
- Continued drilling to 29,671' – high torque. POOH to check bit
- Found problems in expandable. Could not pull out of hole past 27,654ft (with 350K# overpull)
- TIH and attempted blind backoff at 28,760'. Unsuccessful
- Rigged Up TEAS System and severed BHA at 29,501'
- Ran Electric Line Log through collapse casing with fish in hole (MDT's and caliper log)

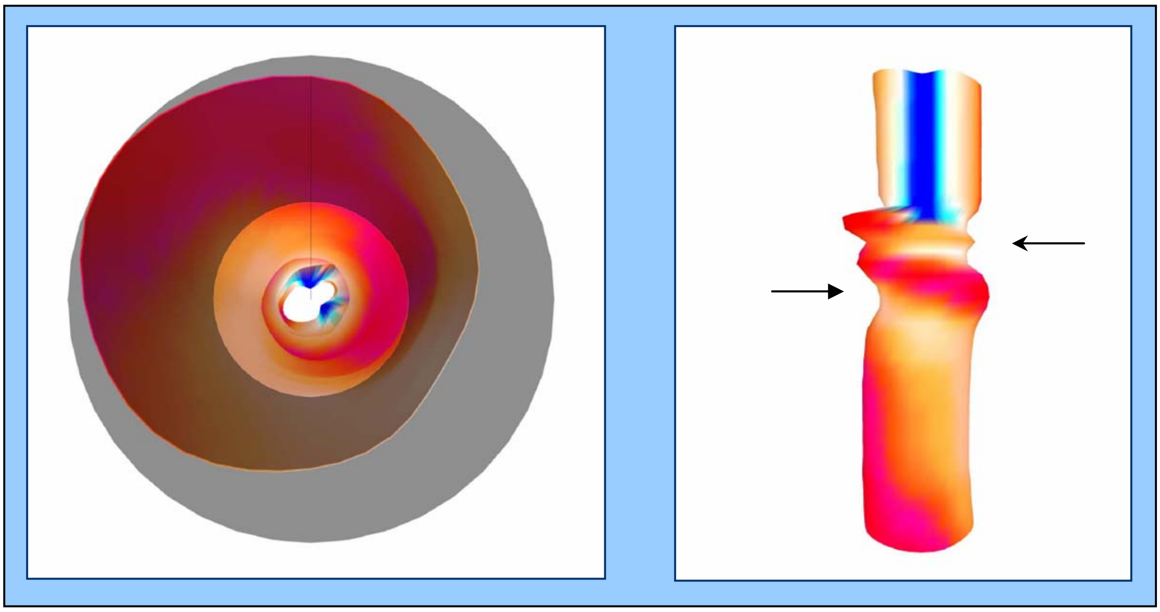


**Figure 4.16-3D image from simulation result of caliper log [5]**

The expandable liner collapsed when the mud density was reduced one ppg which was equivalent to the Enventure collapse rating of the expanded casing. The BHA was severed and left in the hole. The well was logged and plugged.

High collapse expandable casing is **NOT RECOMMENDED** for Erskine case.

| Challenge 4+ : How to avoid post-expansion casing collapse when completions? |
| --- |
| ***Result :***<br>Upon the installation, we need to consider the collapse failure more than the burst failure and the tension failure. The design should be carried out for each specific installation. |

***Discussion*** : [7]

$$P_{collape} = \frac{Pi\,(2\beta - 1) - \sigma z + \sqrt{4\sigma y^2 - 3(Pi + \sigma z)^2}}{2\beta}$$

$$\text{where} \qquad \beta = \frac{\left(\frac{do}{t}\right)^2}{2\left(\left(\frac{do}{t}\right) - 1\right)}$$

As shown in the collapse equation, the low collapse rating can be avoided in three ways:

1. Increase the yield strength (use a good steel material)
2. Increase the internal pressure (increase Pi)
3. Decrease the axial stress (avoid compressive force)

The most appropriate technical action in post expansion casing to assure there is no collapse is to maintain the internal pressure. Maintaining internal pressure could be done by:

- Increasing the specific gravity of completion fluid or drilling fluid. Completion fluid is used when we expand the liner and production casing. Drilling fluid is used when we drill with casing for a surface or intermediate casing.
- Building up the hydrostatic pressure inside the casing by pumping the fluid in the closed casing system.

By maintaining the internal pressure, we can avoid collapse in the post expansion casing.

The yield strength of the material is limited to its properties. The metal ions which bond to each other should remain strong for pre and post expansion conditions. This is challenges for material engineering to develop a strong-thin-metal material that can be used as casing. In additional, decreasing the axial stress can be avoided by using bottom-top expansion instead of top-bottom expansion.

## 4.5 DISCUSSION OF THE COST

***Challenge : Is the cost competitive?***

***Result :***

It is possible to save costs because running this combined method will reduce the rig time used. However, well candidates should be carefully considered prior to using this method.

***Discussion***:

There are no exact cost calculations for drilling with expandable casing. However, there are a few cases that we can use as the reference for cost prediction. The cases presented below are a cost prediction by Chevron external presentation[11] for the Lobo field in the Gulf of Mexico. This field is a 2 km water depth field with a potential for shallow water flow and hydrates. The salt dome which is showed in figures 4.17 to 4.19 is defined as a trouble zone.

