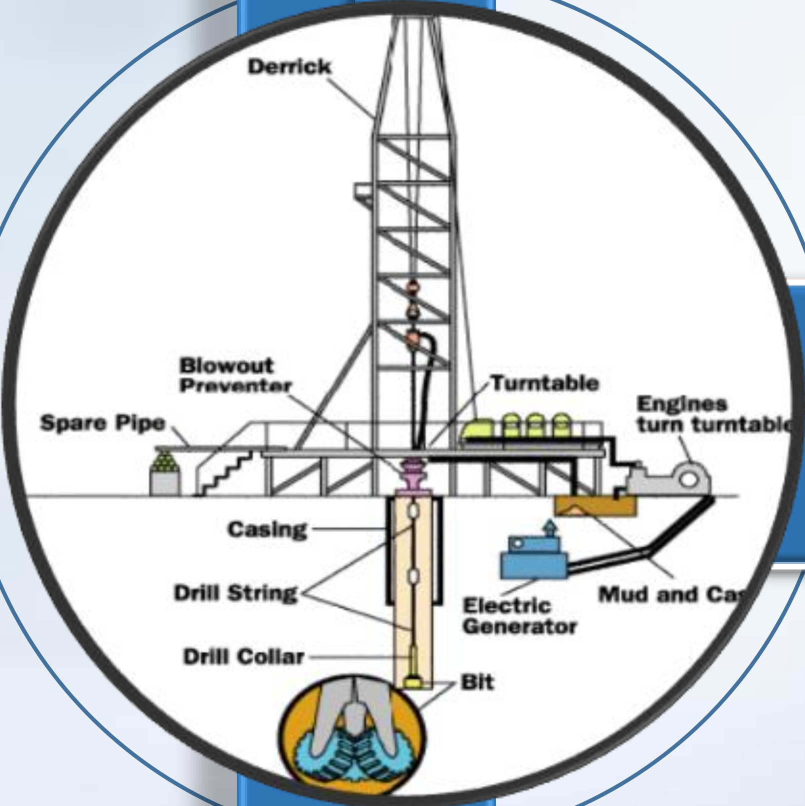
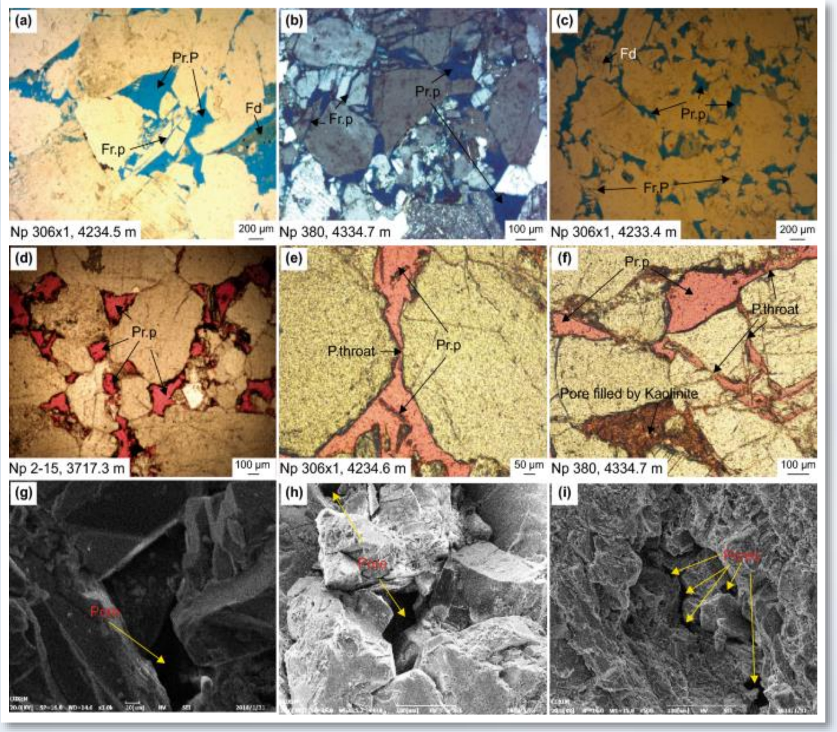


BASIC DRILLING TECHNOLOGY

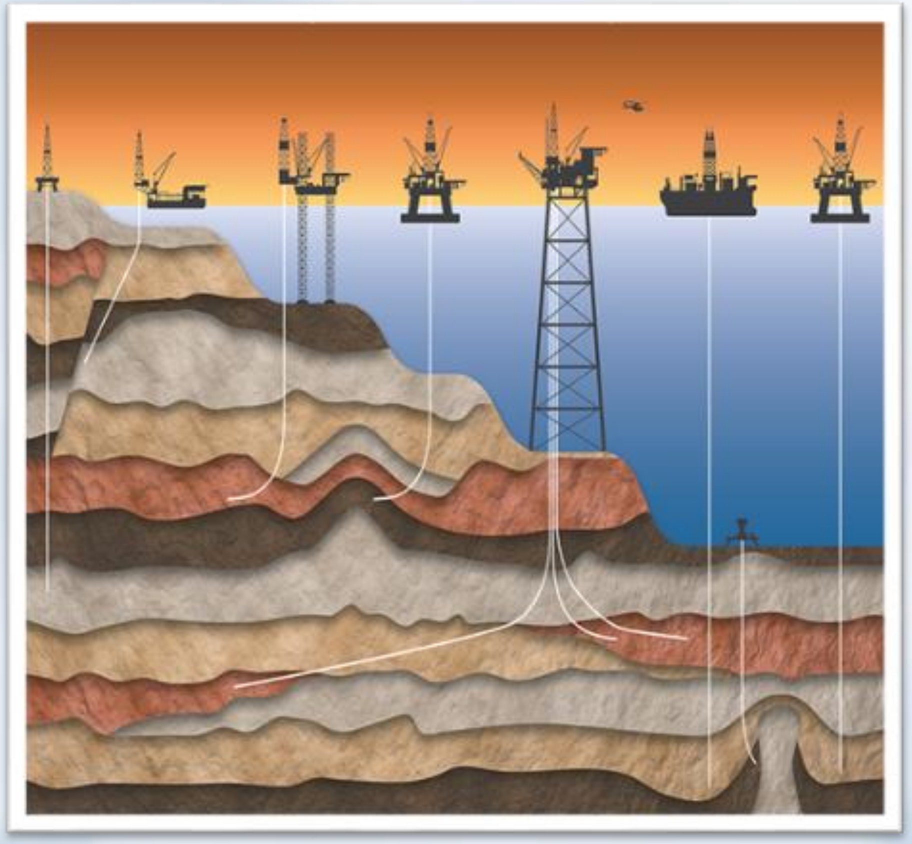
TABLE CONTENT

WHY WE DRILL?



- ✓ Crude oil and Natural gas exists deep under the earth in the pores of the rocks.
- ✓ To access these reservoirs and extract the hydrocarbons a conduit is required.
- ✓Drilling is the sequence of steps undertaken to build this conduit.
- ✓Drilling is done for producing oil & gas or injecting water/steam/gas in the reservoir to assist production of crude oil.

