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Presented by:
Rehouma Abderrahmae
Saci imad Eddine
Sadani Zakarai

- TITTLE–

Elaboration of Casing Design

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President:	Khelifa Cherif	**Univ. Ouargla**
Supervisor:	Abidi Saad Elfaker	**Univ. Ouargla**
Examiner:	Abidi Saad Aissa	**Univ. Ouargal**

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Dedications

The story is over, and I lifted my hat farewell to the past years. I dedicate my graduation to the sea of love, tenderness, and the pulse that dwells in my veins, my tender mother and my dear father, who were my support in my career, to the sparkling stars of my sky and my support in life to my brothers, whom my mother did not give birth to, but they gave birth to me in the days they were Supporting me, thanks to you, I stand in this beautiful and honorable position, thank you to all my friends, thank you to those who taught me a letter, thank you.

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Me and my success is the fruit of your harvest, father

Me and my being the fruit of your mother's sleep

May you always be an asset, pride, and glory, and my success is complete for both of you

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To the one who gave me everything he had to fulfill his hopes, to the one who pushed me forward to achieve success

The goal, to the human being who possessed humanity with all strength, to the one who watched over my education with great sacrifices Translated in his reverence for science, to my first school in life,

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To the one who gave the pleasure of her liver all giving and tenderness, to the one who was patient with everything, who took care of me the right to care, and she was my support in adversity, and her prayer for me was success, she followed me step by step

In my work, to whom I rest whenever I remember her smile on my face, the source of tenderness, my mother, the dearest angel to me

May God reward the heart and the eye on my behalf with the best reward in both worlds to them I dedicate this humble work in order to bring some happiness to their hearts To my brothers and sisters who shared the burden of life with me; To all my honorable teachers who did not hesitate to extend their assistance to me, To everyone who helped me from near or far to accomplish this work To all of them I dedicate this work.

Zakaria

Abstract

casing design in drilling operations Is a crucial aspect of ensuring well integrity, operational safety, and efficiency. By considering factors such as casing materials, wellbore stability, cementing operations, and zonal isolation, engineers can design casing systems that provide robust protection, prevent fluid migration, and optimize drilling operations. Effective casing design contributes to the overall success of drilling projects and the long-term productivity of oil and gas well..

In the work, we dealt with several aspects about casing design, including the functions and types of casing and considerations that help in choosing it, as well as the most important physical characteristics of it and the most important pressures it is exposed to. We also touched on casing design methodology, which contains formation and wellbore data, and design factors and procedure. We mentioned casing failure analysis and prevention, which includes the cause failure and failure analysis techniques and prevention strategies

We also studied a well in which, during cement pumping, the applied pressure exceeded the casing collapse pressure. We have calculated the volume of cement and the length it has reached, and we have proposed appropriate solutions for this situation

Addressing these casing design problems requires a comprehensive understanding of drilling conditions, geology, and wellbore dynamics. Advanced modeling techniques, real-time monitoring, and adherence to industry best practices play vital roles in mitigating risks and ensuring the long-term integrity of the casing system. By addressing these challenges effectively, operators can enhance well integrity, optimize drilling operations, and maximize the productivity of oil and gas wells

Résumé :

la conception du tubage dans les opérations de forage est un aspect crucial pour assurer l'intégrité, la sécurité opérationnelle et l'efficacité du puits. En tenant compte de facteurs tels que les matériaux de tubage, la stabilité du puits de forage, les opérations de cimentation et l'isolation zonale, les ingénieurs peuvent concevoir des systèmes de tubage qui offrent une protection robuste, empêchent la migration des fluides et optimisent les opérations de forage. La conception efficace du tubage contribue au succès global des projets de forage et à la productivité à long terme des puits de pétrole et de gaz.

Dans le travail, nous avons traité plusieurs aspects de la conception du tubage, y compris les fonctions et les types de tubage et les considérations qui aident à le choisir, ainsi que les caractéristiques physiques les plus importantes de celui-ci et les pressions les plus importantes auxquelles il est exposé. Nous avons également abordé la méthodologie de conception du tubage, qui contient des données sur la formation et le puits de forage, ainsi que des facteurs et une procédure de conception. Nous avons mentionné l'analyse et la prévention des défaillances de tubage, qui comprend les techniques d'analyse des causes et des défaillances et les stratégies de prévention.

Nous avons également étudié un puits dans lequel, lors du pompage du ciment, la pression appliquée dépassait la pression d'effondrement du tubage. Nous avons calculé le volume de ciment et la longueur qu'il a atteint, et nous avons proposé des solutions appropriées à cette situation

La résolution de ces problèmes de conception de tubage nécessite une compréhension approfondie des conditions de forage, de la géologie et de la dynamique du puits de forage. Les techniques de modélisation avancées, la surveillance en temps réel et le respect des meilleures pratiques de l'industrie jouent un rôle essentiel dans l'atténuation des risques et la garantie de l'intégrité à long terme du système de tubage. En relevant efficacement ces défis, les opérateurs peuvent améliorer l'intégrité des puits, optimiser les opérations de forage et maximiser la productivité des puits de pétrole et de gaz.

ملخص:

يعد تصميم الغلاف في عمليات الحفر جانبًا مهمًا لضمان سلامة البئر ، والسلامة التشغيلية ، والكفاءة. من خلال مراعاة عوامل مثل مواد التغليف ، واستقرار تجويف البئر ، وعمليات التدعيم ، والعزل النطاقي ، يمكن للمهندسين تصميم أنظمة غلاف توفر حماية قوية ، وتمنع انتقال السوائل ، وتحسن عمليات الحفر. يساهم تصميم الغلاف الفعال في النجاح الشامل لمشاريع الحفر والإنتاجية طويلة الأجل لآبار النفط والغاز تناولنا في العمل عدة جوانب تتعلق بتصميم الغلاف ، منها وظائف وأنواع الغلاف والاعتبارات التي تساعد في اختياره ، فضلاً عن أهم الخصائص الفيزيائية له وأهم الضغوط التي يتعرض لها. لقد تطرقنا أيضًا إلى منهجية تصميم الغلاف ، والتي تحتوي على بيانات التكوين وجوف البئر ، وعوامل التصميم وإجراءاته. ذكرنا تحليل فشل الغلاف والوقاية منه ، والذي يتضمن تقنيات تحليل السبب والفشل واستراتيجيات الوقاية لقد درسنا أيضًا بئرًا ، أثناء ضخ الأسمنت ، تجاوز الضغط المطبق فيه ضغط انهيار الغلاف. لقد قمنا بحساب حجم الأسمنت والطول الذي وصل إليه ، واقترحنا الحلول المناسبة لهذا الموقف تتطلب معالجة مشاكل تصميم الغلاف هذه فهماً شاملاً لظروف الحفر والجيولوجيا وديناميكيات حفر الآبار. تلعب تقنيات النمذجة المتقدمة والمراقبة في الوقت الفعلي والالتزام بأفضل الممارسات الصناعية أدوارًا حيوية في تخفيف المخاطر وضمان سلامة نظام التغليف على المدى الطويل. من خلال مواجهة هذه التحديات بشكل فعال ، يمكن للمشغلين تعزيز سلامة الآبار ، وتحسين عمليات الحفر وزيادة إنتاجية آبار النفط والغاز.

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List of Symbols & Abbreviations

ft or.’	FEET
API	AMERICAN PETROLEUM INSTITUTE
OD	OUTSIDE DIAMETER (IN)
ID	INSIDE DIAMETER (IN)
In or.”	INCH
Lb or Lbm	POUND
Lbf	POUND FORCE
ppg	POUND PER GALON
TST	TUBING STRING TESTING
t	THICKNESS
CT	CASING & TUBING
SPEC	SPECIFICATION
mm	MILLIMETER
Psi	POUND PER SQUARE INCH
HPHT	HIGH PRESSURE HIGH TEMPERATURE
Wn	NOMINAL WEIGHT
Wpe	PLAIN AND WEIGHT
D	OUTSIDE DIAMETER
W	THREADED AND COUPLED WEIGHT
J	DISTANCE FROM END OF PIPE TO CENTRE OF COUPLING IN THE POWER-TIGHT POSITION (IN)
NL	COUPLING LENGTH
σ_{pa}	EQUIVALENT YIELD STRENGTH
σ_a	TOTAL AXIAL STRESS
Peq	EXTERNAL PRESSURE EQUIVALENT IN COLLAPSE DUE TO EXTERNAL AND INTERNAL PRESSURE
YP	MINIMUM YIELD STRENGTH
Pe	EXTERNAL PRESSURE
Pi	INTERNAL PRESSURE
Pb	BURST PRESSURE
Pc	COLLAPSE PRESSURE
Py	YIELD STRENGTH COLLAPSE PRESSURE
Pe	ELASTIC COLLAPSE PRESSURE
Pp	PLASTIC COLLAPSE PRESSURE
MW	MUD WEIGHT
TD	TOTAL DEPTH
TVD	TRUE VERTICAL DEPTH
CSD	CASING DEPTH
Ai	INTERNAL AREA OF THE CASING

Ae	EXTERNAL AREA OF THE CASING
As	CROSS SECTIONAL AREA
Ө	DOGLEG SEVERITY, DEGREES/100FT
Ft	PRESSURE TEST FORCE (LB)
Gf	FORMATION FLUID GRADIENT
°F	UNITE OF TEMPERATURE FAHRENHEIT (DEGREE)
ΔT	TEMPERATURE CHANGE
ΔP	PRESSURE CHANGE
°T	TEMPERATURE (DEGREE)
ν	POISSON RATIO
r	DISTENCE AT WHICH Σ_R AND Σ_T ARE MEASURED
σ_r	RADIAL STRESS
σ_t	TANGENTIAL STRESS
σ_{VM}	VON MISES EQUIVALENT STRESS
VM	VON MISES
DF	DESIGN FACTOR
SF	SAFETY FACTOR
bbl	UNITE OF VOLUME BARREL
Δt	THICKNESS DECREMENT
MPa	MILLIPASCAL
Deg	DEGREE
#	NOMINAL WEIGHT
Sw	WELL BORE DEFFORMATION

Introduction

Casing design is a crucial aspect of drilling operations in the oil and gas industry. It involves the selection and installation of a protective casing around the wellbore to prevent collapse, fluid migration, and other hazards. The casing is typically made of steel or other high-strength materials and is designed to withstand the high pressures and temperatures encountered during drilling and production.

The design of the casing must take into account various factors, including the geological conditions of the well site, the depth and diameter of the wellbore, the type of drilling fluid used, and the expected production rates. The casing must also be able to withstand any external forces or stresses that may be encountered during drilling, such as pressure from surrounding rock formations or seismic activity.

The casing design process typically involves a team of engineers, geologists, and drilling experts who work together to develop a comprehensive plan that meets the specific needs of each well. This may involve the use of computer modeling and simulation tools to test various designs and identify potential issues before construction begins.

Once the casing design has been finalized, it must be installed properly to ensure maximum protection and efficiency. This may involve the use of specialized equipment and techniques, such as cementing and casing centralization, to ensure a secure and stable casing installation.

Overall, casing design plays a critical role in ensuring the safety and success of drilling operations in the oil and gas industry. By selecting the right materials, designing for optimal performance, and installing with precision, operators can maximize production while minimizing risks and costs.

CHAPTER Ⅰ:

FUNDAMENTAL ASPECTS OF CASING DESIGN

1. Introduction

Drilling a hole for extracting hydrocarbon is not an easy job. It is always a challengedue to the highly diversified geological structure and petro physical properties of earth deposition and age. In addition while drilling, the well is drilled in sections from surface (for onshore) or the seabed (for off shore) through all of the formations to the target depth because of the technological limitations. During drilling operations, the wellencounters different formation zones with enormous challenges such as faults, highpressure formations, toxic materials, and thief zones etc. Lining the inside of the borehole with steel pipe to ensure a hydraulic and mechanical seal seals off the well. Once a certain length of hole is drilled it has to be cased with steel pipe, which is called casing and is joined together by threaded sleeves. Therefore, casing is defined as a heavy large diameter steel pipe, which can be lowered into the well for some specific functions.

Casing is using a strong steel pipe used in an oil or gas well to ensure a pressure-tight connection from the surface to the oil or gas reservoir. It is a steel pipe of approximately 40 ft in length that starts from the surface and goes down to the bottom of the borehole.

It is rigidly connected to the rocky formation using cement slurry, which also guarantees hydraulic insulation. The space between the casing string and the borehole is thenfilled with cement slurry before drilling the subsequent hole section. The final depth of the well is completed by drilling holes of decreasing diameter and uses the same diameter protective casings in order to guarantee the borehole stability. According to API standards, the dimensions of the tubes, types of thread and joints are standardized.

However, special direct-coupling casings without a sleeve joint also exist. The selection of casing sizes, weights, grades, and types of threaded connections for a given situation presents engineering and economic challenge of considerable importance. The costs of the casing can constitute 20–30% of the total cost of the well. Sometimes, it is the greatest single item of expense for the well. Since the cost of the casing can represent up to 30% of the total cost of the well, the number of casing strings run into the well should be minimized.

This chapter discusses the types of casings, different components of casing and landing procedures. It also discusses the manufacturing of casings, rig side operations, handling procedures, casing design, and selection criteria. Finally, the current practice and future trends in casing for the oil industry are discussed.

2. History

The development of casing design has evolved over time to meet the changing needs of the oil and gas industry. This has been driven by a variety of factors, including changes in drilling technology, advancements in materials science, and improvements in well control techniques.

- **Early Casing Designs (1850s-1900s):**

The earliest casing designs were made of wood, and were used primarily to prevent the sides of the well from collapsing. In the late 1850s, wrought-iron casing was introduced, which provided greater strength and durability than wood. By the 1900s, steel casing had become the standard in the oil and gas industry, and a variety of designs had emerged, including plain-end, threaded-and-coupled, and bell-and-spigot.