There are 3 cases that are used as an overview for analyzing the cost. The cases are based on the same well conditions, but operated using different approaches:

1. Case example 1: Run DwC and expandable casing separately

   The Drilling with casing method is used to drill and case the hole for all sections until the bottom of the trouble zone. Then drill with conventional method to the top of the reservoir section, run and expand the expandable casing in the bottom of the trouble zone until the top of reservoir, finally drilling the reservoir section with open hole.

2. Case example 2: Run the combined method: Drilling with expandable casing.

   One used drilling with casing method to drill and case the hole for all sections from mudline to the top of the trouble zone. Then used the combined method to drill and expand the casing until the bottom of the trouble zone. The hole from the bottom of trouble zone to the reservoir section drilled with conventional method.

3. Case example 3: Drill with conventional method and expand the casing into a 9.5/8" monobore feature.

   One drilled the entire hole with conventional method and underreamed it. Then run expandable casing all the way down to reservoir section through the trouble zone and then expanded the casing.

Below drilling time is compared between these three case examples.

<u>**Case example 1: Separate operation method**</u>

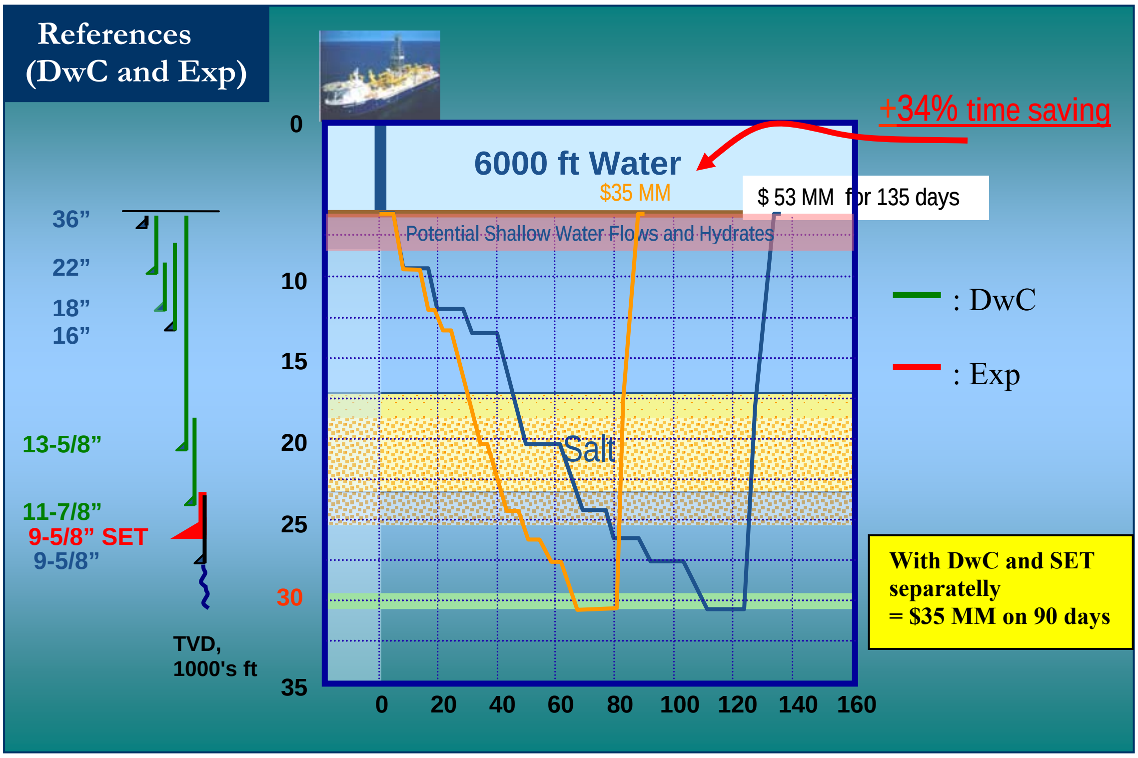



**Figure 4.17-Reference case DwC plus SET separately [11]**

Drill the hole with casing in the 22” section to the 11 7/8” at the base of the trouble zone. Then conventional drilling is used with an underreamer to set 9 5/8” expandable casing for a section of 2,250 ft. Then 9 5/8” casing is expanded. The remainder of the well is drilled using the conventional drilling method with 9 5/8” open hole in the reservoir section.

In the case above, to get through the salt section (lost circulation zone), casing drilling was performed. After 11 7/8” casing reached the expected depth, which is the bottom of the salt zone, then the drilling was continued and the hole was under-reamed. Solid expandable tubular (SET) was installed and the expansion operation was performed after changing the BHA from drilling to expansion BHA. The next hole was drilled and casing size 9 5/8” was run into the hole and drilling continued with open hole across the reservoir with 9 5/8” open hole size.

This case shows that there is a possibility of cost saving, from $ 35MM to $ 53MM, or almost 34% compared to conventional drilling. Drilling conventionally in the case above would risk lost circulation. Lost circulation could add to the total cost by adding additional rig time and other costs related to hole problems. Since casing failure could happen, the risk of having smaller hole diameter of the reservoir section exists.

**<u>Case example 2: Combined method</u>**

In this case, one drills with casing from the mudline to 17,000 ft in sections of 22” casing to 13 5/8” casing. From the top of trouble zone to the bottom of the trouble zone at 25,000 ft the hole is drilled with 11 7/8” casing with underreamer. Then the 11 7/8” casing is expanded giving 12.14” OD and 11.4” ID casing across almost 5,000 ft. Then below the trouble zone, drilling is continued with 10 3/4” open hole across the reservoir section.