RIG TYPES



- ✓ Land Rigs
- ✓ Inland Shallow Water
- ✓ Offshore Shallow Water
- ✓ Deepwater Rigs

LAND RIGS

✓The main features of land rigs are portability and maximum operating depth.

✓Land rigs are built so that the derrick can be moved easily and reused for drilling new holes.

✓The various rigs components are skid-mounted so that the rig can be moved in units and connected easily.

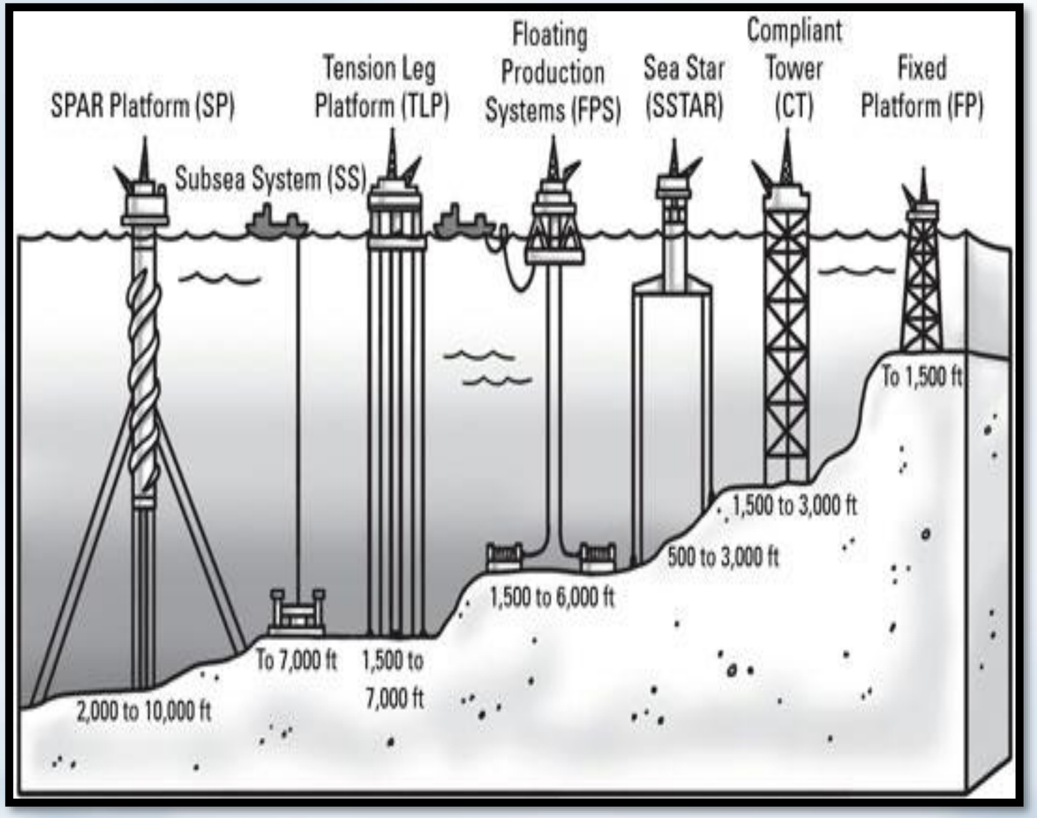
✓The jackknife, or cantilever, derrick is assembled on the ground with pins and then raised as a unit using the rig-hoisting equipment.

✓Types:Truck mounted rigs, Special Terrain rigs (arctic, jungle, desert).

BARGE RIG

- ✓A barge rig is designed to work in shallow water (less than 20 ft deep).
- ✓The rig is floated to the drill site, and the lower hull is sunk to rest on the sea bottom.
- ✓The large surface area of the lower hull keeps the rig from sinking into the soft mud and provides a stable drilling platform.

PLATFORM RIG



✓Platforms use a jacket (a steel tubular framework anchored to the ocean bottom) to support the surface production equipment, living quarters, and drilling rig.

✓Multiple directional wells are drilled from the platform by using a rig with a movable substructure. The rig is positioned over preset wellheads by jacking across on skid beams. After all the wells are drilled, the rig and quarters are removed from the platform.

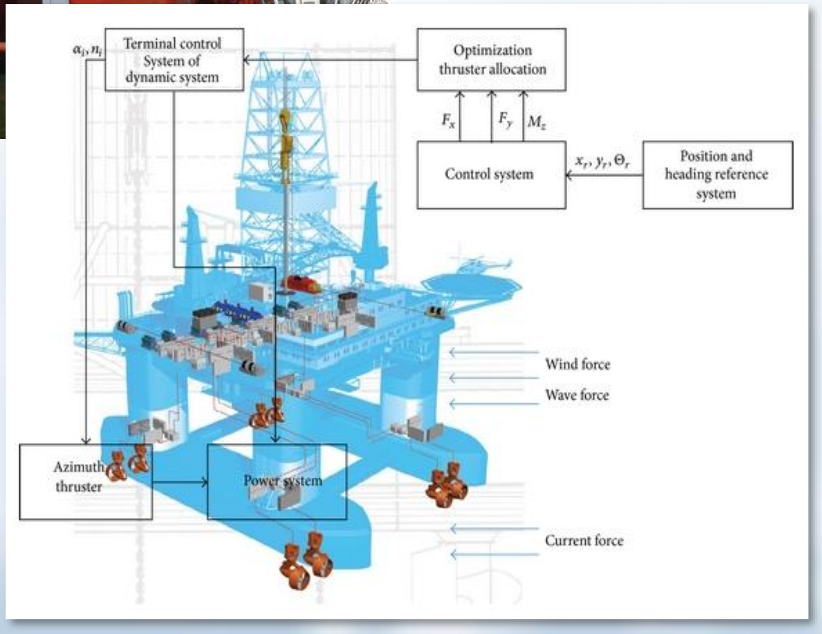
JACK-UP RIG

✓Jack-up rigs are similar to platforms except that the support legs are not permanently attached to the seafloor.

✓The weight of the rig is sufficient to keep it on location. The rig's legs can be jacked down to drill and jacked up to move to a new location.

✓When under tow, a flotation hull buoys the jack-up. The derrick is cantilevered over the rear to fit over preset risers if necessary.