- **Casing Design for Deeper Wells (1910s-1930s):**

As drilling technology advanced, wells were drilled deeper and encountered higher pressures and temperatures. This led to the development of more robust casing designs, such as the "buttress" and "square" threads, which provided greater strength and resistance to buckling. In the 1930s, the "premium" thread was introduced, which provided even greater torque strength and improved sealing.

- **Casing Design for Sour Gas Wells (1950s-1970s):**

The discovery of sour gas (gas containing high levels of hydrogen sulfide) presented new challenges for casing design. Sour gas is highly corrosive and can rapidly degrade casing materials, leading to well failures. To address this, new materials such as corrosion-resistant alloys and fiberglass-reinforced plastic were introduced, along with specialized coatings and treatments to protect the casing.

- **Casing Design for Deepwater Wells (1990s-Present):**

In recent decades, drilling has shifted to deepwater locations, where wells can be thousands of feet below the ocean surface. This has required new casing designs that can withstand the extreme pressures and temperatures encountered at these depths, as well as the corrosive effects of seawater. High-strength steel alloys and advanced coatings have been developed to address these challenges. [1]

These are just a few examples of the many developments in casing design over the years. By examining the evolution of casing design, it is possible to gain insights into the challenges facing the oil and gas industry, and the innovative solutions that have been developed .

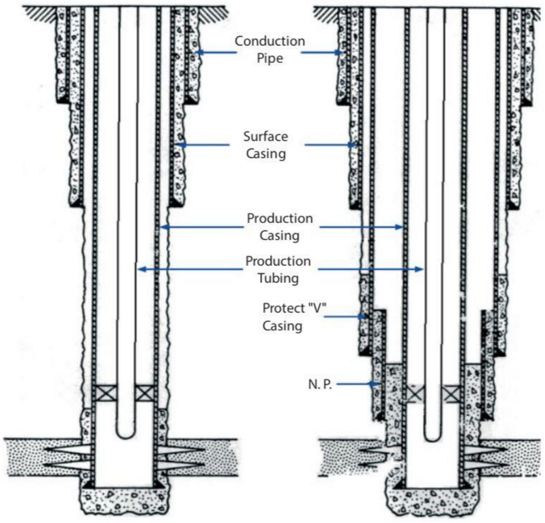
3. Purpose of casing

At a certain stage during the drilling of oil and gas wells. It becomes necessary to line the walls of a borehole with steel pipe which is called casing. Casing serves numerous purposes during the drilling and production history of oil and gas wells, these include:

1. Keeping the hole open by preventing the weak format ions from collapsing.i.e, caving of the hole.
2. Serving as a high strength flow conduit to surface for both drilling and production fluids.
3. Protecting the freshwater-bearing formations from contamination by drilling and production fluids.
4. Providing a suitable support for wellhead equipment and blowout preventers for controlling subsurface pressure, and for the installation of tubing and subsurface equipment.
5. Providing safe passage for running wire line equipment
6. Allowing isolated communication with selectively perforated formation(s) of interest.[2]

4. Types of casing

When drilling wells, hostile environments, such as high-pressured zones, weak and fractured formations, unconsolidated formations and sloughing shales, are often encountered. Consequently, wells are drilled and cased in several steps to seal off these troublesome zones and to allow drilling to the total depth. Different casing sizes are required for different depths, the five general casings used to complete a well are: conductor pipe, surface casing, intermediate casing, production casing and liner. As shown in Figure I .1, these pipes are run to different depths and one or two of them may be omitted depending on th: they may also e drilling conditions be r un as liners or in combination with liners. In offshore platform operations, it is also necessary to run a cassion pipe.



Normally pressured

Abnormally pressured

Fig. Ⅰ.1: A typical different types of casing seats at different well depth.[2]

a. Cassion Pipe

On an offshore platform, a cassion pipe, usually 26” to 42” outside diameter (OD) is driven into the sea bed to prevent washouts of near-surface unconsolidated formations and to ensure the stability of the ground surface upon which the rig is seated. It also serves as a flow conduit for drilling fluid to the surface. The cassion pipe is tied back to the conductor or surface casing and usually does not carry any load.

b. Conductor Pipe

The outermost casing string is the conductor pipe. The main purpose of this casing is to hold back the unconsolidated surface formations and prevent them from falling into the hole. The conductor pipe is cemented back to the surface and it is either used to support subsequent casings and wellhead equipment or the pipe is cut off at the surface after setting the surface casing. Where shallow water or gas flow is expected, the conductor pipe is fitted with a diverter system above the flowline outlet. This device permits the diversion of drilling fluid or gas flow away from the rig in the event of a surface blowout. The conductor pipe is not shut-in in the event of fluid or gas flow, because it is not set in deep enough to provide any holding force. The conductor pipe, which varies in length from 40 to 500 ft onshore and up to 1,000 ft offshore, is 7” to 20” diameter. Generally a 16” pipe is used in shallow wells and a 20” in deep wells. On offshore platforms, conductor pipe is usually 20” in diameter and is cemented across its entire length

a. Surface Casing

The principal functions of the surface casing string are to: hold back unconsolidated shallow formations that can slough into the hole and cause problems, isolate the freshwater-bearing formations and prevent their contamination by fluids from deeper formations and to serve as a base on which to set the blowout preventers. It is generally set in competent rocks, such as hard limestone or dolomite, so that it can hold any pressure that may be encountered between the surface casing seat and the next casing seat.

Setting depths of the surface casing vary from a few hundred feet to as much as 5,000 ft. Sizes of the surface casing vary from 7” to 16” in diameter, with $10^{3/4}$” and $13^{3/8}$” being the most common sizes. On land surface casing is usually cemented to the surface. For offshore wells, the cement column is frequently limited to the kickoff point.

b. Intermediate Casing

Intermediate or protective casing is set at a depth between the surface and production casings. The main reason for setting intermediate casing is to case off the formations that prevent the well from being drilled to the total depth. Troublesome zones encountered include those with abnormal formation pressures, lost circulation, unstable shales and salt sections. When abnormal formation pressures are present in a deep section of the well intermediate casing is set to protect formations below the surface casing from the pressures created by the drilling fluid specific weight required to balance the abnormal pore pressure. Similarly, when normal pore pressures are found below sections having abnormal pore pressure, an additional intermediate casing may be set to allow for the use of more economical, lower specific weight, drilling fluids in the subsequent sections. After a troublesome lost circulation, unstable shale or salt section is penetrated, intermediate casing is required to prevent well problems while drilling below these sections.

Intermediate casing varies in length from 7.000 ft to as much as 15.000 ft and from 7” to $11^{3/4}$”in outside diameter. It is commonly cemented up to 1,000 ft from the casing shoe and hung onto the surface casing. Longer cement columns are sometimes necessary to prevent casing buckling.

c. Production Casing

Production casing is set through the prospective productive zones except in the case of open-hole completions. It is usually designed to hold the maximal shut-in pressure of the producing formations and may be designed to withstand stimulating pressures during completion and workover operations. It also provides protection for the environment in the event of failure of the tubing string during production operations and allows for the production tubing to be repaired and replaced.

Production casing varies from $4^{1/2}$” to $9^{5/8}$”in diameter, and is cemented far enough above the producing formations to provide additional support for subsurface equipment and to prevent casing buckling.

d. Liners

Liners are the pipes that do not usually reach the surface, but are suspended from the bottom of the next largest casing string. Usually, they are set to seal off troublesome sections of the well or through the producing zones for economic reasons. Basic liner assemblies currently in use are shown in Figure Ⅰ .2, these include: drilling liner, production liner, tie-back liner, scab liner, and scab tieback liner (Brown- Hughes Co., 1984).[2]

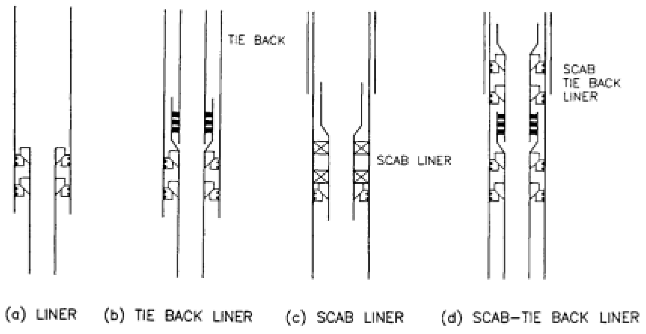


Fig. Ⅰ .2: Basic liner system. (After Brown- Hughes Co., 1984.) [3]

- **Drilling liner:** Drilling liner is a section of casing that is suspended from the existing casing (surface or intermediate casing). In most cases, it extends downward into the open-hole and overlaps the existing casing by 200 ft to 400 ft. It is used to isolate abnormal formation pressure, lost circulation zones, heaving shales and salt sections, and to permit drilling below these zones without having well problems.

- **Production liner:** Production liner is run instead of full casing to provide isolation across the production or injection zones. In this case, intermediate casing or drilling liner becomes part of the completion string.
- **Tie-back liner:** Tie-back liner is a section of casing extending upwards from the top of the existing liner to the surface. This pipe is connected to the top of the liner (Figure I .2(b)) with a specially designed connector. Production liner with tie-back liner assembly is most advantageous when exploratory drilling below the productive interval is planned. It also gives rise to low hanging-weights in the upper part of the well.
- **Scab liner:** Scab liner is a section of casing used to repair existing damaged casing. It may be cemented or sealed with packers at the top and bottom (Figure I .2(c)).
- **Scab tie-back liner:** This is a section of casing extending upwards from the existing liner, but which does not reach the surface and is normally cemented in place. Scab tie-back liners are commonly used with cemented heavy-wall casing to isolate salt sections in deeper portions of the well.[3]

The major advantages of liners are that the reduced length and smaller diameter of the casing results in a more economical casing design than would otherwise be possible and they reduce the necessary suspending capacity of the drilling rig. However, possible leaks across the liner hanger and the difficulty in obtain rig a good primary cement job due to the narrow annulus must be taken into consideration in a combination string with an intermediate casing and a liner.

5. Manufacturing of Casing:

The three basic processes used in the manufacturing of casing:

- Seamless process
- Electric-resistance welding
- Electric-flash welding

a. Seamless Process

In the seamless process, a billet is first pierced by a mandrel in a rotary piercing mill (Figure Ⅰ.3). The heated billet is introduced into the mill, where it is gripped by two obliquely oriented rolls that rotate and advance the billet into a central piercing plug.

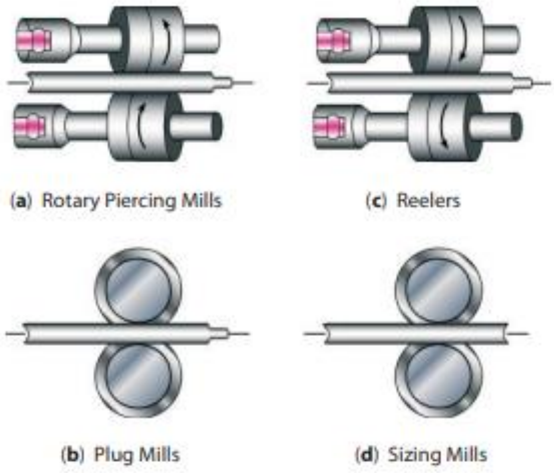


Fig. Ⅰ.3: Manufacturing of seamless casing (Mitchell and Miska, 2011). [4]

a. Electric-resistance welding

In the electric welding processes, flat sheet stock is cut and formed, and the two edges are welded together without the addition of extraneous metal to form the desired tube.

b. Electric-flash Welding

In electric-flash welding technique processes a sheet by cutting it to the desired dimensions, simultaneously forming the entire length into a tube, and flashing and pressing the two edges together to make the weld. Figure Ⅰ.4shows the steps of the manufacturing process for steel pipes and tubes in detail.[4]

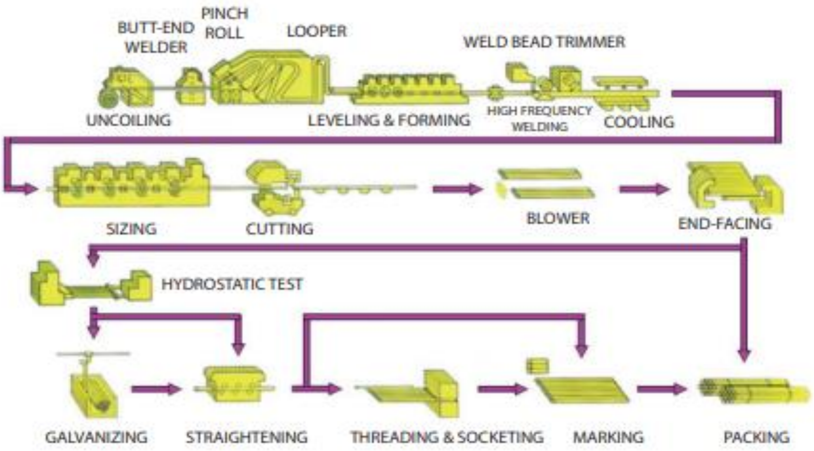


Fig. Ⅰ.4: Manufacturing process for steel pipes and tubes at TST pipes. [4]

6. Classification and Properties of Casing

The casing is manufactured in a wide variety of sizes, lengths, grades, and weights. The casing can be specially made for difficult environments such as highly corrosive, toxic, and high-pressure zones. A number of different coupling types are also available. The detailed specification of the sizes, weights, and grades of casing that are most commonly used has been standardized by the API. The various types of casing and their properties such as sizes, weights, and grades that are available can be found in manufacturer catalogs and cementing company handbooks. The casing is generally classified in manufacturer catalogs and handbooks in terms of:

- Outside diameter, Inside diameter and Wall thickness
- Rang of length.
- Casing grade.
- Casing weight in(lb/ft)
- Type of coupling i.e. connections. American Petroleum Institute (API) declared the standardization of casing based on these standards.

a. Outsidediameter, Insidediameter and Wallthickness

As mentioned earlier in this Chapter, different casing sizes are run at different parts of the hole to allow the drilling of the well to its total depth with minimum risk. Since pressures vary along every section of hole, it is possible to run a casing string having the same outside diameter but with different thicknesses (different ID's) or strength properties. Thus, a heavy or high-grade casing can be run only along the portions of the hole containing high pressures or near the surface, where tensile stresses are high. This arrangement provides the most economical way of selecting a given casing string.