If we use the case one as the reference, we can predict the rough expenses from drilling with expandable casing case. With information provide by Enventure based on their experiences the cost estimate is shown below:

- Rate of Expansion = ± 20 – 30 ft /min = 72000 – 108000 ft/day
- Rate of Penetration = ± 30 ft/hr (normal assumption)
- Cost per feet for expansion = ± $175/ft - $200 /ft

From 18,000 ft to 25,000 ft, which is 5,000 ft, we run drilling with expandable casing. So we will have:

<u>Time consumption</u>

- Drilling time = (5,000ft / 30 ft/hr) = 167 hr = 7 days
- Changing BHA = 4 days (drilling BHA to expansion)
- Expansion time = (7,000ft / 100,000 ft/day) = 0.07 day = 2 hour
- Changing BHA = 4 day (expansion BHA to drilling)

Total time consumption = (7 + 2 + 0.07 + 3) days = ±16 days

A more detailed of cost study should be done for real cases.

<u>Cost consumption</u>

If we assume for a deepwater well, the rig and surface equipment for DwC and expandable will cost you $ 0.5 Million/day, therefore

- For 16 days operation = 16 days x $ 0.3 Million/day = $ 3,2 Million
- For expansion process = 7,000 ft x $ 200 /ft = $ 1.4 Million
- For DwC process = $ 1.09 Million (see table 3.7 and 3.8)

Total cost for SET operation and equipments is = $ 5.5 Million

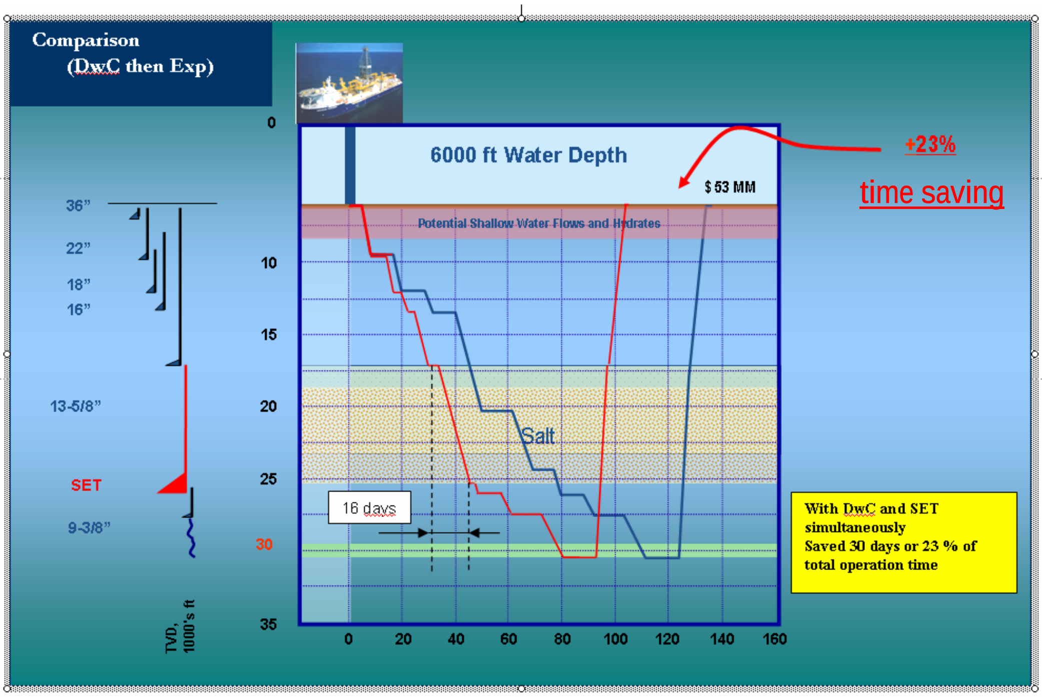



**Figure 4.18-Comparison case DwC plus SET continuously**

Based on our rough estimate, if using drilling with expandable casing, we will save almost 23 % of total project time and the project will be saver and faster.

## Case example 3: Monobore system

For an overview and additional information, the author presents the cost prediction and time saving for the case where we drill and expand into a monobore system.