SUBMERSIBLE RIG



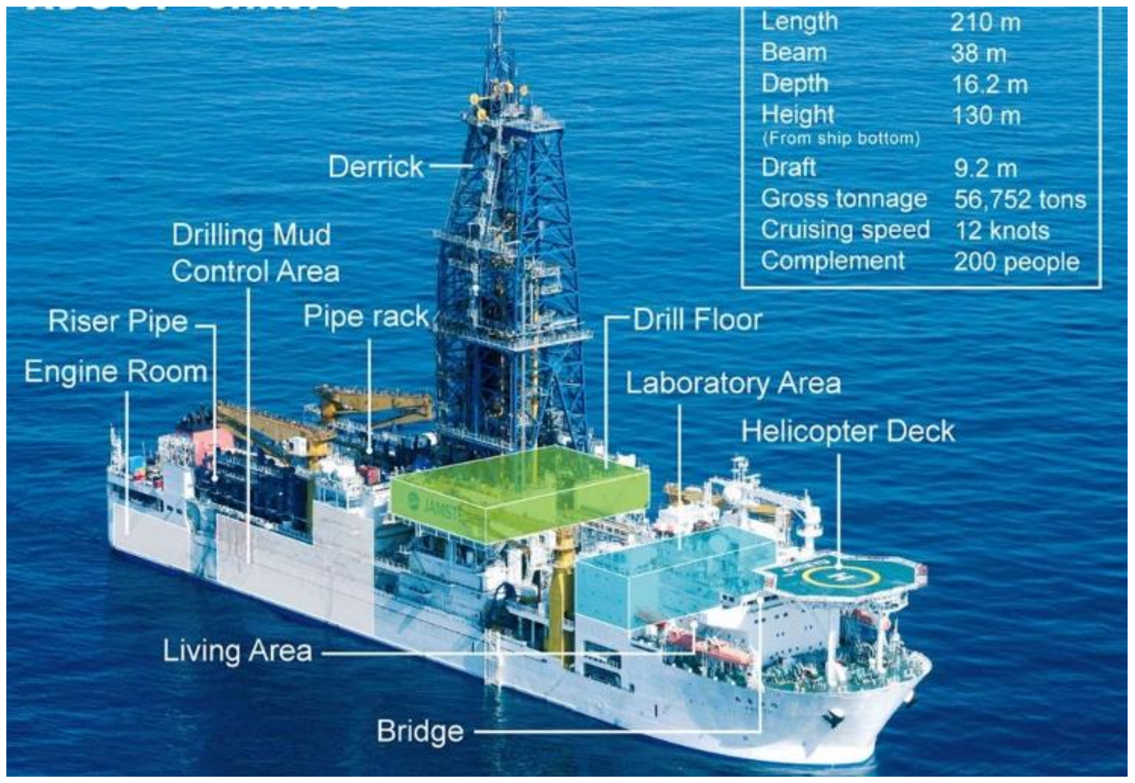
✓A submersible rig is a barge that is designed to work in deeper water (200 to 1800 Meters deep).

✓Although a few semis are self-propelled, most require towing.

✓Because floaters are subject to wave motion, their drilling apparatus is located in the center where wave motion is minimal. Semis are flooded to a drilling draft where the lower pontoons are below the active wave base, thereby stabilizing the motion.

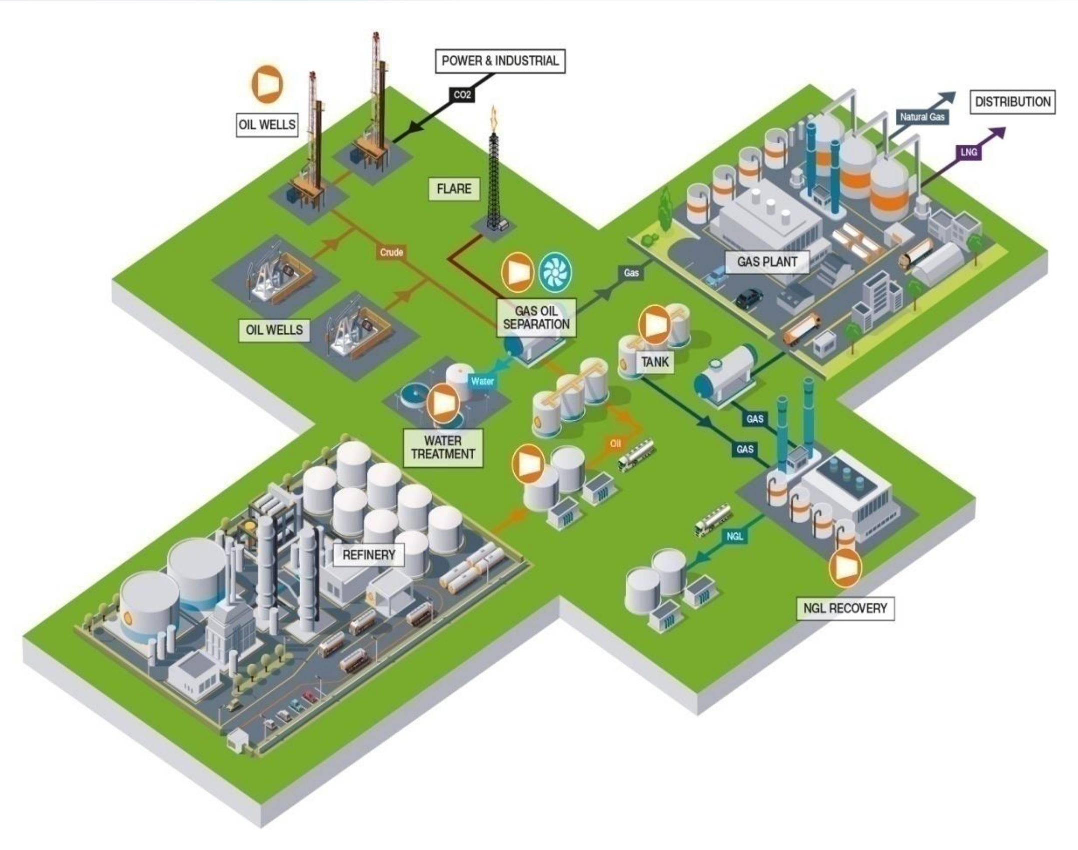
✓It has steel legs/ extensions that allow it to have a raised upper hull above the water level to avoid waves.

DRILL SHIPS



- ✓ The drilling apparatus on a drill ship is mounted in the center of the ship over a moon pool, which is a reinforced hole in the bottom of the ship through which the drill string is raised and lowered.
- ✓ drillships work in water depths ranging from 2,000 to more than 10,000 feet (610 to 3,048 meters).
- ✓ The ship can be turned into the oncoming wind or currents for better stability, and it can operate in water too deep for anchors.

WELL PLANNING



Well planning is perhaps the most demanding aspect of drilling engineering.It requires the integration of engineering principles, corporate or personal philosophies, and experience factors. Although well planning methods and practices may vary within the drilling industry, the end result should be a safely drilled, minimum-cost hole that satisfies the reservoir engineer.

The skilled well planners normally have three common traits:

•They are experienced drilling personnel who understand how all aspects of the drilling operation must be integrated smoothly.
•They utilize available engineering tools, such as computers and third-party recommendations, to guide the development of the well plan.
•They usually have an investigative characteristic that drives them to research and review every aspect of the plan in an effort to isolate and remove potential problem areas.

WELL PLANNING

The major decisions involved in the oilfield development planning phase are the following:

- ✓Determining the operations logistics requirement needed
- ✓Selecting platforms to install and their sizes
- ✓Deciding which fields to develop and what should be the order to develop them
- ✓Deciding which wells and how many are to be drilled in the fields and in what sequence
- ✓Deciding which fields are to be connected to which facility
- ✓Determining how much oil and gas to produce from each field
- ✓Determining the best technology to use to safely & optimally produce the well till depletion

INPUT DATA FOR WELL PLANNING

✓The objective of the well.