The full details of API tolerances on outside diameter and weights are given in API SPEC 5CT. The API tolerance on outside diameter for non-upset casing is ±0.031 in. for 4 in. and smaller and ±0.75% for 4.5 in. and larger. The API tolerance on wall thickness is -12.5%.

Under casing dimensions, it is usual to find two values for inside diameter. The first is the inside diameter which is equal to outside diameter minus twice the nominal wall thickness. The second is described as the drift diameter. The latter refers to the diameter of a cylindrical drift mandrel that can pass freely through the casing with a reasonably exerted force equivalent to the weight of the mandrel being used for the test. The API stipulates that theleading edge of the mandrel shall be rounded to permit easy entry into the pipe. [5] The API recommended dimensions of drift mandrels are as follows (Table Ⅰ.1):

Table Ⅰ.1: The API recommended dimensions of drift mandrels. [5]

Casing and Liner Size (in)	**Drift Mandrel Size**			
	Length		**Diameter**	
	in	**mm**	**in**	**mm**
8$^{5/8}$" and smaller	6	152	ID-1/8	ID-3.18
9$^{5/8}$" to 13$^{3/8}$" inclusive	12	305	ID-5/32	ID-3.97
16" and larger	12	305	ID-3/16	ID-4.76

- ID: inside diameter

b. Range of Length

Casing is normally available in three length ranges as shown in Table Ⅰ.2. The joint length of the casing has been standardized and classified by the API recommendation.

In reality it is not possible to manufacture the casing to a specific length. Therefore, when the casing is delivered to the rig side, the length of each joint should be measured

Table Ⅰ.2: API casing length ranges [6]

Range	Length (ft)	Average length (ft)
R-1	16-25	22
R-2	25-34	31
R-3	>34	42

And recorded on the tally sheet. The length is measured from the top of the collar to the uppermost thread. Lengths are recorded to the nearest 100th of a foot. The most common range of lengths is 25–34 ft. However, the shorter lengths are useful as pup joints when spacing out the hanger.[6]

a. Casing Grade

API classification:

Casing grades are very much dependent on the chemical composition and the mechanical properties of steel. These properties of casing differ extensively. A variety of compositions and treatment processes are used during the manufacturing process to develop desired properties. The steel materials manufactured through the process have been classified by the API into a series of grades (Table Ⅰ.3). The table shows the maximum and minimum yield strength in addition to the minimum ultimate tensile strength. The minimum elongation is also shown to the corresponding grades. A letter and a number designate each grade. The letter refers to the chemical composition of the material and the number refers to the minimum yield strength of the material (i.e. N-80 casing means a minimum yield strength of 80,000 psi and K55 has a minimum yield strength of 55,000 psi). Therefore, the grade of the casing provides an indication of the strength of the casing, and the higher the grade is, the higher the strength of the casing shows up. Inaddition to the API grades, certain manufacturers produce their own grades of material. Both seamless and welded tubular are used as casing although seamless casing is the most common type of casing and only H and J grades are welded. [6]

Table Ⅰ.3: API Recommended Casing Grades and Properties [5]

API Grade	Yield Strength		Minimum Ultimate Tensile Strength	Minimum Elongation
	Minimum	**Maximum**	**psi**	**%**
H-40	40,000	80,000	60,000	29,5
J-55	55,000	80,000	75,000	24,0
K-55	55,000	80,000	95,000	19,5
C-75	75,000	90,000	95,000	19,5
L-80	80,000	95,000	95,000	19,5
N-80	80,000	110,000	100,000	18,5
C-90	90,000	105,000	100,000	18,5
C-95	95,000	110,000	105,000	18,0
S-95	95,000	110,000	110,000	18,0
T-95	95,000	110,000	105,000	18,0
P-110	110,000	140,000	125,000	15,0
Q-125	125,000	150,000	135,000	18,0

Non-API classification:

There is a casing in use around the globe that does not conform to the general API standards. These are usually casing designed for a very specific set of parameters, often stronger andwith high resistance to corrosive environments. An example of this is the casing developed for the Kristin field to combat HPHT challenges like sulfide stress cracking, where vanadium was added as an alloy, and the steel was tempered at a higher temperature.Table Ⅰ.4below shows a list of commonly used non-API grades. [7]

Table Ⅰ.4: Examples of non-API steel grades [7]

API Grade	**Manufacturers**	**Yield Strength**		**Minimum Ultimate Tensile Strength**	**Minimum Elongation**
		Minimum	**Maximum**	**psi**	**%**
S-80	Lone Star Longitudinal	75,000 55,000	- -	75,000 -	20,0 -
modN-80	Mannesmann	80,000	95,000	100,000	24,0
C-90	Mannesmann	90,000	105,000	120,000	26,0
SS-95	Lone Star Longitudinal	95,000 75,000	- -	95,000 -	18,0 -
S00-95	Mannesmann	95,000	110,000	110,000	20,0
S-95	Longitudinal Lone Star	95,000 92,000	- -	110,000 -	16,0 -
SOO-125	Mannesmann	125,000	150,000	135,000	18,0
SOO-140	Mannesmann	140,000	165,000	150,000	18,0
V-150	U.S. steel	150,000	180,000	160,000	14,0
SOO-155	Mannesmann	155,000	180,000	165,000	20,0

c. Casing Weight

AP1 defines three types of casing weight: (1) nominal weight; (2) plain end weight, and (3) threaded and coupled weight. The API tolerances on weights are +6.5% and -3.5%.

Nominal Weight

The term nominal weight is used primarily for the purpose of identification of casing types during ordering. It is expressed in lbm/ft or kg/m. Nominal weights are not exact weights and are normally based on the calculated, theoretical weight per foot for a 20 ft length of threaded and coupled casing joint.

Nominal weight, Wn, is calculated using the following formula:

$$W_n\left(\mathrm{lbm}/_{\mathrm{ft}}\right) = 10.68(D - t)t + 0.0722.\,D$$

Where:

- D = outside diameter (in.)
- t = wall thickness (in.)

Casing weights required for design purposes are usually reported as nominal weights.

Plain End Weight

The plain end weight(Wpe) is the weight of the casing joint without the inclusion of threads and couplings. The plain end weight can be calculated by use of the following formula:

$$\mathrm{W_{pe}}\left(\mathrm{lbm}/_{\mathrm{ft}}\right) = 10.68(\mathrm{D} - \mathrm{t})\mathrm{t}$$

Threaded And Coupled Weight

The threaded and coupled weight (W) is the average weight of a joint of casing including the threads at both ends and a coupling at one end when power-tight. This weight is calculated from the following formula:

$$W = \left(1/_{20}\right) \times \left\{W_{pe}\left[20 - \frac{(NL - 2J)}{24}\right] + weight\ of\ coupling \right.$$
$$\left. - weight\ removed\ in\ threading\ two\ pipe\ ends\right\}$$

Where:

- W = threaded and coupled weight (lbm/ft);
- NL = coupling length (in);
- J = distance from end of pipe to centre of coupling in the power-tight position (in) and
- Wpe = plain end weight, as calculated in Equation

The choice of which weight specification to use depends on the specific requirements of the drilling operation. Nominal weight is useful for comparing different casing pipes, while plain-end weight is important for design calculations.Threaded and coupled weight is used for determining the total weight of casing needed for a given length of the borehole.

It is important to note that the actual weight of the casing pipe may vary due to manufacturing tolerances and material properties, and the weight specification should be chosen based on the specific requirements of the drilling operation. Consulting with a qualified engineer or drilling specialist is recommended to determine the appropriate casing weight and specifications. [8]

a. Casing Connections

As already mentioned in the length ranges of casing in Table 8.1, sections of piece-wise casing are delivered to the rig side. Therefore, it must be joined with threaded connectors as each length is run in the well. A threaded connection is used to connect individual joints of the casing. It consists of a pin and a box.

Connections can be of three types: threaded and coupled, integral-joint, and flush joints (Figure Ⅰ.5).

Threaded and coupled connections have pins on both ends of the pipe that screw into a common coupling. For most threaded and coupled casings, the threads are cut into the unaltered diameter of the tubes.

Integral-joint casing connections often have the ends of the casing tube thickened (swaged) on either the tube OD or ID (or both). This provides more metal into which threads can be cut. These connections are classified into four types such as API, premium, gastight, and metal-to-metal seals. [9]

Table Ⅰ.5: API Recommended $9^{5/8}$” Casing Weight. [8]

Weight	**Outer diameter**	**Inner diameter**	**Wall thickness**	**Drift diameter**
lb_f/ft	**in**	**in**	**in**	**in**
53,5	9.625	8.535	0.545	8.379
47	9.625	8.681	0.472	8.525
43,5	9.625	8.755	0.435	8.599
40	9.625	8.835	0.395	8.679

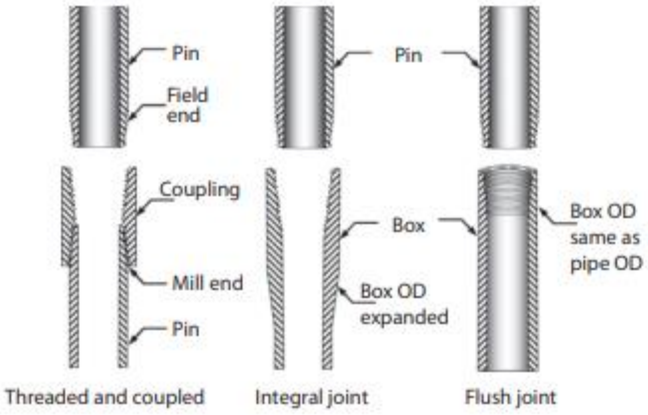


Figure Ⅰ.5: Different types of joints.[9]

Proprietary Couplings

In recent years, many proprietary couplings with premium design features have been developed to meet special drilling and production requirements. Some of these features are listed below:

- **Flush Joints:** Flush joints are used to provide maximal annular clearance in order to avoid tight spots and improve the cement bond.
- **Smooth Bores:** Smooth bores through connectors are necessary to avoid the turbulent flow of fluid.
- **Fast Makeup Threads:** Fast makeup threads are designed to facilitate fast makeup and reduce the tendency to cross-thread.
- **Metal-to-Metal Seals:** Multiple metal-to-metal seals are designed to provide improved joint strength and pressure containment.
- **Multiple Shoulders**: The use of multiple shoulders can provide improved sealing characteristics with adequate torque and compressive strength.
- **Special Tooth Form:** Special tooth form, e.g., a squarer shape with negative flank angle provides improved joint strength and sealing characteristics.
- **Resilient Rings:** If resilient rings are correctly designed, they can serve as secondary pressure seals in corrosive and high-temperature environments. [9]

7. Casing strength specifications:

In the oil drilling industry, casing is used to support the walls of the wellbore and prevent collapse. There are several key strength specifications that are important to consider when selecting casing for a well. These include yield strength, collapse strength, and burst strength.

a. Yield Strength:

Yield strength is the maximum stress that a material can withstand without undergoing permanent deformation. It is a critical parameter when selecting casing, as it determines the maximum load that the casing can bear before it permanently deforms. For oil drilling, the yield strength of casing is typically specified in units of pounds per square inch (psi). Casing with higher yield strength is preferred, as it can withstand higher loads without deformation.

b. Collapse Strength:

Collapse strength refers to the amount of pressure that the casing can withstand without collapsing. The collapse strength is determined by the external pressure applied to the casing, such as the weight of the rock and sediment above the well. The collapse strength of casing is typically specified in units of psi. Casing with higher collapse strength is preferred for deep wells or wells in regions with high formation pressure, as it can withstand the external pressure without collapsing.

c. Burst Strength:

Burst strength is the maximum pressure that the casing can withstand before rupturing. This is a critical parameter when drilling under high-pressure conditions, such as in deep wells or in regions with high formation pressure. The burst strength of casing is typically specified in units of psi. Casing with higher burst strength is preferred, as it can withstand higher pressures without rupturing.

In summary, yield strength, collapse strength, and burst strength are all important strength specifications to consider when selecting casing for oil drilling. The selection of casing with appropriate strength specifications is critical to ensure the safety and success of the drilling operation.

CHAPTER Ⅱ:

CASING MATERIAL SELECTION & PROPERTIES

1. Introduction:

In this chapter, we cover the first three steps of basic casing design:

- Determined casing depths
- Selected casing sizes
- Developed pressure load plots for collapse and burst

We continue the process to make our initial casing design, and then refine it to account for combined loads. Our method will proceed as follows:

- Develop design loads for collapse and burst.
- Select casing for collapse and burst design.
- Develop axial load plots.
- Develop axial design plots.
- Adjust preliminary casing selection for axial loads.
- Refine basic design/selection for combined loads.

As previously discussed, casing selection is primarily a two-step procedure when done manually. Just like writers make a first draft then revise it to make it better, we make a preliminary casing selection based on published strength properties of the tube then refine it, if necessary, to account for the effects of combined loads. It is very easy to use the published values to get a preliminary design; and when used with appropriate design factors, many of these preliminary designs become a final design with no need for further refinement. However, the currently published values for collapse, burst, and tension are based on tests and formulas that assume no other loads are present in the casing. In other words, the collapse rating you see in the tables is the collapse rating with no tension in the tube; the collapse rating is lower if the tube is in tension, but such a value does not appear in any standard tables. We begin with the initial selection process then discuss ways to refine it for combined loading.

2. Casing Design Principles:

2.1.Casing Strength

The most significant load cases are investigated in relation to the burst, collapse, axial and triaxial strength of the casing.