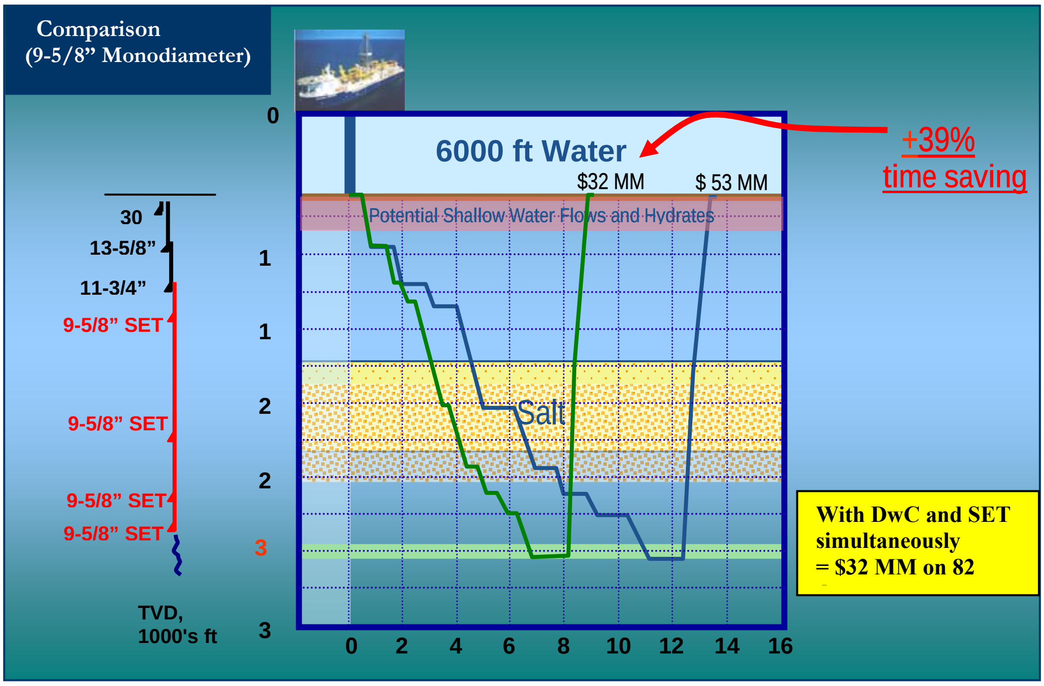



**Figure 4.19-Comparison case using Monobore [11]**

This case is a conceptual plan. The operation still has a lot of challenges because of the risk. The major risk on this operation is the casing weakness in the collapse rating post expansion. The casing has a big tendency to collapse and there is a technical challenge associated with expanding it for 18,000 ft. So if our casing collapses slightly after expansion, our hole is in an uncontrolled situation where we may not be able to run the tools through the hole to continue the operation. One of the alternatives is to run a caliper to map the collapse shape to decide on the next action. Plugging and abandoning the well may in some cases be the preferred option. This case is shown in the Erskine case.

***Comparison for each case***

If we compare between case 1 and case 2 we will find that case 1 saves more operation time than case 2. Case 1 will save approximately 45 days and case 2 will save approximately 30 days of total project time. However we should keep in mind that case 1 has more operational risks than case 2.

In case 1, the risk could be high due to drill through trouble zone, trip and run casing into trouble zones. Lost circulation or blow out situations could occurr. In addition, to install 9 5/8" SET one has to underream the trouble zone. To run the SET, one needs to trip out the drillstring and leave it with an open hole before running in hole with the expandable casing. This operation will bring a very high risk both technically and cost wise.

Although case 2 takes almost 15 days more than case 1, the risks in case 2 could be lower. Since we do not trip the drillpipe and run the casing in separate operations then the risk of lost circulation and kicks could be eliminated. This is a special case, where we also should remember that there are also the risks within all operations including drilling with conventional methods. Besides that, case 2 will be end up with a bigger hole diameter (10 3/4") compared to case 1 (9 5/8") diameter hole. The bigger hole should give a higher production rate. That may add to the cost efficiency of this case. A more detailed study is recommended to be carried out for a more accurate comparison.

Since the technology is rare and monopolized by only some service companies the cost is high. The total operation time strongly depends on the skills and experiences of the rig crews. The more experience the crews, the faster the operation should be.

## 4.6 DISCUSSION OF THE OPERATIONAL LIMITATIONS AND RISKS

***Challenge: Are there any limitations and risks on the operation?***

***Result :***

There are a lot of technical limitations and risks of drilling with expandable casing especially due to the fact that expandable casing has low post-expansion material properties and its connection has low limitation on the torsion ratings. However a good engineering approach and improvements in technology can hopefully overcome these limitations and risks.

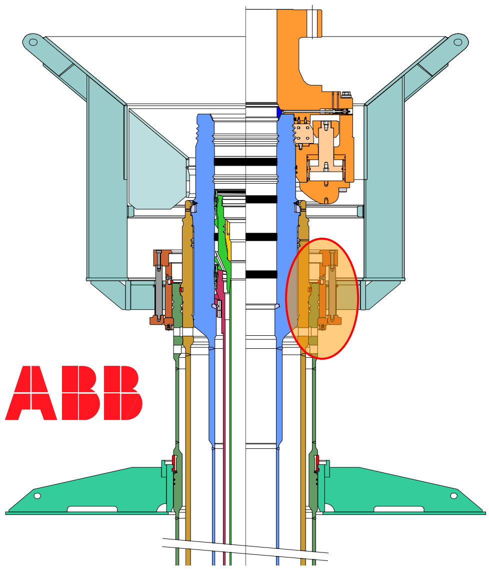
***Discussion:***

Limitations of Drilling with casing:

The limitation of drilling with casing through a subsea wellhead system is on the casing hanger landing operation. Basically, one has a hanger assembly that must be "landed" in the wellhead. In conventional drilling, the casing hanger is run on drill pipe in a separate operation. However, if one drills with casing in place, one would have to attach the hanger assembly onto the casing string. Then drill and run in hole until the casing hanger is landed in the wellhead. This means that rotating the hanger (and the casing) in the wellhead is impossible because it would damage the seals and landing profiles of casing hanger.