✓Well data package consisting of seismic data, location map, structural map, expected pore pressures, offset and correlation logs and information on formation type, top and thickness.

✓Offset and correlated drilled wells data consisting of bit record, mud reports. Mud logging data, drilling reports, well completion reports, complication reports and production/injection histories.

✓Proposed logging, testing and coring programmes.

✓Government reflection and Company's policy.

GEO- TECHNICAL ORDER

The various input data are thoroughly analyzed and the Geo- Technical Order (G.T.0) is prepared which provides broad guidelines for drilling of the well.

(a) General data like well name, well number, area location, water depth, elevation, well type, category, objectives of the well etc.

(b) Geological data consists of following details:

- ✓ Depth
- ✓ Age
- ✓ Formation
- ✓ Lithology
- ✓ Interval of coring
- ✓ Electro logging
- ✓ Collection of cuttings
- ✓ Angle of Dip
- ✓ Oil/gas shows
- ✓ Formation pressure
- ✓ Formation temperature
- ✓ Mud loss/caving

GEO- TECHNICAL ORDER

(c) Mud parameters consist of

- ✓Type of mud
- ✓Specific gravity
- ✓Viscosity
- ✓PH
- ✓Percentage of sand
- ✓Filtration loss

(d) Drilling data includes

- ✓Casing policy and rise of cement
- ✓Type of drilling
- ✓Type and size of bit
- ✓Number of bits expected
- ✓ Meterage per bit
- ✓Weight on bit RPM of rotary
- ✓Stand-pipe pressure
- ✓Pump discharge
- ✓Bit nozzle details
- ✓Drilling time

DRILLING PROGRAMME PREPARATION

The preparation of good Drilling Programme is very vital for safe and effective drilling operation.
Drilling Programme can be broken down into 12 main sections:

- ✓Well details
- ✓Well objectives
- ✓Casing policy
- ✓Wellhead selection
- ✓BOP requirements
- ✓Cementing programme
- ✓Deviation programme
- ✓Survey requirements
- ✓Mud programme
- ✓Bit and Hydraulics programme
- ✓Evaluation requirements
- ✓Estimation of well cost

WELL DETAILS

This is a brief summary of the well location, field/structure, type, depth, operatorship and ownership.

A typical layout of this is shown below:

✓**Location**	SP 1700 off line GK-2
✓ **Field/ Structure**	Kutch/GKH
✓**Well Name**	GKH-2
✓**Well Type**	Exploratory '8' Expendable
✓**Location Data**	Latitude 220 27’ 19” N Longitude 670 36' 09.5" E
✓**Water Depth**	108 m
✓ **Target Tolerance**	50m
✓**Total Depth**	4515 m
✓**Operator**	ONGC
✓**Name of the rig**	Sagar Vijay
✓**Type of rig**	Floater

OBJECTIVE OF WELL PLANNING

✓**The objective of well planning is to formulate from many variables a program for drilling a well that has the following characteristics:**

- Safe
- Minimum cost
- Usable

✓ **Unfortunately, it is not always possible to accomplish these objectives on each well because of constraints based on:**

- Geology
- Drilling equipment
- Temperature
- Casing limitations
- Hole sizing
- Budget

WELL-TYPE CLASSIFICATION

The drilling engineer is required to plan a variety of well types, including:

- ✓Wildcats
- ✓Exploratory holes
- ✓Step-outs
- ✓Infills
- ✓Re-entries

FORMATION PRESSURE

✓The formation, or pore, pressure encountered by the well significantly affects the well plan. The pressures may be normal, abnormal (high), or subnormal (low).
✓Normal-pressure wells generally do not create planning problems.
✓The mud weights are in the range of 8.5 to 9.5 lbm/gal. kicks and blowout-prevention problems should be minimized but not eliminated altogether.
✓Casing requirements can be stringent even in normal-pressure wells deeper than 20,000 ft because of tension/collapse design constraints.

Abnormal pressures affect the well plan in many areas, including:

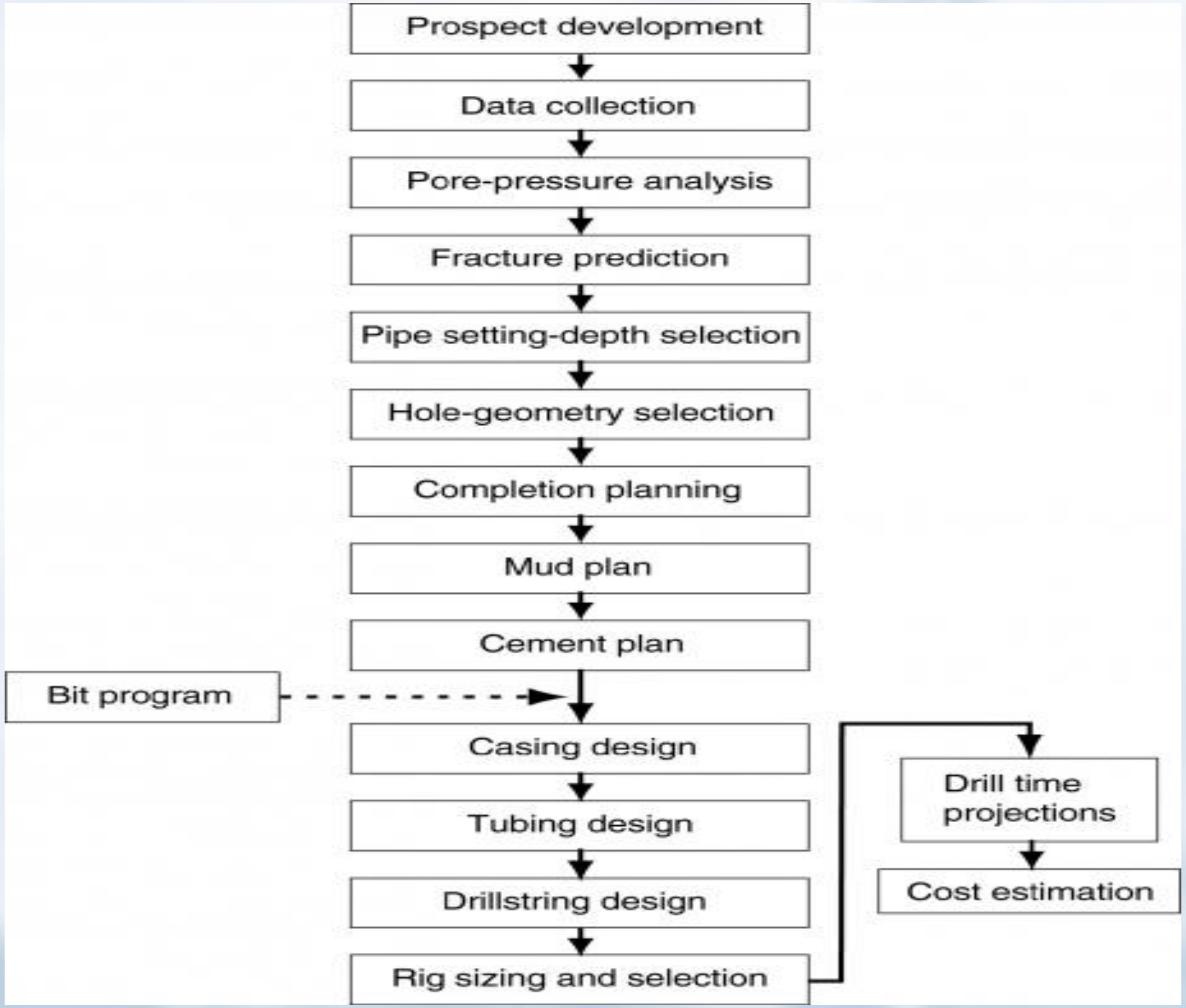
✓Casing and tubing design

✓Mud-weight and type-selection

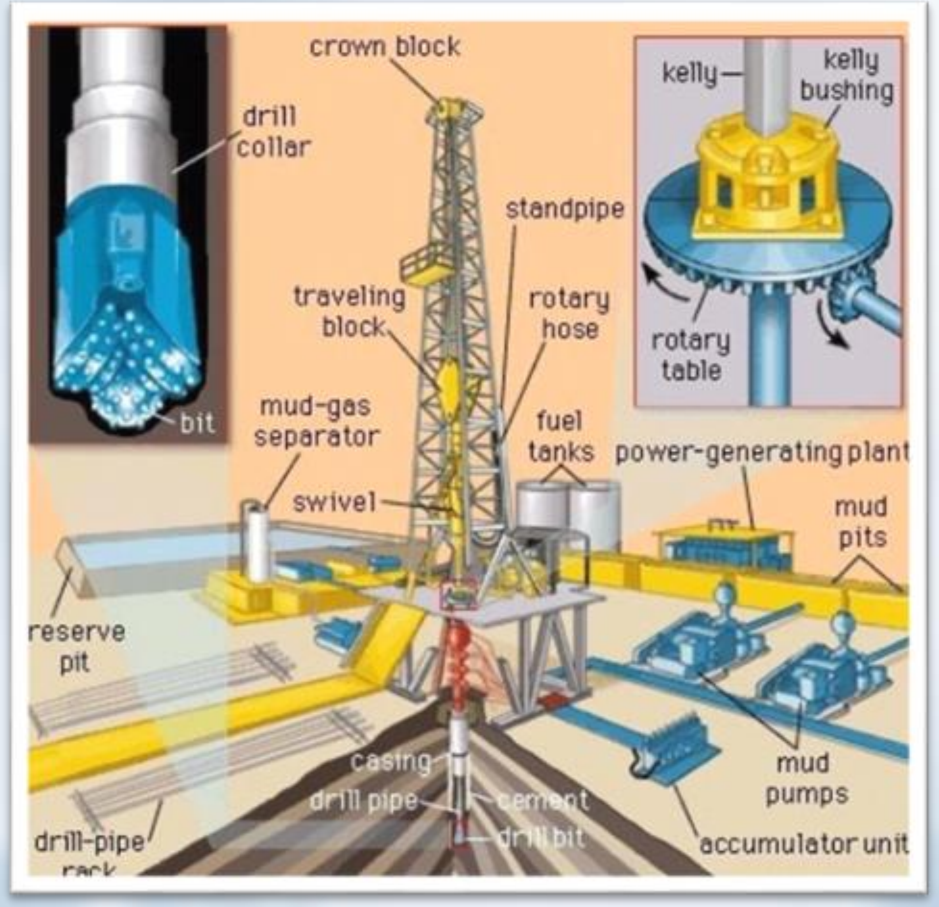
✓Casing-setting-depth selection

✓Cement planning

WELL PLANNING PROCESS



DRILLING RIG SYSTEMS



- ✓ Rotary System
- ✓ Hoisting System
- ✓ Circulation System
- ✓ Well Control System

ROTARY SYSTEM

The function of the rotary system is to transmit rotation to the drilling string and consequently rotate the bit. During drilling operation, this rotation is to the right. The main part of the rotary system are as follows: Swivel, Rotary hose, Kelly, Rotary drive (master bushing, Kelly bushing), Rotary table and Drilling string.

Swivel:

The swivel which established a connection among hook and Kelly, has to be constructed or built extremely robust since or because it has to carry the total drill string weight and simultaneously, provide a high-pressure seal (connection between flexible, non-rotating rotary hose and the rotation Kelly).

Kelly:

The Kelly has a square or hexagonal cross-section and provides the rotation of the drill string. Because the Kelly is made of high quality, treated steel, it is a flashy part of the drill string. Thus, to prevent the Kelly from excessive wear caused by making and breaking connections, a Kelly sub is mounted at the bottom end of it. To prevent backward flow of the mud in case of a kick, a Kelly cock providing a backflow restriction valve is often mounted between Kelly and swivel.

ROTARY SYSTEM

Kelly Spinner:

A pneumatically controlled device for spinning the drill pipe. It is mounted below the Swivel When actuated causes the Kelly to spin.

Kelly Bushing:

A device that when fitted to master bushing transmits torque to the Kelly and simultaneously permits vertical movement of the Kelly. It engages the master bushing by drive pins or square on the bottom.

Master Bushing:

A device that fits into the rotary table to accommodate the slips and to drive the Kelly bushing so that the rotating motion of the rotary table can be transmitted to the Kelly.

Rotary Table:

It used to rotate the drill stem and support the drilling assembly. It has a bevel gear arrangement to create the rotational motion and It has an opening into which the bushings are fitted to drive and support the drilling assembly.

Rotary Drive:

The rotary drive consists of master pushing and Kelly pushing. The master pushing receives its rotational momentum from the compound and drives the Kelly pushing which in turn transfers the rotation to the Kelly.

HOISTING SYSTEM

Drawwork:

The purpose of the drawworks is to provide the hoisting and breaking power to lift and lower the heavy weights of drill string and casings. The draw work itself consists of: Drum (which provides the movement of the drilling line), Brakes, Transmission and Catheads.

Crown Block:

A block located at the top of the derrick is known as crown block. It contains a number of sheaves on which the drilling line is wound/reeved. The crown block provides a means of taking the drilling line from the hoisting drum to the travelling block. Each sheave inside the crown block acts as an individual pulley.

Travelling Block:

An assembly of sheaves or pulleys through which the drilling line is reeved and which moves up and down in the Derrick or Mast. In the travelling block number of sheaves is always less than those in the crown block. The drilling line is wound continuously on the crown and travelling blocks, with the two outside ends being wound on the hoisting drum and attached to the deadline anchor respectively.

HOISTING SYSTEM

Deadline Anchor:

An equipment that holds down the deadline part of the wire rope. It is usually bolted on to the substructure.