2.1.1. Burst Strength

The maximum value of internal pressure required to cause the casing to yield is called burst strength (Rabia, 1987, p.41). The API burst rating, the minimum burst resistance of casing, is calculated by Barlow's formula:

$$P_b = \frac{[0.875 \times (2.YP)]}{D}$$

The factor 0.875 in was introduced by the API to allow a 12.5% variation in wall thickness due to manufacturing defects. This factor obviously introduces an unnecessary derating of casing burst strength and with today's accurately controlled manufacturing processes, the factor can be relaxed or even eliminated altogether. For this reason, the author recommends using burst strength values as supplied by the manufacturers.[6]

2.1.2. Collapse Strength

Collapse strength is defined as the maximum external pressure that is required to collapse the casing (Rabia, 1987, p.29). There are four different modes of collapse; yield-strength collapse, plastic collapse, transition collapse and elastic collapse. The slenderness ratio determines the type of collapse, and is defined as the ratio of the outer diameter to the wall thickness, D/t. In the following equations it is assumed that there is no internal pressure or axial stress (Bourgoyne et al., 1986, p.308).

A) Yield-Strength Collapse Pressure Formula:

The yield-strength collapse-pressure formula calculates the external pressure that generates the minimum yield stress on the inside wall of a tube and can be derived theoretically using the Lamé equation. He formulated this equation for the thickest-walled tubulars used in oil wells. The equation can be written as:

$$P_y = 2YP\left[\frac{\left(\frac{D}{t}\right) - 1}{(\frac{D}{t})^2}\right]$$

The range of D/t values is applicable is given by:

$$\frac{D}{t} \leq \frac{\left[(A-2)^2 + 8(B + \frac{C}{YP})\right]^{0.5} + (A-2)}{2(B + \frac{C}{YP})}$$

B) Plastic-Collapse Pressure Formula:

The equation is based on 2,488 physical collapse tests of K-55, N-80, and P-110 casings (API TR 5C3 2800). Statistical methods were used to analyze the results of the physical tests, and a plastic-collapse formula was developed to calculate a collapse value with a 95% probability that the actual collapse pressure will exceed the minimum stated with no more than a 0.5% failure rate:

$$\mathrm{P_p} = \mathrm{YP}\left(\frac{\mathrm{A}}{\frac{\mathrm{D}}{\mathrm{t}}} - \mathrm{B}\right) - \mathrm{C}$$

The range of D/t values is applicable is given by:

$$\frac{\left[(\mathrm{A}-2)^2 + 8(\mathrm{B}+\frac{\mathrm{C}}{\mathrm{YP}})\right]^{0.5} + (\mathrm{A}-2)}{2(\mathrm{B}+\frac{\mathrm{C}}{\mathrm{YP}})} \le \frac{\mathrm{D}}{\mathrm{t}} \le \frac{\mathrm{YP}(\mathrm{A}-\mathrm{F})}{\mathrm{C}+\mathrm{YP}(\mathrm{B}-\mathrm{G})}$$

C) Transition-Collapse Pressure Formula:

The transition-collapse formula was developed to provide a transition from the plastic-collapse formula to the elastic-collapse formula:

$$P_t = YP\left(\frac{F}{\frac{D}{t}} - G\right)$$

The range of D/t values is applicable is given by:

$$\frac{\mathrm{YP}(\mathrm{A}-\mathrm{F})}{\mathrm{C}+\mathrm{YP}(\mathrm{B}-\mathrm{G})} \le \frac{\mathrm{D}}{\mathrm{t}} \le \frac{2+\frac{\mathrm{B}}{\mathrm{A}}}{3\frac{\mathrm{B}}{\mathrm{A}}}$$

D) Elastic-Collapse Pressure Formula:

This equation was theoretically derived and was found to be an adequate upper bound for collapse pressures as determined by testing. API adopted this equation in 1968.

$$P_c = \frac{46.978 \times 10^2}{\frac{D}{t} \times \left(\frac{D}{t} - 1\right)^2}$$

The range of D/t values is applicable is given by:

$$\frac{D}{t} \geq \frac{2+\frac{B}{A}}{3\frac{B}{A}}$$

E) Collapse Resistance of Casing with Combined Loading Formula:

API offers an equation to calculate the external pressure equivalent when both external and internal pressures are applied to a tubular:

$$P_{eq} = P_e - \left[1 - \frac{2}{\frac{D}{t}}\right] P_i$$

F) Collapse Pressure with Axial Stress:

The current API formula accounts for the combined influence of tension and collapse loading on a casing by modifying the minimum yield strength to the yield strength of an axial-stress-equivalent grade. [6]. The equivalent yield-strength formula is:

$$\sigma_{pa} = \left[\sqrt{1 - 0.75\left(\frac{\sigma_a}{YP}\right)^2} - 0.5\left(\frac{\sigma_a}{YP}\right)\right] YP$$

Where:

- σ_{pa} = equivalent yield strength, psi
- σ_a = total axial stress, not included bending due to hole deviation, doglegs, or buckling
- Peq = external pressure equivalent in collapse due to external and internal pressure
- Pe= external pressure,
- Pi = Internal pressure
- T = thickness of Casing (in.)
- D=OD Of casing (in.)
- YP= minimum yield strength (psi)
- $A = 2.8762 + 0.10679 \times 10^{-5}YP + 0.21301 \times 10^{-10}YP^2 - 0.53132 \times 10^{-16}YP^3$
- $B = 0.026233 + 0.50609 \times 10^{-6}YP$
- $C = 465.93 + 0.030867.\,YP - 0.10483 \times 10^{-7}YP^2 + 0.36989 \times 10^{-13}YP^3$

$$F = \frac{46.95 \times 10^6 \times \left(\dfrac{3\frac{B}{A}}{2+\frac{B}{A}} \right)^2}{YP \times \left(\dfrac{3\frac{B}{A}}{2+\frac{B}{A}} - \frac{B}{A} \right) . \left(1 - \dfrac{3\frac{B}{A}}{2+\frac{B}{A}} \right)^2}$$

1.1.Casing load

1.1.1. Collapse Load

The casing will experience a net collapse loading if the external radial load exceeds the internal radial load (Figure 15). The greatest collapse load on the casing will occur if the casing is evacuated (empty) for any reason. The collapse load, Pc at any point along the casing can be calculated from:

$$Pc = Pe - Pi$$

1.1.2. Burst Load

The casing will experience a net burst loading if the internal radial load exceeds the external radial load. The burst load, P_b at any point along the casing can be calculated from:

$$P_b = P_i - P_e$$

In designing the casing to resist burst loading the pressure rating of the wellhead and BOP stack should be considered since the casing is part of the well control system. The internal, Pi and external, Pe loads which are used in the determination of the burst and collapse loads on the casing are derived from an analysis of operational scenarios.

1.1.3. External Loads, Pe :

The following issues are considered when deciding upon the external load to which the casing will be subjected:

(a.)The pore pressure in the formation (pore pressure)

If the engineer is satisfied that it will be possible to displace all of the mud from the annulus between the casing and borehole during the cementing operation, and that a satisfactory cement sheath can be achieved, the formation pore pressure is generally used to determine the load acting on the casing below the top of cement in the annulus, after the cement has hardened.

(b.) The weight of the mud in which the casing was run.

If a poor cement bond between the casing and cement or cement and borehole is anticipated then the pressure due to a colom of mud in the annulus is generally used to determine the load acting on the casing below the top of cement in the annulus, after the cement has hardened. If the mud has been in place for more than 1 year the weighting material will probably have settled out and therefore the pressure experienced by the casing will be due to a colom of mud mixwater (water or base oil).

(c.) The pressure from a colom of cement mixwater

The pressure due to the cement mixwater is often used to determine the external load on the casing during the producing life of the well. This pressure is equal to the density of fresh or seawater in the case of water-based mud and base oil in the case of oil based mud. The assumption is that the weighting material in the mud (generally Barite) has settled from suspension.

(d.) The pressure due to a colom of cement slurry

The pressure exerted by a colom of cement slurry will be experienced by the casing until the cement sets. It is assumed that hardened cement does not exert a hydrostatic pressure on the casing.

(e.) Blockage in the annulus

If a blockage of the annulus occurs during a stinger cement operations (generally performed on a conductor casing). The excess pumping pressure on the cement will be transmitted to the annulus but not to the inside of the casing. This will result in an additional external load during stinger cementing. In the case of conventional cementing operations a blockage in the annulus will result in an equal and opposite pressures inside and outside the casing.

1.1.4. Internal Loads, Pi ::

It is commonplace to consider the internal loads due to the following:

(a.) Mud to Surface:

This will be the predominant internal pressure during drilling operations. The casing designer must consider the possibility that the density of the drilling fluid may change during the drilling operation, due to for instance lost circulation or an influx.

(b.) Pressure due to influx:

The worst case scenario which can arise, from the point of view of burst loading, is if an influx of hydrocarbons occurs, that the well is completely evacuated to gas and simultaneously closed in at the BOP stack.

(c.) Full Evacuation:

The worst case scenario which can arise, from the point of view of collapse loading, is if the casing is completely evacuated.

(d.) Production Tubing Leak:

In the case of production casing specifically a leak in the production tubing will result in the tubing pressure being exposed to the casing. The closed in tubing pressure is used as the basis of determining the pressure on the casing. This is calculated on the basis of a colom of gas against the formation pressure. The pressure below surface is based on the combined effect of the tubing head pressure and the hydrostatic pressure due to a colom of packer fluid (if there is any in the annulus).

(e.) Fracture Pressure of Open Formations:

When considering the internal loads on a casing string the fracture pressure in any formations open to the internal pressures must be considered. The pressure in the open hole section cannot exceed the fracture pressure of the weakest formation. Hence, the pressures in the remaining portion of the borehole and the casing will be controlled by this fracture pressure. The formation just below the casing shoe is generally considered to be the weakest formation in the open hole section. [12]

2. Casing Design Process:

2.1.Introduction to the casingdesign process:

The casing design process involves three distinct operations: the selection of thecasing sizes and setting depths; the definition of the operational scenarios which willresult in burst, collapse and axial loads being applied to the casing; and finally thecalculation of the size of these loads and selection of an appropriate weight andgrade of casing. The steps in the casing design process are shown in Figure Ⅱ.1.

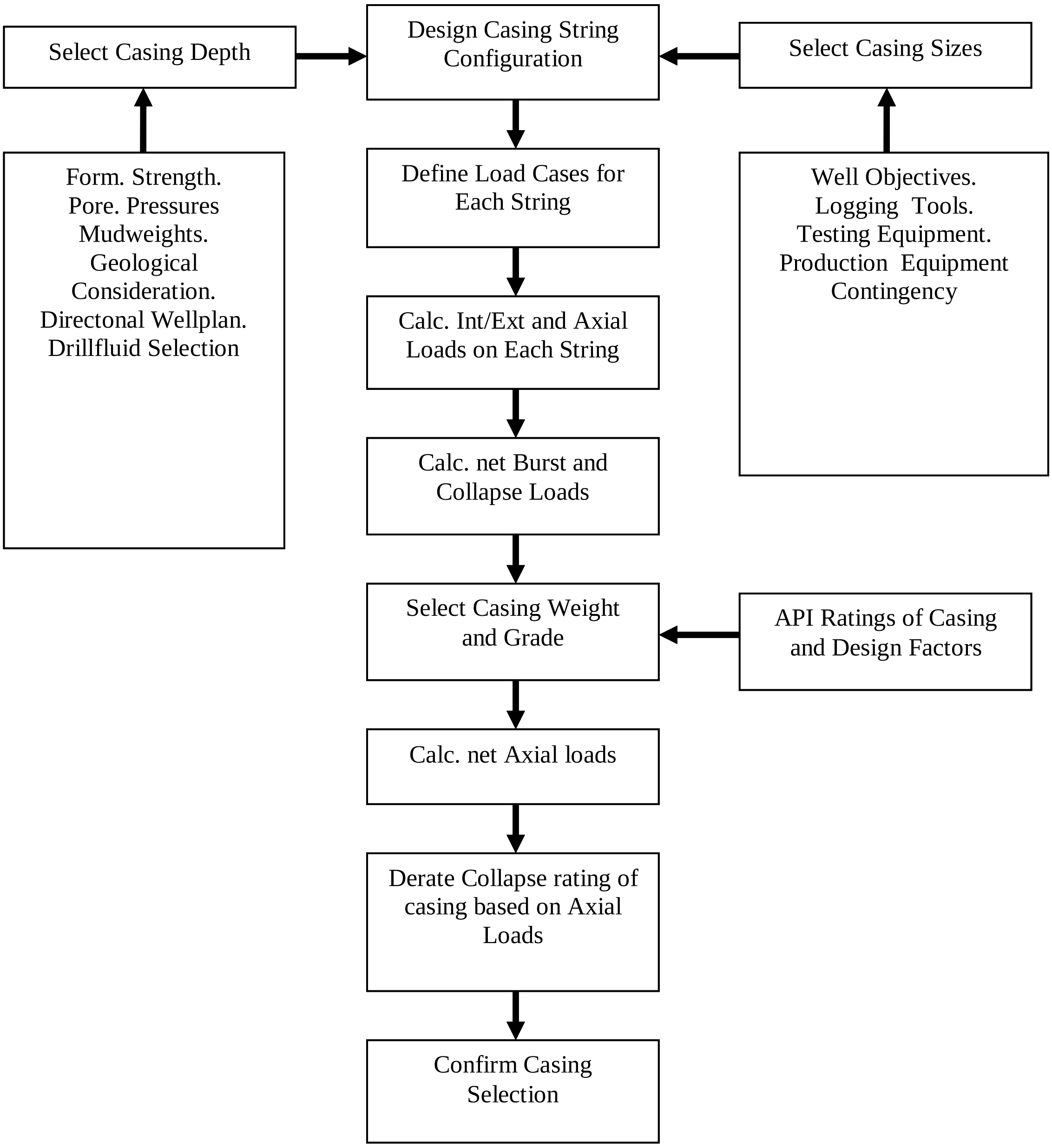


Fig.Ⅱ.1: Casing design process [13]

2.2.Design casing scheme configuration - select casing sizes andsetting depths:

The casing setting depths are selected on the basis of an assessment of the conditionsto be encountered when drilling the subsequent hole section or, in the case ofproduction casing, the completion design.