Also, when getting close to "landing" the hanger, the hanger seals would begin to move into their profiles. This would stop the circulation of fluids before you truly TD'ed the section. This would possibly result in setting the casing in compression which is not a good operation. Then there might be the problem of how do we get the running tool (the remainder of the casing) to release from the hanger so we can pull it back to the surface. Also if we get stuck (before landing the hanger) we risk having junked the well. This is why when drilling through a subsea system we prefer to have liner drilling but not casing drilling.

This hanger system is installed at the sea floor. The hanger must be seated on the wellhead. If we are drilling the casing down, these hangers are not designed to allow us to rotate them into place. Also, notice there is a small clearance between the red and green casing (figure 4.20). When DwC through this area we have to circulate the flow, and this is a challenging process. We would then have to retrieve back the casing, leaving only the hanger in the well head.




There is operationally possible to land the casing into the wellhead in DwC. First, drill deeper than the target depth of the casing shoe, so when one pulls out of the hole the trouble zone is still cased. On the rig floor, the casing hanger is installed on top of the casing and run in hole until it rests on the wellhead. No rotation is allowed in this operation. The length of extra hole and the length of the casing that needs to pull should be designed carefully.

**Figure 4.20-Hanger system on subsea wellhead [6]**

In a deepwater well that could mean we need to pull 4,000 to 8,000 ft of pipe back to the surface and run it back to the mudline. This operation would take time. The new overdrive system may help in handling the pipe. Casing cannot be handled in the derrick in the same manner that drillpipe is handled. The benefits would have to be larger to justify the cost of doing this. We would also have a problem of having the casing shear rams in the Blow Out Preventer (BOP) stack during such an exercise.

We probably cannot shear anything larger than about 7" because of the BOP limitations. In general, many operational issues that would require specialized tools that don't exist are needed. As we would have to recover the casing from the mudline, we probably wouldn't save any time. Therefore, a good engineering approach should be applied because this operation is high risk and cost expensive.

The author believes if there is a demand for the solution, the development or modification of a subsea wellhead could be done by its provider. Due to deep water and a harsh working environment, some of the companies in Norway are now developing the subsea wellhead to meet the costumers demand.

Limitation of Expandable casing:

The biggest limitation on expandable casing is the low material properties due to collapse limitation. There is a challenge for material engineers to find a metal that strong enough in properties and economical enough to be used as casing. With today's technology we can try to maintain the internal pressure to balance the formation pressure.

As long as the resultant pressure in and outside the casing does not exceed the casing strength, collapse can be avoided. However, maintaining or increasing the internal pressure also brings a lot of engineering challenges. The completion fluid has its limitation on properties and there are a lot of other operations on the completion that need to be operated in low borehole pressure.

Limitation of Combined method:

Limitation of combined method practically is a combination of both limitations from drilling with casing and expandable casing. The major limitations are the low collapse rating of post expansion casing and the low torque limit of the expandable casing connector. The consequences of its limitations and mitigate plans will be presented on below.

Risk Analysis

The figure 3.21 shows that the risk assessment falls in the "yellow" area on the risks matrix. This means that the combined method operationally is possible to be accepted or rejected, depends on the design. The yellow colour means that improvements are needed in order to make this technology more acceptable.

Refer to figure 3.21, to make this technology more acceptable, we have to bring the risk assessment to the green area. There are two things that we could do to avoid or reduce the risks:

- Reduce the probability, which means reduced the frequencies it happens (In other words, take prior actions to eliminate the failure).
- Reduce the consequence, which means reduced the impact of the outcome (In other words, take action during and post the failure).

The prior, during and post actions to reduce the risks of

1. The expandable connection falling apart when drilling or expanding. The actions are:
   - Reducing the probability (prior the failure) can be done by:
     - Installing appropriate number of stabilizer to reduce the drillstring torque
     - Use a better lubricator and drill with low RPM, or high RPM using a mud motor
     - Improve and use a stronger expandable casing connector
     - Improve the well control skills and equipments (barriers)
     - Test the barriers frequently
     - Improve the understanding of safety and schedule the emergency exercise

   - Reducing the consequence (during or post failure) can be done by:
     - Gradually reduce the pipe rotation until it stops
     - Stop the drilling operation and decrease the pump rate
     - Run caliper log to map the connection geometry
     - Reduce the tension on the drillstring
     - Run an expandable casing to clad as the connections coupling or,
     - Do the squeeze cementing on the leaking spots
     - After the impact is dismissed, run and continue drilling with smaller casing
     - Prepare for abandonment and worker allocation if the well is on un-control condition

2. The expandable casing collapse post expansion. The actions are;
   - Reducing the probability (prior the failure) can be done by:
     - Use a stronger casing on collapse rating.
     - Use a good expansion method.
     - Adjust the drilling or completion fluid to maintain internal hydraulic pressure.

   - Reducing the consequence (during or post failure) can be done by:
     - Run logging to map the collapse hole geometry
     - Reduce the tension on the drillstring
     - Run a mill into the collapse hole
     - Run an expandable casing to clad and cover the leaking spots
     - Do the squeeze cementing on the leaking spots
     - Prepare for abandonment and worker allocation if needed

## CHAPTER V
## APPLICATIONS OF TECHNOLOGY

Although the market for emergency/contingency use of drilling with expandable tubular in drilling will always exist, it is vital that operators are convinced of the need to develop the right mind-set where drilling with expandable becomes an integrated part of the well planning. Among some operators right now, drilling with casing and expandable casing are only used when "all else fails". The goal should be that drilling with expandable casing becomes the first alternative not the last. It is believed that through the diligence and discipline being exercised by the service providers, and with the recommendations provided here, the large market potential existing for drilling with expandable casing will become a reality.