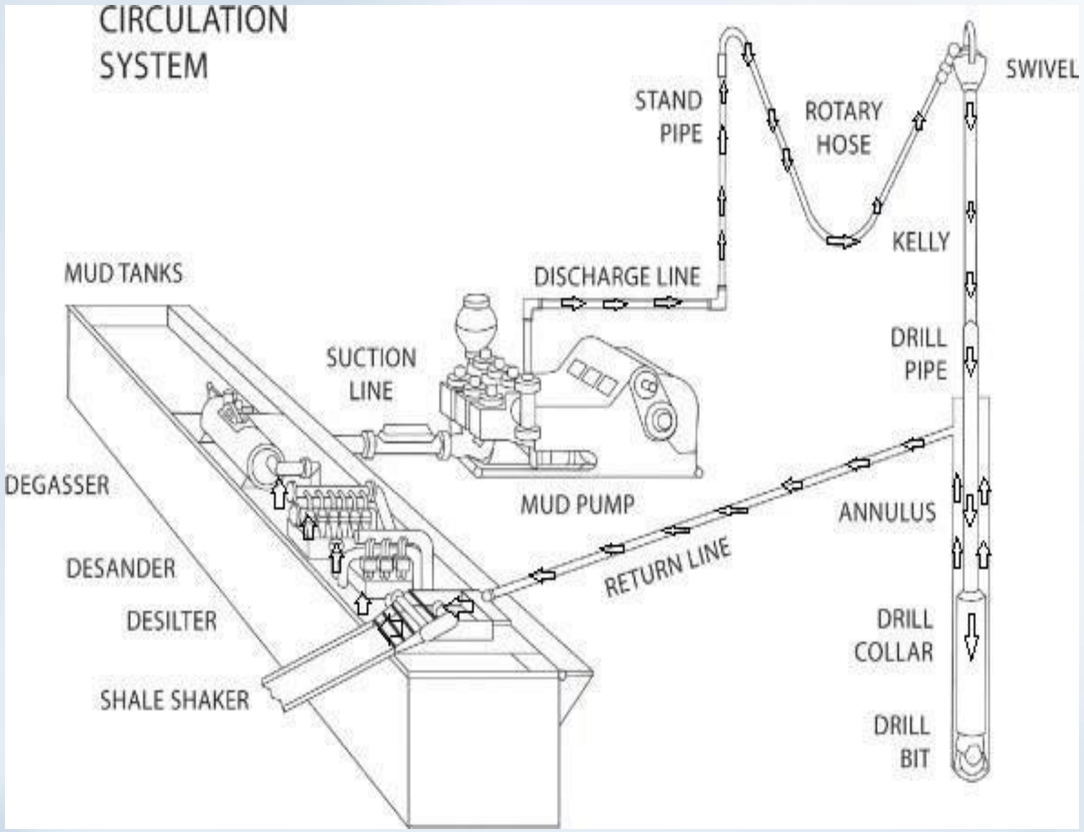
The Hook:

Connects the Kelly with the travelling block. The hook carries the entire load of drilling load.

Supply Reel:

A spool that stores the unused portion of drilling line

CIRCULATION SYSTEM



The principle components of the mud circulation system are as follows:

✓Mud pumps

✓Flowlines, drillpipe

✓Nozzles

✓Mud pits and tanks (settling tank, mixing tank, suction tank)

✓Mixing equipment (mud mixing hopper)

✓Contaminant removal equipment (shale shaker, desander, desilter, degasser)

SOLIDS CONTROL EQUIPMENTS

Flo-Line Primer

DE-AG Agitator

Divider

Pyramid Screens

Cleaner 2000

Centrifuge

Hi’G Dryer

Desilter

Desander

Degasser

CIRCULATION SYSTEM

There are 2 types of mud pumps

Duplex pump (consists of two cylinders and is double-acting)

Triplex pump (consists of three cylinders and is single-acting)

Mud Pits or Mud Tanks:

Steel Tanks fixed in the grounds in series. They are the mixing tanks in which mud is mixed & treated and sent to mud pump for circulation.

Pump Manifold:

An arrangement of piping and valves that receives drilling fluid from one or more mud pumps and transmit the drilling fluid to the succeeding circulating component.

Stand Pipe:

The vertical pipe rising along the side of the Derrick or Mast, which joins mud pump manifold to the rotary hose.

Return Line:

The passageway of the drilling fluid as it comes out of the well.

CIRCULATION SYSTEM

Shale Shaker:

It is an equipment having inclined vibrating screen. It helps to remove larger particles/cuttings. Liquid moves down to the tank and cutting moves on. Shale shakers are designed to handle 100-1600 gpm flow-rate of mud and be able to remove cutting to size of 77 microns using a 200 mesh screen.

Settling Tank: Smaller particles are settles down

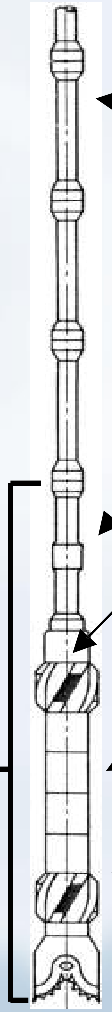
Desander (centrifugal action): Smaller particles/sands (super fine) are settles down to prevent abrasive action of the pump. - A series of hydrocyclones are put in series

Desilter(centrifugal action):Further used to remove micro particles (free particles if silt) It has same structure as desander

Degasser Centrifugal (vacuum) Pump:Removes gas from the mud coming from the formation. Used only when gas is detected.

DRILLING TOOLS

Bottom Hole Assembly (BHA)



Drill pipe

Heavy Wall Drill Pipe

(Crossover, Jar)