The first step in deciding upon the setting depth for the surface and intermediate casingstrings is to calculate the maximum pressures that could be encountered in the holesection below the string in question. These pressures must not exceed the formationstrength at any point in the hole and in particular at the casing shoe. The highestpressure that will be encountered in the open hole section will occur when circulatingout a gas influx The formation strength can beestimated from nearby well data or by calculation procedure for establishing the acceptable setting depthis illustrated in Figure Ⅱ.2:

1. Start at Total Depth (TD) of the Well
2. Determine the formation fracture pressure at all points in the well
3. Calculate the borehole pressure profile when circulating out a gas influx fromTD
4. Plot the formation fracture pressure and the wellbore pressure when circulating out an influx, on the same axes
5. The casing must be set at least at the depth where the two plots cross i.e. this is the shallowest depth at which the casing can be safely set. If the casing is set any shallower when drilling this hole section then the formation will fracture if an influx occurs.
6. Repeat steps 2 to 5 moving up the well, with each subsequent string starting at the casing setting depth for each string.[14]

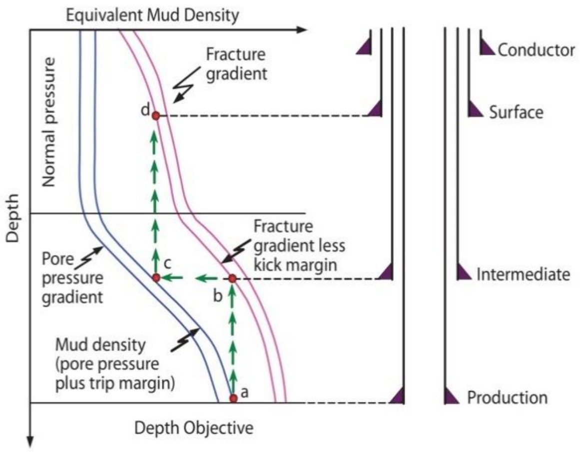


Fig.Ⅱ.2: Casing setting depthdetermination [14]

The setting depth of the casing will also be determined by a range of other considerations such as: the need to isolate weak formations from high mud weights; isolate lost circulation zones; and to isolate troublesome formations, such as shales, which can cause hole problems whilst drilling subsequent formations.

The casing sizes and string configuration are dictated by the size of the smallest casing string to be run in hole. Once the smallest casing size is known all subsequent casing sizes (and hole sizes) are selected from Figure Ⅱ.3. The smallest casing size is selected on the basis of operational considerations such as: the size and configuration of the completion string or well testing and/or the size of the logging tools to be run through the casing. The drilling engineer will collate this information from the geology, reservoir engineering and production engineering departments. The objective of the drilling engineer is to use the smallest casing sizes possible. It can be readily appreciated that if it is acceptable to use a 4” casing string as the production casing then the next string will be 7”, the next 9 5/8” and so forth. Hence, if only three casing strings are required then the surface string can be 9 5/8”. This slim hole design will result in considerable savings in drilling and equipment costs**.**[5]

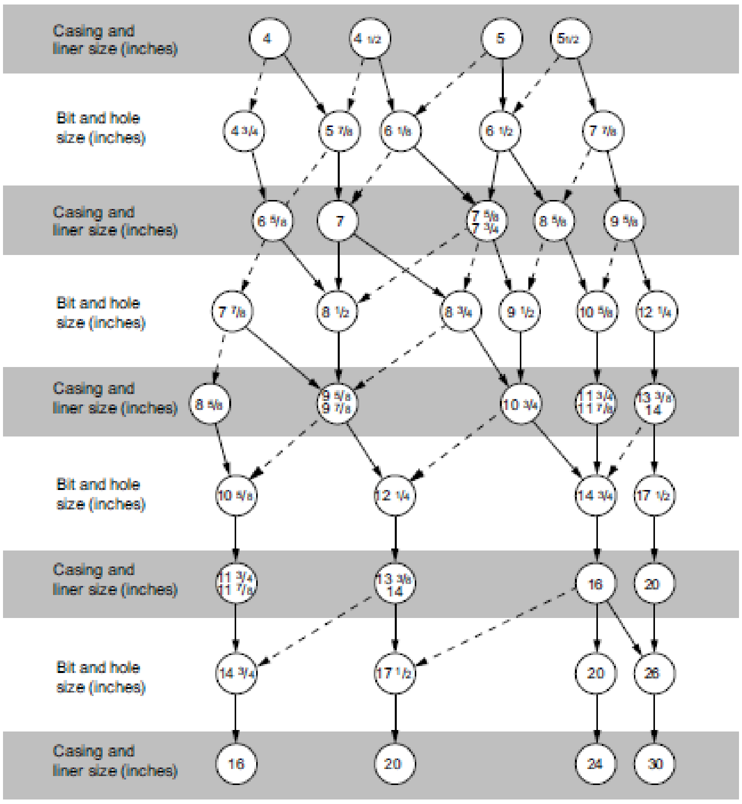


Fig. Ⅱ.3: Casing string sizes [5]

2.3.Calculate the loads on the casing and select the appropriate weight and grade of casing

Having defined the size and setting depth for the casing strings, and defined the operational scenarios to be considered, the loads to which the casing will be exposed can be computed. The particular weight and grade of casing required to withstand these loads can then be determined.

2.3.1. CollapseCriterion:

Collapse pressure originates from the column of mud used to drill the hole, and acts on the outside of the casing. Since the hydrostatic pressure of a column of mud increases with depth, collapse pressure is highest at the bottom and zero at the top,

This is a simplified assumption and does not consider the effects of internal pressure. For practical purposes, collapse pressure should be calculated as follows:

Collapse pressure = External pressure – Internal pressure

Casing is usually designed against worst collapse conditions. The worst collapse conditions happen when the casing inner portion is assumed to be empty and the annulus completely filled with the drilling mud. Casing collapse stress increases with the mud hydrostatic depth.

2.3.2. Burst Criterion:

Burst pressure is also called internal yield pressure for pipe. In general, the casing experiences a net burst loading if the internal radial load exceeds the external radial load. The burst load, P_b at any point along the casing can be calculated using Equation:

$$\text{Burst pressure} = \text{Internal pressure} - \text{External pressure}$$

In designing the casing to resist burst loading the pressure rating of the wellhead and BOP stack should be considered since the casing is part of the well control system. The following assumptions need to be considered while designing burst pressure.

Assumptions:

1. Based on well-control condition assumed to occur while circulating out a large kick
2. The burst design should ensure that formation fracture pressure should be exceeded before the burst pressure of the casing is reached
3. The formation fracture pressure is used as a safety pressure release mechanism.
4. The design pressure at the casing seat is equal to the fracture pressure plus a safety margin.
5. The pressure inside the casing is calculated assuming that all of the drilling fluid in the casing is lost to the fractured formation leaving only formation gas in the casing
6. The external pressure (backup pressure) outside the casing is assumed to be equal to the normal formation pore pressure
7. A safety factor is assumed (1.1-1.2) [15]

2.3.3. Tension Criterion:

Most axial tension arises from the weight of the casing itself. Other tension loadings can arise due to: bending, drag, shock loading and during pressure testing of casing.

In casing design, the uppermost joint of the string is considered the weakest in tension, as it has to carry the total weight of the casing string. Selection is based on a design factor of 1.6 to 1.8 for the top joint. Tensile forces are determined as follows:

calculate weight of casing in air (positive value) using true vertical depth;

$$\text{Casing air weight} = \text{casing weight}\left({}^{\text{lb}}/_{\text{ft}}\right) \times \text{hole TVD}$$

calculate buoyancy force (negative value);

- For open-ended casing :Buoyancy force $= \mathrm{P_e} - (\mathrm{A_e} - \mathrm{A_i})$
- For closed casing :Buoyancy force $= \mathrm{P_e A_e} - \mathrm{P_i A_i}$

Since the mud inside and outside the casing is invariably the same, the buoyancy force is almost always given by:

$$\text{Buoyancy force} = \mathrm{P_e}(\mathrm{A_e} - \mathrm{A_i})$$

If a tapered casing string is used then the buoyancy force at TD is calculated as above. At a cross-sectional change, the buoyancy force is calculated as follows:

$$\text{Buoyancy force} = \mathrm{P_{e2}}(\mathrm{A_{e2}} - \mathrm{A_{e1}}) - \mathrm{P_{i2}}(\mathrm{A_{i2}} - \mathrm{A_{i1}})$$

calculate bending force in deviated wells (positive value) :

$$\text{Bending force} = 63\mathrm{W_n} \times \mathrm{OD} \times \theta$$

calculate drag force in deviated wells (this force is only applicable if casing is pulled out of hole);

calculate shock loads due to arresting casing in slips;

$$\text{Shock load (max)} = 1500 \times \mathrm{W_n}$$

calculate pressure testing forces :

$$\mathrm{F_t} = \frac{\pi.\,\mathrm{ID}}{4} \times \text{test pressure}$$

Forces (1) to (3) always exist, whether the pipe is static or in motion. Forces (4) and (5) exist only when the pipe is in motion. The total surface tensile load (sometimes referred to as installation load) must be determined accurately and must always be less than the yield strength of the top joint of the casing. Also, the installation load must be less than the rated derrick load capacity so that the casing can be run in or pulled out of hole without causing damage to the derrick. [16]

Where:

- Pe = external hydrostatic pressure, psi
- Pi = internal hydrostatic pressure, psi
- Ae and Ai are external and internal areas of the casing.
- Wn = weight of casing lb/ft (positive force).
- θ= dogleg severity, degrees/100 ft.
- Ft = pressure test force, lb
- ID = inside diameter of casing, in

- **Load Cases**

Load Case 1: Running Conditions

This applies to the case when the casing is run in hole and prior to pumping cement:

Total tensile force = buoyant weight + shock load +bending force

Load Case 2: Pressure Testing Conditions

This condition applies when the casing is run to TD, the cement is displaced behind the casing and mud is used to apply pressure on the top plug. [16]

2.4.Graphical method description:

The graphical method to select casings with the suitable grades, weights and section lengths is the most often applied one. Here, the individual loads (burst, collapse and tensions) are represented as graphs on a pressure vs. depth diagram. The minimum strength values of the individual casing sections are drawn as vertical lines where the suitable ones have to be to the right of the respective loads (stronger)

2.4.1. Diagram construction

In this way, the depth where the minimum safety (load and casing minimum strength are closest) can be easily spotted and the respective factors calculated.

To construct the diagram, following procedures can be applied:

2.4.1.1.Burst line:

1) Calculate the external pressure due to an assumed fluid column of 0.465 [psi/ft] (salt saturated completion fluid),
2) Calculate the internal pressure due to the maximum anticipated pressures when drilling the next section,

3) Calculate the burst pressure P_b as the difference between the external and the internal pressures,

$$P_b = P_f - (TD - CSD).G_f - 0.052.M_w.CSD$$

Where:

- P_f[psi] maximum anticipated formation pressure to drill next section
- TD [ft] total depth (TVD)
- CSD [ft] casing setting depth (TVD)
- G_f [psi/ft] formation fluid gradient
- M_W [ppg] mud density

4) In this way the burst pressure at the surface is calculated as:

$$P_b = P_f - TD.G_f$$

5) On the pressure vs. depth graph draw a straight line between the maximum Burst pressure at the casing top and the minimum burst pressure at the casing shoe:
   - Select from API tables casings with burst resistance above the burst loading line.
   - Draw the vertical lines of the casings with the individual grades.
   - The individual intersections of the burst loading line and the casing burst resistances determine the depths from which upwards the casing grades can be used.

2.4.1.2.Collapse line:

1) Calculate the external and internal pressure
   - due to the mud columns outside and inside the casing,
2) Calculate the collapse pressure pc as the difference between the external and the internal pressures,
3) On the pressure vs. depth graph draw a straight line between the maximum collapse pressure at the casing shoe and the zero at the casing top,
   - Select from API tables casings with collapse resistance above the collapse loading line,
   - Draw the vertical lines of the casings with the individual grades,
4) The individual intersections of the collapse loading line and the casing collapse resistances determine the depths up to the casing grades can be used.

2.4.1.3.Tensile line:

Calculate the weight of the casing string in air,

Calculate the buoyancy force,

Calculate the bending force.

Calculate shock loads due to setting of the casing

Draw tensile loading on the pressure vs. depth graph, Select casings from table that have higher body yield strength than the tensile loading,

2.4.2. Final steps of the graphical design:

1) Having drawn all three major design criteria within one plot, a combined casing sting that is strong enough at all depth can be selected (Figure Ⅱ.4).
2) Finally check that the joint strengths are larger the calculated tensile loading.
3) Note that this procedure for casing design considers strength criteria only and is not optimized for real casing costs.
    - Thus a stronger casing might be preferred since it is cheaper (availability, etc.) than a weaker one.[17]

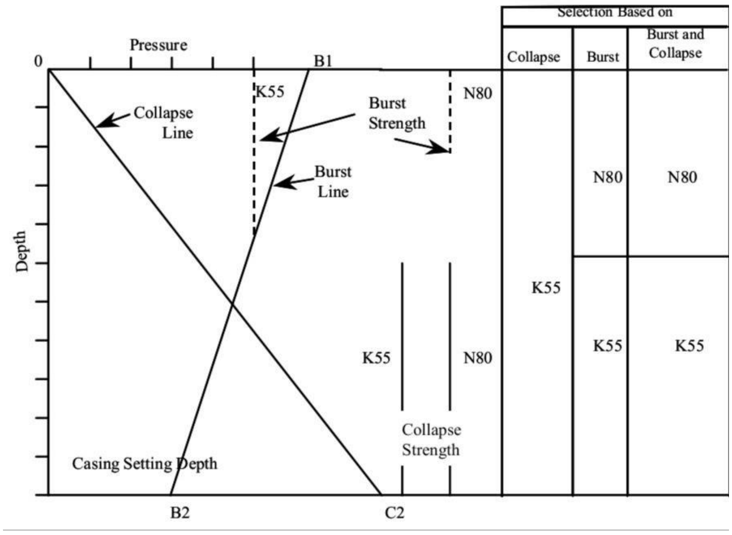


Fig. Ⅱ.4: Sketch of graphical design of a casing string [17]

2.5.Other Casing Design Consideration:

2.5.1. Collapse design consideration:

- ✓ The load criteria assumed above are based on a 100 % empty casing (collapse) and a 100% gas-kick filled (burst) one respectively.
- These are very conservative assumptions that lead to over-design causing unnecessary high cost of the casing string.