Proposing criteria field applications of this combined technology is quite challenging. Each application already has limited technical applications and high cost. If we neglect the budget and the risk, the boundary conditions for this application are:

### 5.1 Wells which drill through trouble zones.

With conventional drilling through trouble zones, lost circulation and kicks could happen. This could impact on the environment, safety and the lives of the crew who work on the site. Since this combined method can dismiss these risks, it is recommended to be applied on drilling when dealing with these trouble zones.

This method could also be recommended on exploration wells, as the formations we drill through have a lot of unknowns and uncertainties.

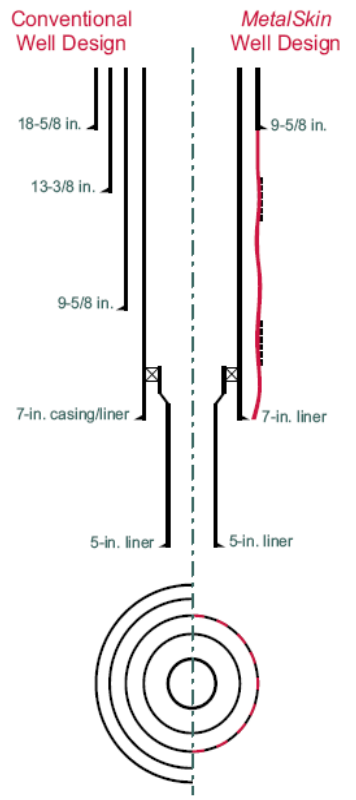
Weatherford for example, describes the following application of their expandable technology. If we combine with our proposed method then it will reduce the risk of drilling the trouble zone (figure 5.1).

By drilling and expanding the SET, we can seal the trouble zones.

- Drill monobore w/ 9 5/8" casing
- Continue hole through the trouble zones, set 7-5/8" expandable casing.
- Expand 7 5/8" casing into 9 5/8" casing
- Set 7" casing to TD as protection since collapse rating of monobore is low.
- Continue drill hole through the reservoir
- A 5" liner can be hung in 7" casing for production liner.

Target:

To dismiss hole problems while maintaining the hole sizes.




After the monobore openhole clad is expanded to seal a trouble zone, another clad can be passed through it to isolate the next trouble zone encountered. Drilling can proceed to the planned total depth of the hole section, at which point a conventionally cemented casing program can be installed.

**Figure 5.1-Well profile for the trouble zones** [17]

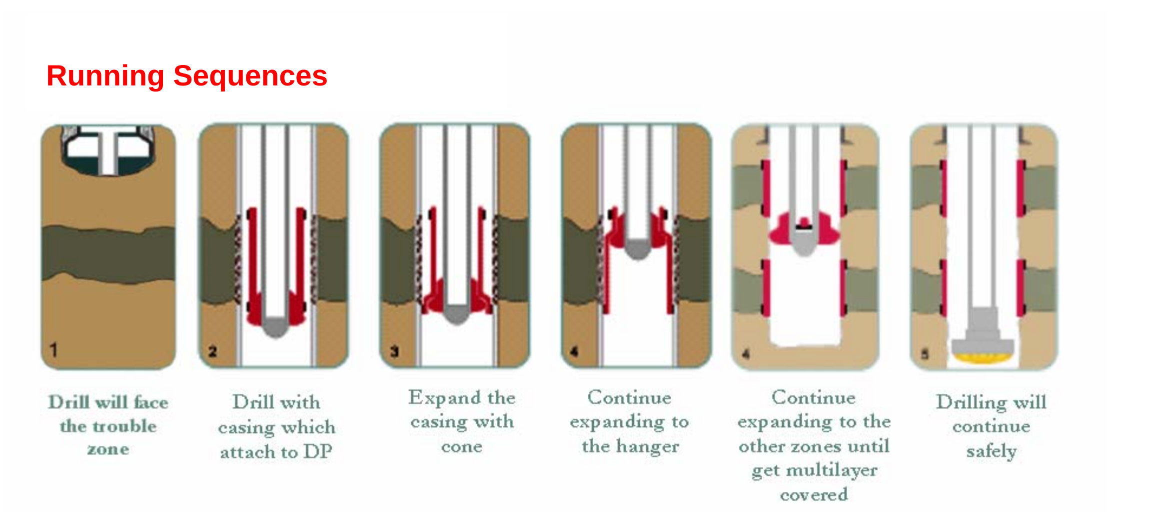



**Figure 5.2-Drilling with expandable casing sequence for the trouble zones** [17]

## 5.2 Wells which have low formation pressure

As discussed before, the biggest limitation on expandable casing is the low collapse rating. Having a low collapse rating makes it only possible to be run on the well with low formation pressure. Engineering design including all the possible considerations should be performed before we decide to apply this combined method.

It is shown in Erskine field HPHT well, that the design of expandable casing is not acceptable to be run in these conditions. Mistakes in design will have high impacts. Besides costing a lot of money, the lives of the rig crew can also be threatened.

High-pressure reservoir could possibly become a good well candidate for this combined technology  If we drilled and expanded the casing just limited to the trouble zone, larger diameter casing in the high-pressure reservoir can be obtained. The non-expandable production casing or liner casing could be run and it could withstand the high reservoir pressure.