Stabilizer

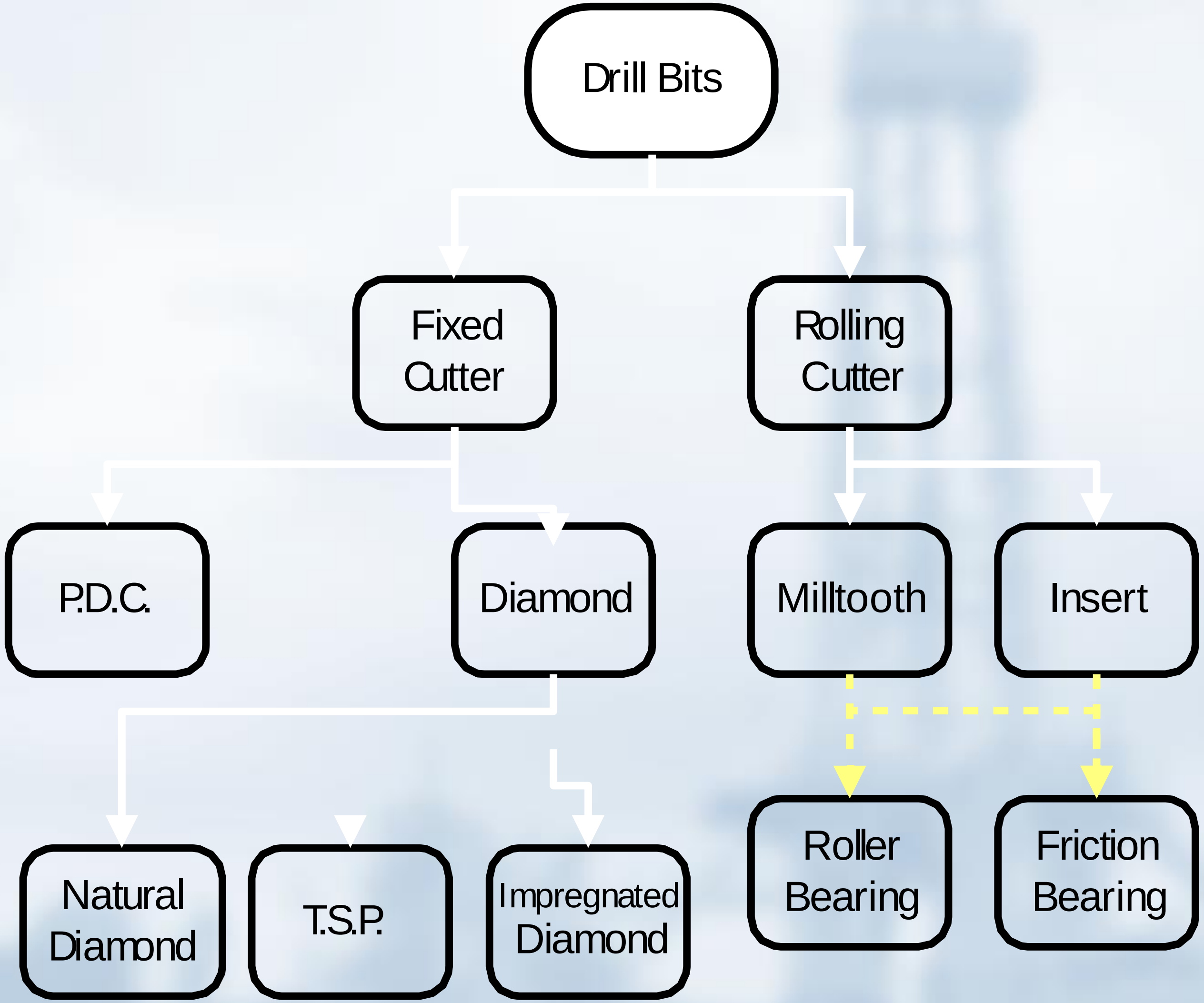
Drill

Collars

Stabilizer

Drill bit

DRILL BIT CLASSIFICATION



DRILL BIT CLASSIFICATION

Different types;

- Roller cone, mill tooth; teeth machined out of the same block f steel

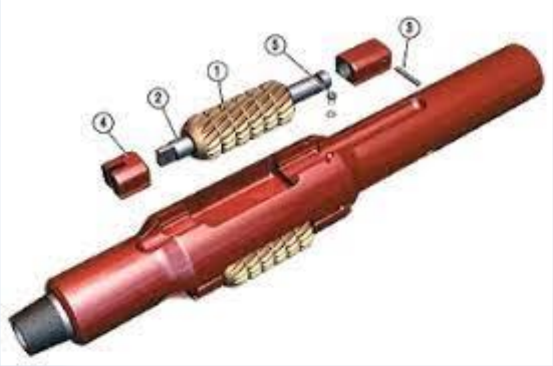
- Roller cone, TCI

- Fixed cutter, PDC

- Fixed cutter, natural diamond

BHA

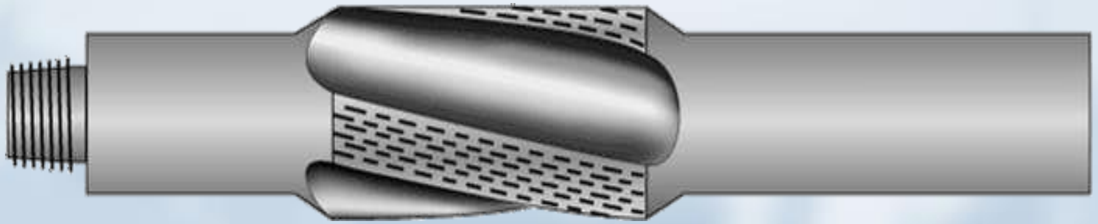
Heavy-weight drill pipe – These pieces of pipe have thicker walls compared to the outer diameter of a regular drill pipe, and are used as a tapered transition between the drill collars and drill pipe while helping to add weight and stiffness. As previously mentioned the drill pipe functions to connect the rig surface equipment with the bottom hole assembly and the drill bit, allowing us to pump fluid to the bit and to move the bottom hole assembly as needed.



Drill collars – These are the large diameter and heavy pieces of pipe above the drill bit and below the drill pipe, which constitute the fundamental structure of the BHA. The weight of the drill collars applies compressional force (WOB) directly to the bit while keeping the more flexible drill pipe in tension to prevent buckling. This also conveys momentum and stiffness as the entire drilling assembly rotates, in order to keep the bit drilling smoothly and consistently.

Reamers – These are tools that enlarge, maintain or trim the side of the wellbore for various reasons, including easier electric logging, improved drilling performance and bit life, and reduced friction and vibration caused by a miss-shaped hole.

BHA



Stabilizers – These are short components with larger diameter fins called “blades” which stick out close to the diameter of the hole being drilled and are used to centralize the drilling assembly within the hole. Stabilizers have these blades attached or integrated to their external surface and are distributed from above the bit and through the drill collars depending on what form of stabilization is required. As the components with the largest diameter in the BHA they often interact with the sides of the well, creating friction and a restriction on fluid flow, so their design and positioning is crucial.

Various Subs – These are short components that are often used to connect other pieces of the BHA (crossover subs), or carry out specific functions. Some examples of the latter are subs which redirect or control the fluid flow (diverter and float subs), and subs which absorb movement and vibration to protect the assembly (shock subs and vibration dampening tools).

BASIC PROPERTIES OF DRILLING FLUID

- ✓Weighting Material (Density)
- ✓Rheology
- ✓Fluid loss
- ✓Inhibition
- ✓Solids
- ✓Content
- ✓Alkalinity and Ph control materials
- ✓Loss Circulation material
- ✓These must be achieved in an environmentally friendly, safe and cost