- If standard drilling procedures and precautions are followed, these assumptions are not to be expected.
- When drilling into a weak or fractured formation that causes lost circulation,
    - the remaining fluid height can be estimated with:

$$L = \frac{0.465.\,\mathrm{CSD}}{0.052.\,\mathrm{Mw}}$$

Where:

M_W [ppg] weight of mud used to drill next section.

✓ For this reason the casing is supported in the inside by the hydrostatic pressure of the remaining mud column of length L.

2.5.2. Burst design consideration:

In case of burst, the conservative assumption can be relaxed with the assumption that

- The gas-kick will fill between 40% to 60% of the hole before the well is shut in and steps to circulate the kick out are taken.
- Modern kick detection systems detect kicks of 20 [bbl] and below (depending on the hole size) and thus the assumption above could be even more relaxed.[17]

2.6.Define the operational scenarios and consequent loads on the casing

Once the casing is landed and cemented, it will be subjected to additional forces if drilling is continued beyond this casing or if this casing is used as a production casing. These service loads represent extra set of load cases which must be checked before the casing is selected.

To calculate the tensile load on the casing, the base load must first be calculated:

$$F_{\text{base load}} = \text{Air weight} - \text{Buoyancy force} + \text{bending force} + \text{pressure testing force} + \text{landingforce (if applied)} \dots (1)$$

The additional forces that must be added include ballooning force and temperature force.

$$\text{Ballooning force} = 2\,\nu\,(Ai\,\Delta Pi - Ae\,\Delta Pe) \dots (2)$$

Where:

- ν = Poisson’s ratio
- Δ Pi = change in internal pressure inside the casing
- Δ Pe = change in external pressure outside the casing
- Force due to temperature change = - 207 as ΔT
- ΔT = temperature change, °F
- As = cross-sectional area, in^2

To use Equation (2), the engineer therefore must define all possible changes in internal and external pressures to calculate the ballooning force. For the majority of conventional wells, the base load case in Equation (1) provides most of the forces the casing is likely to see in its service life.

Other loadings that may develop in the casing include: (a) bending with tongs during makeup; (b) pull-out of the joint and slip crushing; (c) corrosion and fatigue failure, both of the body and of' the threads; (d) pipe wear due to running wire line tools and drillstring assembly which can be extremely detrimental to casing in deviated and dog-legged holes; and (e) additional loadings arising from treatment operations. The latter operations include acidising, cementing and hydrofracturing operations.

As a design rule, it usually accepted that casings which are subjected to a great deal of wear as a result of drilling and wireline operations should be upgraded to the next weight up. In other words if the design shows that 43.5 lb/ft,95/8" casing satisfy collapse, burst and tension, then it should be upgraded to 47 lb/ft if this casing is expected to see a great deal of wear.[16]

2.7.Biaxial Effects:

The combination of stresses due to the weight of the casing and external pressures are referred to as 'biaxial stresses’. The determination of the collapse resistance under tensile load was presented in detail,

The procedure for allowing for biaxial effects is as follows:

1. Select grade/weight based on burst/collapse calculations
2. Check the grade/weight satisfy the tension criterion

3. Determine the tension at critical points within the well
4. Apply the procedure to calculate the reduced collapse strength
5. Re-calculate the new design factor in collapse

2.8.Triaxial Analysis :

In the previous sections, pressure and axial loads were treated separately in what is termed as uniaxial approach. In practice, pressure loads and axial stresses exist simultaneously. For example, in a casing string subjected to collapsing load, the stresses within the string will depend on the magnitude of the external pressure causing the collapse load as well as on the resisting internal pressure and the axial load at the point of interest.

The axial force, external and internal pressure generates triaxial stresses within the casing body. These triaxial stresses are more representative of the loading at any point as they consider the effects of all applied stresses at that point. In other words, tension is not considered separately from burst or collapse. The three generated triaxial stresses are: axial, radial and tangential.

To perform triaxial analysis, the axial, radial and tangential stresses need to be calculated at each point of interest, e.g. at surface, top of cement and shoe. These stresses will also need to be calculated at both the internal and the external radii of the casing at critical points.

2.8.1. Points of interest for triaxial checks :

The following points should be checked:

- At surface
- At top of cement
- At change in casing weight, grade, ID, or OD (ie in combination strings)
- At change in external pressure
- At changes in hole geometry: dogleg severity, washouts etc.

2.8.2. Conditions For Carrying Out Triaxial Checks

- Pore pressure is greater than 12000 psi
- Bottom hole temperature is greater than 250 °F
- For all HPHT intermediate and production casing strings
- H2S service
- For casing with OD/t ratio less than 15

2.8.3. Radial And Tangential Stresses

The presences of fluids inside and outside the casing generate radial and tangential stresses which are given by:

$$\sigma_r = \frac{d_i^2\, P_i - d_e^2\, P_e}{d_e^2 - d_i^2} - \frac{d_i^2 d_e^2 (P_i - P_e)}{(d_e^2 - d_i^2) r^2}$$

$$\sigma_t = \frac{d_i^2\, P_i - d_e^2\, P_e}{d_e^2 - d_i^2} + \frac{d_i^2 d_e^2 (P_i - P_e)}{(d_e^2 - d_i^2) r^2}$$

Where:

- r = distance at which σr and σt are measured.
- Pi = Internal pressure, psi
- Pe = external pressure
- di and de = internal and external diameter respectively

The magnitude of the radial and tangential stresses depends on the magnitude of external and internal pressures and on the distance r.

2.8.4. Axial Stress

The effective axial stress is given by:

$$\sigma_a = \left(\frac{\text{air weight}}{\text{casing cross} - \text{sectional area}}\right) - \text{buoyancy force}$$

2.8.5. Von Mises Equivalent Stress

The Von Mises (VM) distortion energy theory is used to predict the onset of yielding in ductile materials such as casing. The axial, radial and tangential stresses can be combined into an equivalent triaxial stress ($\sigma_{VM)}$ acting at a particular point, given by

$$\sigma_{VM} = \frac{1}{\sqrt{2}}[(\sigma_a - \sigma_t)(\sigma_t - \sigma_r)(\sigma_r - \sigma_a)]^{0.5}$$

The yield criterion is satisfied when the combined VM stress is equal to the material yield stress (YP).In the absence of bending forces, the maximum VM stresses occur at the inner radius, r= di. With bending, the maximum stresses can occur at the inside or outside diameter of the casing. [16]

The calculated VM stress is then compared with the yield strength of the casing and a design factor > 1.25 should be obtained:

$$\mathrm{DF} = \frac{\text{Material Yield Stress}}{\sigma_{\mathrm{VM}}}$$

2.9.Summary of design process:

The design process can be summarized as follows:

1. Select the Casing sizes and setting depths on the basis of: the geological and pore pressure prognosis provided by the geologist and reservoir engineer; and the production tubing requirements on the basis of the anticipated productivity of the formations to be penetrated.
2. Define the operational scenarios to be considered during the design of each of the casing strings. This should include installation, drilling and production (as appropriate) operations.
3. Calculate the burst loading on the particular casing under consideration.
4. Calculate the collapse loading on the particular casing under consideration.
5. Increase the calculated burst and collapse loads by the Design Factor which is appropriate to the casing type and load conditions considered.
6. Select the weight and grade of casing (from manufacturers' tables or service company tables) which meets the load conditions calculated above.
7. For the casing chosen, calculate the axial loading on the casing. Apply the design factor for the casing and load conditions considered and check that the pipe body yield strength of the selected casing exceeds the axial design loading. Choose a coupling whose joint strength is greater than the design loading. Select the same type of coupling throughout the entire string.
8. Taking the actual tensile loading from? Above determine the reduction in collapse resistance at the top and bottom of the casing.

Several attempts may have to be made before all these loading criteria are satisfied and a final design is produced. When deciding on a final design bear the following points in mind:

- Include only those types of casing which you know are available. In practice only a few weights and grades will be kept in stock.
- Check that the final design meets all requirements and state clearly all design assumptions.
- If several different designs are possible, choose the most economical scheme that meets requirements. [13]

Capter Ⅲ

Casing Failure Analysis and Prevention

Ⅲ.1.Introduction:

As oil and gas fields development continues, casing damaged wells increase in number year by year. Especially in mature oilfields where the casing mechanism is complex and the problem of casing failure is extra severe, the production is adversely impacted.

Therefore, the casing failure characteristics and pre correlated and compared, covering the worldwide oilfields casing failures and researches.

For maturevention and control measures of mature oilfields at home and abroad are investigated and correlated and compared, covering the worldwide oilfields casing failures and researches For mature .

Ⅲ.2.Causes of Casing Failure:

Existing and induced down hole stresses in conventional and unconventional wells pose several challenges to casing integrity over well life cycle. Existing down hole stresses however, are attributed to in-situ stress variations specific to well location, digenesis, reservoir characteristics and regional geo-stress distribution.

On the other hand; induced stress caused from drilling and completion characteristics, well configurations, production related stresses and well stimulation processes pose additional sets of stresses, which undermine the robustness of casing integrity.

In-situ stresses, regional tectonic as well as micro earthquakes are key sources of potential wellbore failures. In-situ stress in an area can change before and after drilling owing to rock removal and well configuration.

Depending on stress variation and degree of rock consolidation and strength - wellbore instability issues could occur during and after drilling and can initiate down hole integrity challenges. Radial and tangential stresses are critical to borehole stability.

In addition, tangential (hoop) stress variation in horizontal wells is even much more severe which can lead to casing plastic deformation. **[17]**

Ⅲ.3.Casing Failure Analysis Techniques:

Casing failure analysis techniques are used to identify and diagnose the causes of casing failures. These techniques include:

Ⅲ.3.1.Visual Inspection:

This involves examining the casing for signs of damage or wear, such as cracks, corrosion, or deformation.

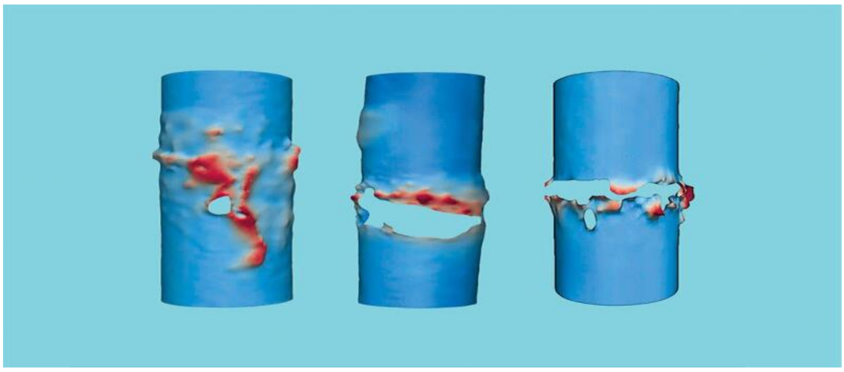


FIGURE Ⅲ.1. VISUAL INSPECTION OF CASING

Ⅲ.3.2.Ultrasonic Testing:

This technique uses high-frequency sound waves to detect defects in the casing, such as cracks or corrosion.

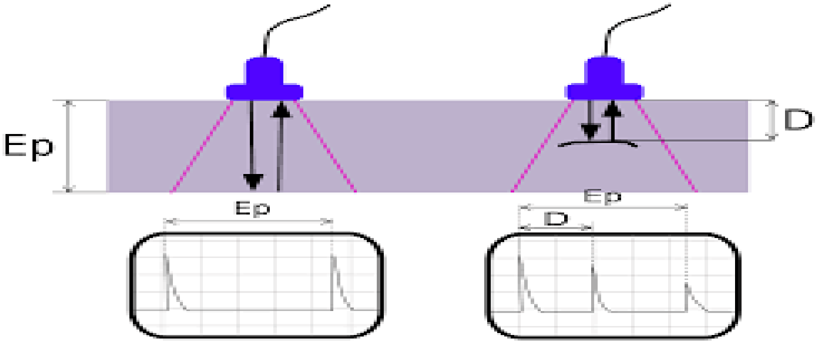


FIGURE Ⅲ.2. Ultrasonic Testing

Ⅲ.3.3.Magnetic Particle Inspection:

This technique uses magnetic fields and iron particles to detect surface and near-surface defects in the casing.

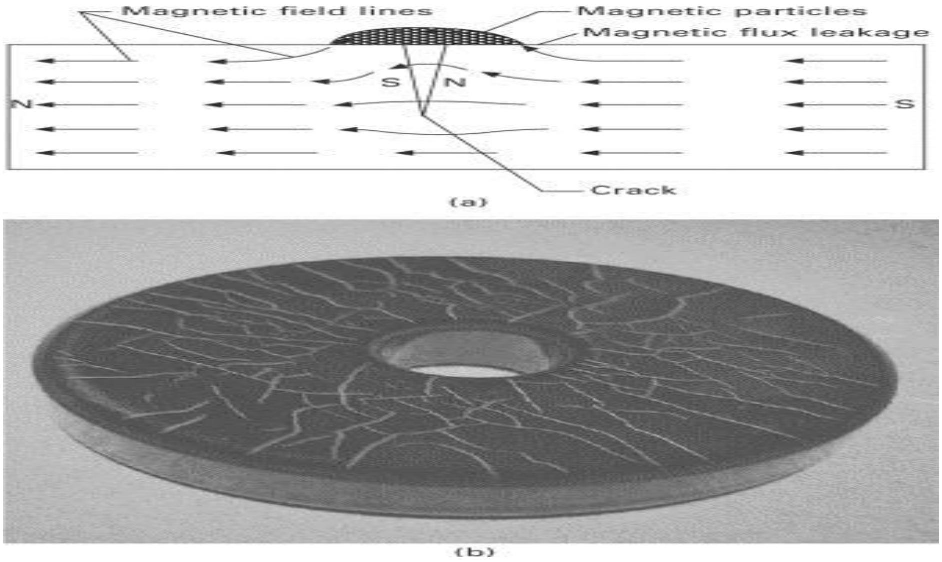


FIGURE Ⅲ.3. MAGNETIC PARTICLE INSPECTION OF CASING

Ⅲ.3.4.X-ray Inspection:

This technique uses X-rays to detect internal defects in the casing, such as cracks or corrosion.