## 5.3 Well where higher production rates are needed

In evaluating whether to use this combined technology, the economic analysis of the well should be done through the entire field life. The higher production rate because of the larger ID could be able to pay the incremental cost of this method. Having a larger casing ID makes it possible to install larger ID of completion string. This will bring more significant effects on gas production rates rather than oil, because of the flow phase properties.

Weatherford, for example, describes the following application for their expandable technology. If we combine with our proposed method then it will solve the trouble zone risk and also attain bigger final ID (figure 5.3).

By drilling and expanding the SET, we can complete the final production liner in a larger diameter than by using a conventional drilling. This operation is done by:

- Drill w/ conventionally and set 18 5/8” casing to section of TD
- Continue drilling w/ 13 3/8” casing to its TD with expandable casing.
- Expand 13 5/8” casing to get 14 1/2” oversized shoe.
- Drill with expandable 11 3/4” casing until section TD is reached.
- Expand 11 3/4” casing to 13 3/8”.
- Drill and set 9 5/8” casing conventionally to its TD as protection since collapse rating of monobore is low.
- Continue drill hole to the reservoir
- A 7” liner can be hung in 9 5/8” casing for a production liner.

Target: to optimize the size of production liner

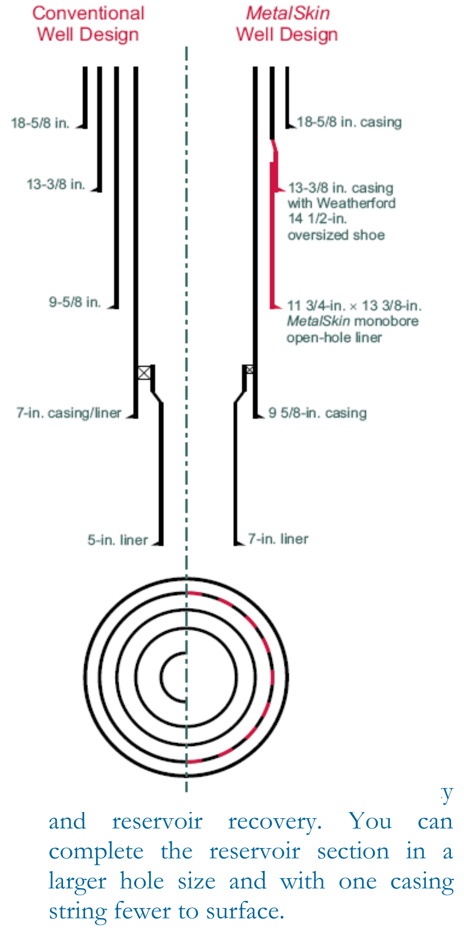



**Figure 5.3-Well profile for optimizing ID size** [17]

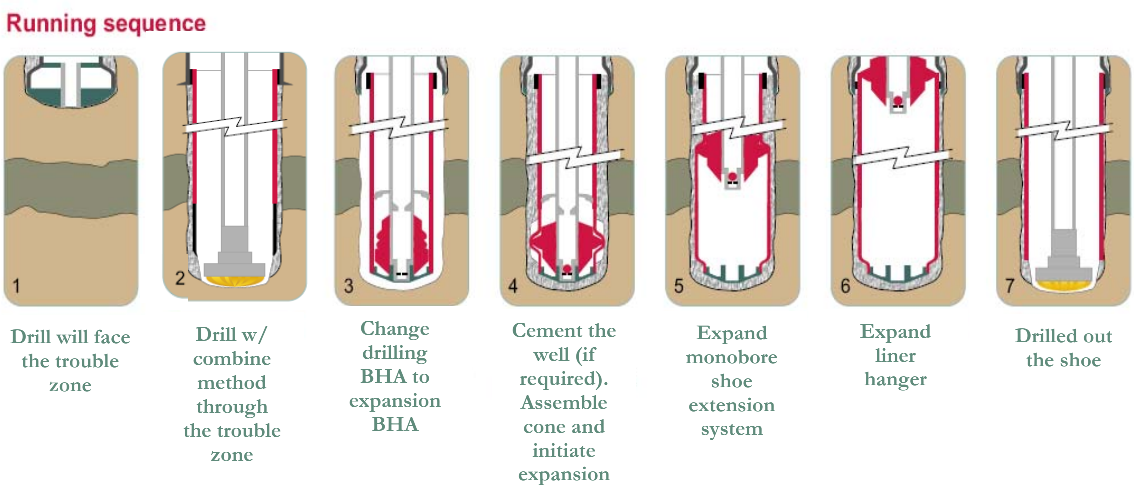



**Figure 5.4-Drilling with expandable casing sequence for optimizing ID size** [17]

## 5.4 Wells which are drilled on land or in shallow water

Wells that are drilled on land or in shallow water will have a lower rig and operation cost and less technical challenges than deep-water wells. As we discussed before, it will be a technical challenge to seat the casing hanger on the deep-water wellhead. Besides, land and shallow water rigs being cheaper than deep-water rigs, the risk of failure in drilling the hole is more tolerable and easier handled.