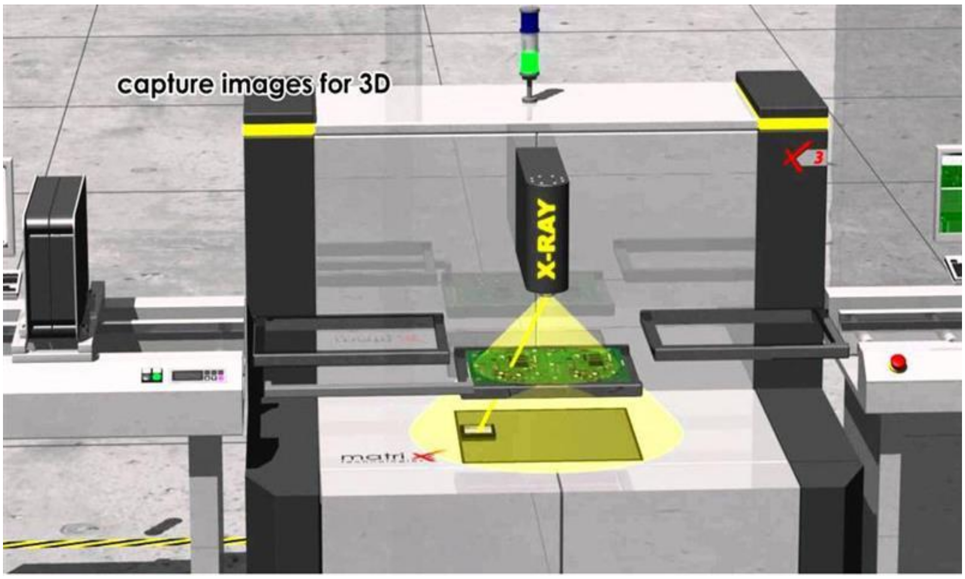


FIGURE Ⅲ.4. X-RAY INSPECTION OF CASING

Ⅲ.3.5.Chemical Analysis:

This involves analyzing the chemical composition of the casing to determine if it has been affected by corrosion or other chemical reactions.

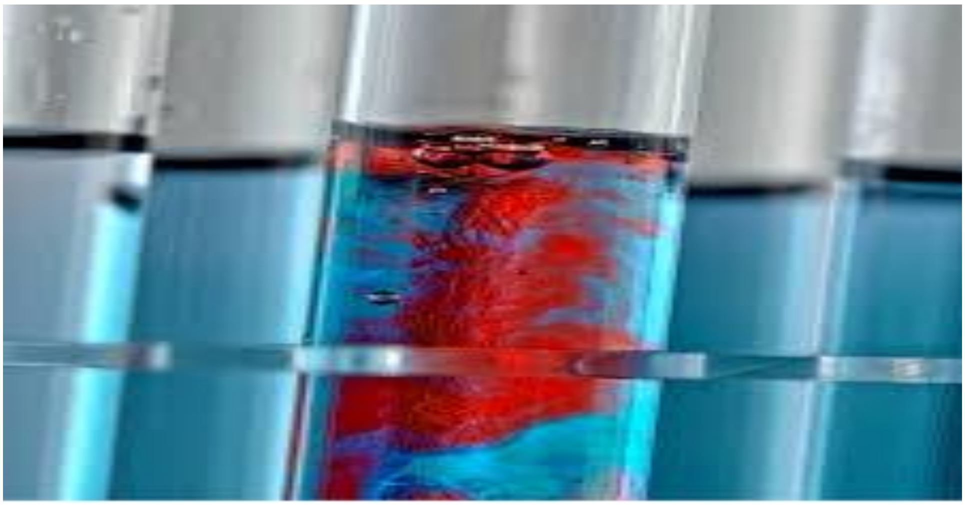


FIGURE Ⅲ.5. CHEMICAL ANALYSIS OF CASING

Ⅲ.3.6.Mechanical Testing:

This involves subjecting the casing to various mechanical tests, such as tensile or compression tests, to determine its strength and durability.

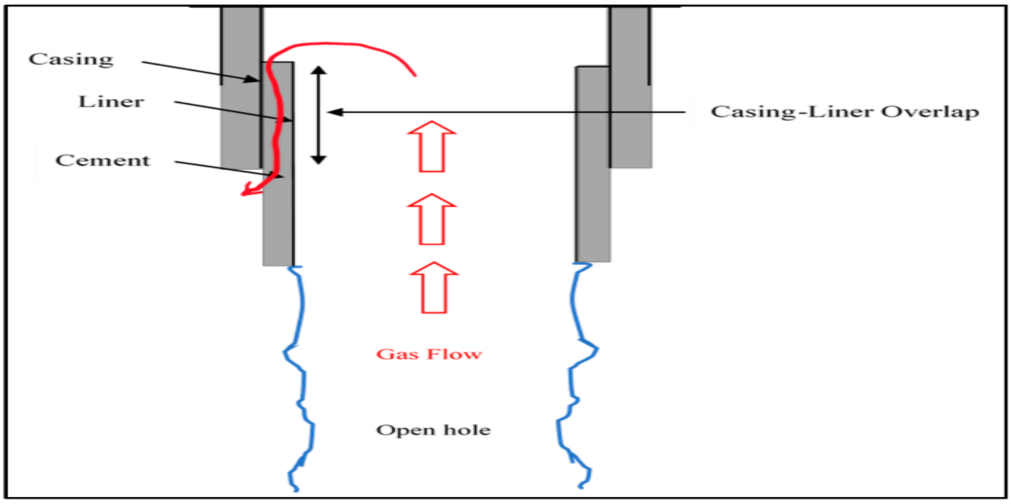


FIGURE Ⅲ.6. MECHANICAL TESTING OF CASING

By using these techniques, engineers can identify the root causes of casing failures and develop strategies to prevent them from occurring in the future. **[18]**

Ⅲ.4.Casing Failure Prevention Strategies:

There are several strategies that can be used to prevent casing failure in the oil and gas industry:

Ⅲ.4.1.Proper material selection:

Choosing the right casing material for the specific well conditions is critical in preventing corrosion and mechanical damage.

Ⅲ.4.2.Regular inspection and maintenance:

Regular inspections of the casing can help identify any potential issues before they become major problems. Maintenance activities such as cleaning and corrosion prevention treatments can also help extend the life of the casing.

Ⅲ.4.3.Well design optimization:

Proper well design, including casing placement and cementing techniques, can help prevent mechanical damage and ensure the casing is properly supported.

Ⅲ.4.4.Real-time monitoring:

Real-time monitoring of well conditions, including temperature, pressure, and corrosion rates, can help identify potential issues before they become major problems.

Ⅲ.4.4.Training and education:

Proper training and education of personnel involved in well operations can help ensure proper handling and maintenance of the casing. **[19]**

Ⅲ.5.Case Studies of Casing Failure:

Casing failure case studies that have been reported in the oil and gas industry:

Ⅲ.5.1.Corrosion-induced casing failure:

In one case, a well operator experienced a casing failure due to corrosion caused by hydrogen sulfide (H2S) gas. The failure occurred in the lower section of the casing, which was exposed to high concentrations of H2S. The operator used chemical analysis and X-ray inspection to identify the extent of the corrosion and replaced the damaged casing with corrosion-resistant materials.

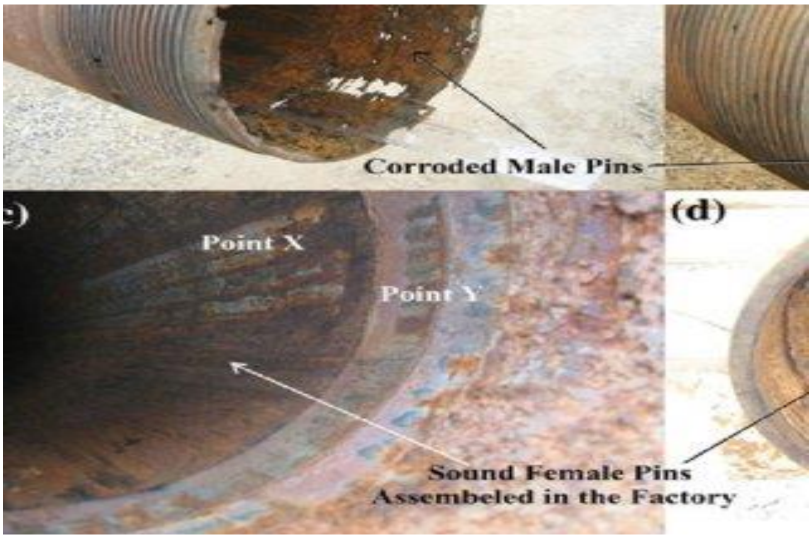


FIGURE Ⅲ.7. CORROSION-INDUCED CASING

Ⅲ.5.2.Mechanical damage-induced casing failure:

In another case, a well operator experienced a casing failure due to mechanical damage caused by a drill bit during drilling operations. The damage occurred in the upper section of the casing, which was subjected to high loads during drilling. The operator used visual inspection and ultrasonic testing to identify the extent of the damage and replaced the damaged casing with stronger materials.

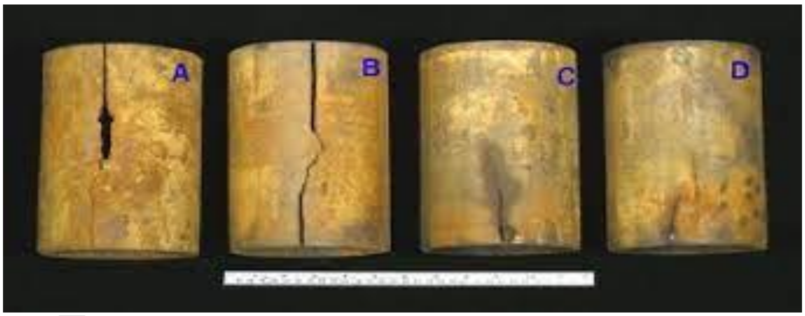


FIGURE Ⅲ.8. MECHANICAL DAMAGE-INDUCED CASING FAILURE

Ⅲ.5.3.Manufacturing defect-induced casing failure:

In a third case, a well operator experienced a casing failure due to a manufacturing defect in the casing. The defect caused a crack in the casing, which propagated over time and eventually led to a catastrophic failure. The operator used X-ray inspection and mechanical testing to identify the defect and replaced the damaged casing with defect-free materials.

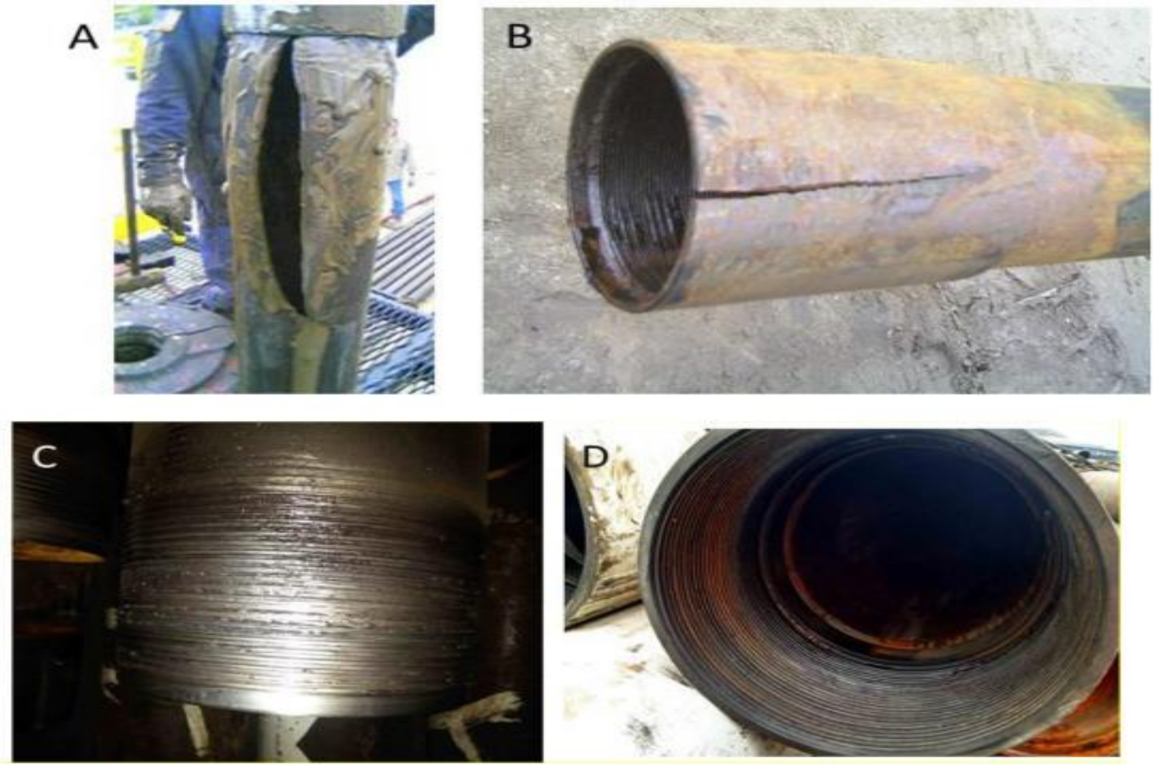


FIGURE Ⅲ.9. MANUFACTURING DEFECT-INDUCED CASING FAILURE

These case studies highlight the importance of using casing failure analysis techniques to identify and diagnose the root causes of failures and develop strategies to prevent them from occurring in the future Failure Analysis of Cracking of Cast Aluminum Alloy. **[20]**

Ⅲ.6.Conclusion:

Casing failure can be divided into many types and can occur at various sections. The time when casing failure occurs is closely related to the time when oilfields adjust development strategies. Casing failure can be caused by a variety of factors. Conventional technology serves as the main method for preventing and controlling casing damage but is not effective. No integrated system combining the preventing and controlling method has been introduced.

Chapter Ⅳ

Case study

Ⅳ.1.Introduction :

The applied part of the pressures affecting the well casing includeincludees various factors such as formation pressure, pore pressure, fracture pressure, and collapse pressure. Formation pressure is the pressure exerted by the rock formation on the wellbore, while pore pressure is the pressure of fluids in the rock pores. Fracture pressure is the pressure at which the rock formation fractures, and collapse pressure is the pressure at which the well casing collapses due to external forces. These pressures can vary depending on the depth and location of the well, and it is crucial to consider them in casing design to ensure well integrity and productivity. Advanced software tools and techniques can aid in modeling and predicting these pressures to optimize casing programs and reduce risks.

In this part, we deal with a specific case study of the forces affecting the cover represented by collapse pressure

Where we explain the problem and the reasons leading to this, and how to avoid it again. What are the proposed solutions to avoid falling into them

Ⅳ.2 Case study

The design and optimization of casing programs are crucial in the oil and gas industry as they provide support and protection for wellbores. This graduate thesis aims to create a comprehensive casing design plan that considers all critical factors affecting well integrity and productivity, utilizing advanced software tools and techniques. The study's results will contribute to improving drilling operation efficiency, safety, and reducing costs and environmental impact.

During a recent drilling operation, losses occurred at a depth of 1528' while drilling the 22" hole section. After running the 18 5/8" casing, we faced issues passing through the Wasia formation at 1020'. We made a reaming trip and successfully ran the casing through the tight spot. While pumping cement, we faced increasing pressure that exceeded the critical limit, and attempts to restore the flow failed. We pulled out the stinger with unexpected over pull force and circulated the cement out of the drill pipe. Evidence showed that collapsed casing, indicating that the applied pressure exceeded the casing collapse pressure, held the DP string. The contingency plan of action was not defined, and stop-work authority was not firmly exercised by DSV. The IWS PMT did not have a formal escalation and approval process. Future cementing programs will include a contingency plan, highlight collapse risks, and outline actions to take in case of sudden pressure rise, included in the risk matrix.

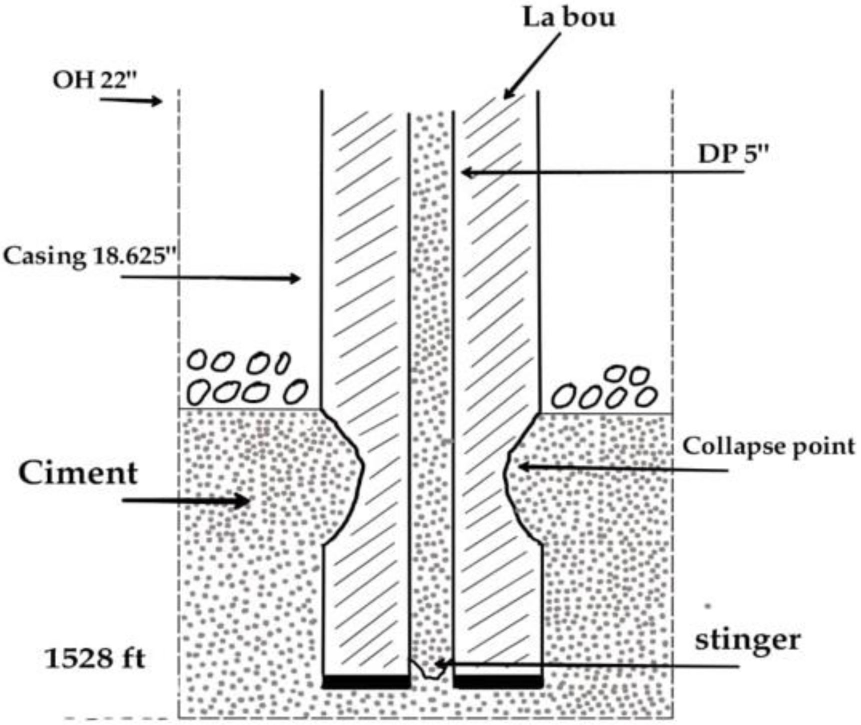


FIGURE Ⅳ.1. COLLAPSE PRESSURE

Ⅳ.3.Casing Design Checking:

Casing design checking refers to the process of verifying and evaluating the adequacy and integrity of a casing design for an oil or gas well. It involves performing various engineering calculations and analyses to ensure that the selected casing materials, dimensions, and specifications meet the requirements of the wellbore environment.

Ⅳ.3.1.Collapse Strength:

For thin wall pipes (D/t > 25±), the equation given In API 5C3 is based on a theoretical Equation describing an elastic instability failure of the wall which occurs before the yield Strength of the material is reached.

$$A = 2.8762 + 0.10679 \times 10^{-5} \times Yp + 0.21301 \times 10^{-10\times} \times Yp^2 - 0.53132 \times 10^{-16} \times Yp^3$$

A=2.99053019

$$B = 0.026233 + 0.5060910^{-6} \times Yp$$

B=0.05406795

$$C = -465.93 + 0.030867 \times Yp - 0.1043 \times 10^{-7} \times Yp^2 + 0.36989 \times 10^{-13} \times \mathrm{Yp}^3$$

C=1206.19797

$$F = \frac{46.96 \times 10^6 \left(\frac{3 \times \frac{B}{A}}{2 + \frac{B}{A}}\right)^2}{Yp \times \left(\left(\frac{3 \times \frac{B}{A}}{2 + \frac{B}{A}}\right) - \frac{B}{A}\right)\left(1 - \left(\frac{3 \times \frac{B}{A}}{2 + \frac{B}{A}}\right)\right)^2}$$

F=74.0370761

$$G = F \times \frac{B}{A}$$

G=1.33856964

$$t = \frac{\mathrm{OD} - \mathrm{ID}}{2}$$

$$t = \frac{18.63 - 17.44}{2} = 0.594\mathrm{in}$$

D/t = 18.63/0.594=31.355

D/t > 25±

$$\frac{2 + \frac{B}{A}}{3 \times \frac{B}{A}} = 37.2469158$$

$$\frac{2 + \frac{B}{A}}{3 \times \frac{B}{A}} \geq \frac{\mathrm{D}}{\mathrm{t}}$$

Ⅳ.3.2.Elastic equation unrealized:

Transition collapse pressure

$$\frac{Yp(A - F)}{C + Yp(B - G)} \leq \frac{D}{t} \leq \frac{2 + \frac{B}{A}}{3 \times \frac{B}{A}}$$

$$\frac{Yp(A - F)}{C + Yp(B - G)} = 2523.045985$$

$$\frac{2 + \frac{B}{A}}{3 \times \frac{B}{A}} = 37.2469158$$

$$\frac{\mathrm{D}}{\mathrm{t}} = 31.355$$

Ⅳ.3.3.Transition equation unrealized:

Ⅳ.3.4. Plastic collapse pressure

$$\frac{\left[(A-2)^2+8\left(B+\frac{C}{Yp}\right)\right]^{0.5}+(A-2)}{2\left(\mathrm{B}+\frac{\mathrm{C}}{Yp}\right)} \le \frac{\mathrm{D}}{\mathrm{t}} \le \frac{\mathrm{Yp(A-F)}}{\mathrm{C+Yp(B-G)}}$$

$$\frac{\left[(A-2)^2+8\left(B+\frac{C}{Yp}\right)\right]^{0.5}+(A-2)}{2\left(\mathrm{B}+\frac{\mathrm{C}}{Yp}\right)} = 14.815$$

$$\frac{\mathrm{Yp(A-F)}}{\mathrm{C+Yp(B-G)}} = 56.29406$$

$$\frac{\mathrm{D}}{\mathrm{t}} = 31.355$$

Plastic equation realized:

$$Pp = Yp\left(\frac{A}{\left(\frac{D}{T}\right)} - B\right) - C$$

$$Pp = 55000\left(\frac{2.99}{31.355} - 0.054\right) - 1206.9$$

Pp=1068.5875psi

Where:

Pp = Plastic collapse pressure.

T = nominal wall thickness.

Ⅳ.3.5.Burst Strength:

The burst strength of the pipe body is determined by the internal yield pressure formula Found in API Bulletin 5C3

$$P = 0.875\left[\frac{2\,Yp.\mathrm{t}}{\mathrm{D}}\right]$$

$$t = \frac{\mathrm{OD-ID}}{2}$$

$$t = \frac{18.63-17.44}{2} = 0.594\mathrm{in}$$

Yp=55000 psi

$$P = 0.875\left[\frac{2\,Yp.\mathrm{t}}{\mathrm{D}}\right] = 0.875\left[\frac{2\times 55000\times 0.594}{18.63}\right]$$

$$P = 3069.664psi$$

Where:

- P = minimum internal yield pressure.
- Yp = minimum yield strength.
- T = nominal wall thickness.
- D = nominal outside diameter.

Ⅳ.3.6.Yield Strength:

$$Y = Yp \times Ap$$

$$Ap = \frac{\pi}{4}(OD^2 - ID^2)$$

$$Ap = \frac{\pi}{4}(OD^2 - ID^2)$$

$$A_{\mathrm{P}} = 33.63 \ in^2$$

$$Y = 55000 \times 33.63$$

Y = 1849688.498 Ib

Where:

- Ap: cross sectional area
- OD: Outside Diameter
- ID: Inside Diameter

Ⅳ.4.Collapse pressure Pc:

Ⅳ.4.1Cementing process:

While pumping a volume of 87bbl of cement needed to protect the casing, after pumping a volume of 81bbl, the pressure increased more than the required value, which led to stopping the cement process due to a blockage in the cavity between the casing and the well

We calculate the volume of external cement V_{cement}

$$V = V_{pump} - (V_{int\ DP} + V_{bottom})$$

$V = 81\ bbl$

$$V_{bottom} = L_{rat\ hole}\left(\frac{ID^2}{1029.4}\right) \times 1.5$$

$$= 8\left(\frac{22^2}{1029.4}\right) \times 1.5 = 5.642\ bbl$$

$$V_{int\ DP} = L_{DP}\left(\frac{OD^2 - ID^2}{1029.4}\right)$$

$$V_{int\,DP} = 1500\left(\frac{5^2 - 2^{11/_{16}\;2}}{1029.4}\right) = 27bbl$$

$$V = V_{pump} - (V_{int\,DP} + V_{bottom})$$

$$V = 81 - (27 + 5.642)$$

$$V_{cement} = 48.36\ bbl$$

$$V_{cement} = 48.36 \times 0.5$$

the volume of external cement V_{cement}:

$$V_{cement} = 24.18\ bbl$$

We calculate the length of the external cement l

$$V_{cement} = l\left(\frac{OD^2 - ID^2}{1029.4}\right)$$

$$l = \frac{V \times 1029.4}{OD^2 - ID^2}$$

$$l = \frac{24.18 \times 1029.4}{22^2 - 18.625^2}$$

$$l = 181.56 - 20$$

$$l = 161.56\ ft$$

We calculate the pressure needed to avoid collapse

$$P_{poit\ collapse} = 0.052 \times 18.48 \times 161.56$$

$$= 159.11\ psi$$

$$P_{\mathrm{int}} = 0.052 \times 11.88 \times 1500$$

$$P_{\mathrm{int}} = 926.64\ psi$$

$$P_{collapse} = P_{EX} - P_{IN}$$

$$P_{collapse} = 159.11 - 926.64$$

$$P_{collapse} = -767.53\ psi$$

$$P_{collapese\ necessary} = 1065.75\ psi$$

$$-767.53 + 1833 = 1065.75$$

$$1065.75 + 767.53 = 1833\ \mathrm{psi}$$

the pressure needed to avoid collapse

$$P = 1833\ psi$$

the engineere increased the pressure by about 167 psi, which led to a collapse in the casing

Ⅳ.4.2.Comment:

The engineers made a mistake in designing the well before inserting the casing. They had to carefully design the casing and the well to avoid problems again.

Ⅳ.5.suggested solutions:

To avoid similar Issues in future drilling operations, the following solutions can be implemented:

- Conduct a thorough geological and geophysical study before drilling to identify potential trouble zones and design casing programs accordingly.
- Use advanced software tools and techniques to optimize the casing design and ensure that the casing is strong enough to withstand the expected pressures and stresses.
- Develop a contingency plan that outlines actions to take in case of sudden pressure rise or other unexpected events during cementing operations.
- Include collapse risks in the risk matrix and highlight them in the cementing program to ensure that all stakeholders are aware of the potential risks.
- Define a clear escalation and approval process for the IWS PMT to ensure that stop-work authority is firmly exercised when necessary.
- By implementing these solutions, drilling operations can improve efficiency, safety, and reduce costs and environmental impact.

Ⅳ.6.Conclusion:

the incident during the drilling operation highlights the importance of a comprehensive casing design plan that considers all factors affecting well integrity and critical productivity. It also emphasizes the need for a contingency plan and a formal escalation and approval process to ensure safety and minimize environmental impact. By utilizing advanced software tools and techniques, drilling operation efficiency can be improved, costs reduced, and risks minimized. It is crucial to prioritize safety and exercise stop-work authority when necessary to prevent incidents and ensure the success of drilling operations.

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