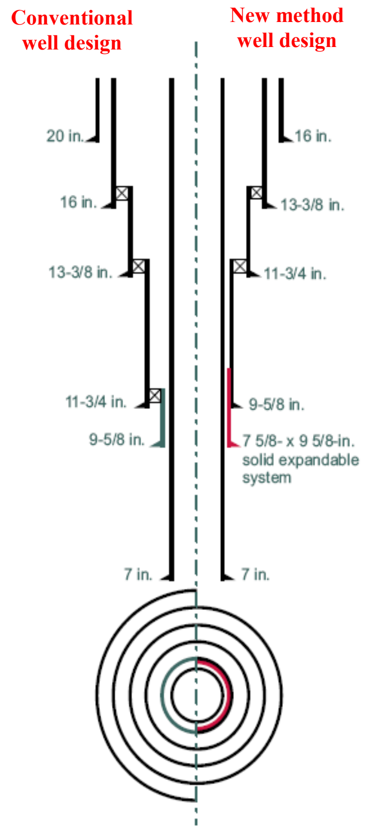
For example, Weatherford describes the following application for their expandable technology. If we combine with our proposed method then it will need a smaller surface equipment which mean a lot of cost saving and will provide the same performance (figure 5.4).

Wells with a bigger inside diameter will make the modification of completion and the option of drilling a multilateral well or sidetrack easier, with less challenges. Therefore the engineering, economical and safety considerations should be evaluated for each specific well.

By installing and expanding the SET, we can use a smaller rig and surface equipments because we can start drilling with a smaller diameter and lighter casing.

- Drilling starts w/ 16" casing instead of 20" casing.
- After 16" casing reach the section TD, one can drill and set accordingly 13 3/8", 11 3/4" and 9 5/8" casing using the conventional method.
- Where 11 3/4" casing hangs on 13 5/8" casing and 9 5/8" casing hangs on 11 3/4" casing.
- To maintain large production liner sizes, we can use the combined method to drill and expand 7 5/8" casing into 9 5/8".
- This expandable casing clad inside its 9 5/8" casing.
- Drill and set 7" casing conventionally from surface to reservoir section as protection.

Target: to start with as small as possible surface equipments




The system cuts well construction costs by reducing the need to telescope down to smaller and smaller casing sizes. You can start drilling with smaller-diameter upper-hole sections and finish with the same size or larger hole sections for optimal production string size

**Figure 5.5-Well profile using smaller rig [17]**

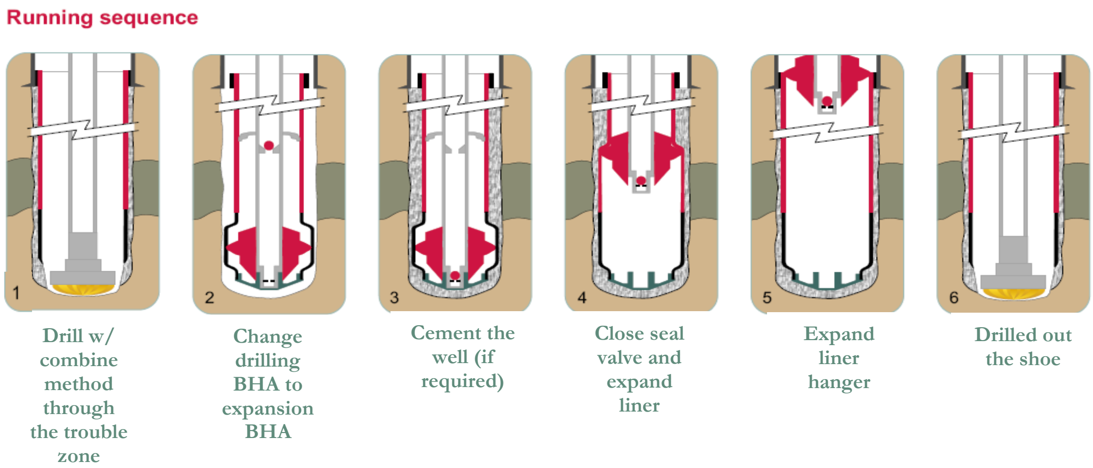



**Figure 5.6-Drilling with expandable casing sequence on smaller rig size [17]**

## CHAPTER VI

## CONCLUSIONS

The two main purposes of this thesis are:

1 To study the feasibility of combining drilling with casing and expandable casing methods. The feasibility study will be done on technical and cost effective point of view.

2 To propose the appropriate applications for this method.

The concept of this thesis is to use expandable casing as a drillstring during the drilling operation, which will then be expanded when the target depth is reached. The conclusion of my study is that the drilling with expandable concept is possible. Table 6.1 shows and concludes the pros and cons of this combined technology.

**Table 6.1-Pros and cons of the combined technology**

| PROS | CONS |
|---|---|
| • Can mitigate risks when drilling through troubled zones. | • Considered as a new technology, therefore high risks because of lack of procedures and experiences. |
| • Can obtain bigger ID of the completion string, which will impact on a higher production rate. | • Need a tool improvement on drilling-expansion bottom hole assembly (BHA). |
| • Can save rig time which will impact on cost saving. (Showed on case study, ± 23% of saving rig time can be achieved if this technology is applied). | • Risk of weakened material properties especially low collapse rating of post expansion casing and low on torque rating of casing connections. |

This combined technology shows a huge potential for cost savings, higher production and better well control. Therefore, it is recommended to continue studying and developing this immature technology. The goal should be the drilling with expandable casing becomes the first alternative not the last.

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