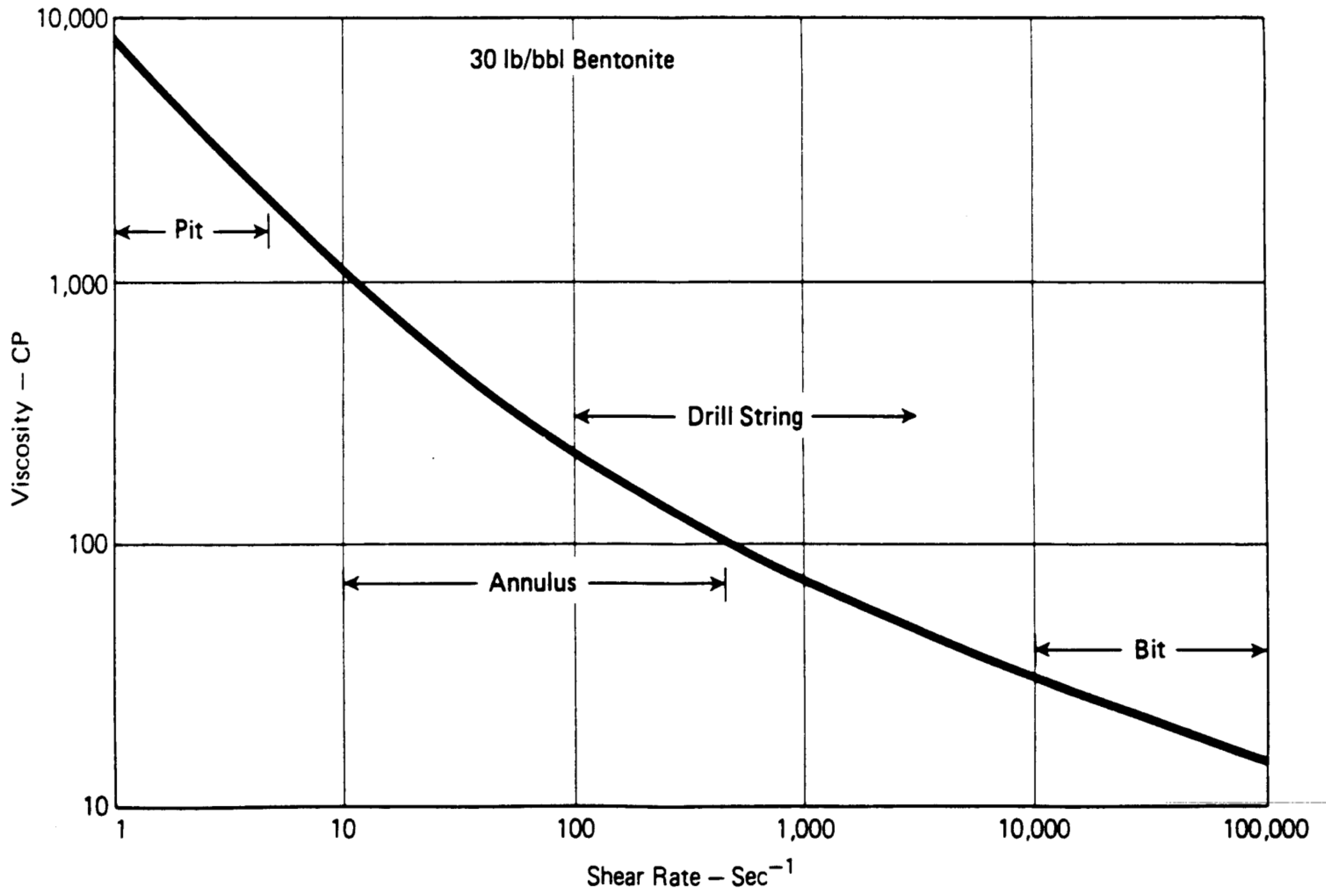
BASIC FUNCTIONS OF DRILLING FLUIDS

- ✓ To cool and lubricate the bit and drill string.
- ✓ To remove and transport cuttings from bottom of the hole.
- ✓ To carry cuttings to the surface.
- ✓ To suspend cuttings during time when circulation is stopped.
- ✓ To control subsurface pressure and formation pressure.
- ✓ To seal permeable hole and to wall with an impermeable filter cake.
- ✓ To stabilize bore hole and to maintain hole integrity.
- ✓ To minimize corrosion of the drill string, casing and tubing.
- ✓ To minimize contamination problems.
- ✓ To minimize torque, drag and pipe sticking.
- ✓ To maintain optimum penetration rate.
- ✓ To minimize formation damage.

VISCOSITY CURVE

Figure 1

Viscosity Curve for Bentonite Suspension



MUD PROGRAMME

In practice, mud programming can be broken down as follows:

✓Determination of mud weight requirement to maintain primary well control.
✓Determination of suitable 'trip margin' which is added to the primary well control mud weight to give a programmed mud weight.
✓Confirmation that this mud weight does not exceed formation fracture strengths when considered in a dynamic mode.
✓Analysis of formations to be drilled and the likely reaction of these to the available drilling fluid alternatives. Using this information. select a basic mud type such as:
Water-based: Freshwater mud , Seawater mud, Calcium mud ,Lignosulphonate mud, Polymer mud
Oil-based: Invert oil emulsion mud ,Environmentally sensitive oil-based mud, True oil mud
✓Determination of fluid loss requirements
✓Determination of pH requirements
✓Determination of viscosity requirements
✓Determination of temperature stability requirements
✓Analysis of rig mud treatment equipment to meet hole requirements with selected mud types

CLASSIFICATION OF DRILLING FLUIDS

- ✓Fresh water Muds.
  - •Simple clay water mixture
  - •Chemically treated clay water mixtures
  - •Calcium treated muds. High lime treated and low lime treated muds.
- ✓Salt water muds.
- ✓Emulsion based muds.
  - •Oil in water emulsion
  - •Water in oil emulsion (invert emulsion)
- ✓Oil based muds
- ✓Surfactant based muds
- ✓Polymer based muds

COMMON MUD ADDITIVES

- **Weighting materials:Barite**, Galena, Magcobar, Baroid, Milbar, Controlbar, Maccowate etc
- **Clays:** Wyoming clay, Bentonite, High yield drilling mud clay, Attapulgite, Montmorrilonite etc.
- :Quebracho organic dispersant mixture, Lignite, mineral lignin, **Lubricants (Thinners)** Sodium Tetra phosphate, Lignosulphonate, Reacted caustic tannin etc.
- **Fluid loss controller:** Gelatin, Starch, CMC, HEC, pre gelatinised drilling mud starch etc.
- **Lost Circulation materials:** wood fibres, cane fibres, cellophones, flakes, mica, tree bark, walnut shell, ground nut shell, Time setting clay cement, rubber tyre, mineral wool, perlite etc.
- **For Anhydrite or gypsum:** Barium Carbonate
- **For cement contamination:** Sodium bi carbonate
- **Starch preservative:** Formaldehyde
- **Higher alcohol anti foaming agent:** Ethyle Hexanol
- **Anti foaming agent:** Corning silicon

DENSITY INCREASING MATERIAL

Material	Principal Component	Specific Gravity
Galena	PbS	7.4-7.7
Haematite	Fe_2O_3	4.9-5.3
Magnetite	Fe_3O_4	5.0-5.2
Illmenite	$FeO.TiO_2$	4.5-5.1
Barite	$BaSO_4$	4.2-4.6
Siderite	$FeCO_3$	3.7-3.9
Celestite	$SrSO_4$	3.7-3.9
Dolomite	$CaCO_3.MgCO_3$	2.8-2.9
Calcium Carbonate	$CaCO_3$	2.6-2.8

VISCOSITY

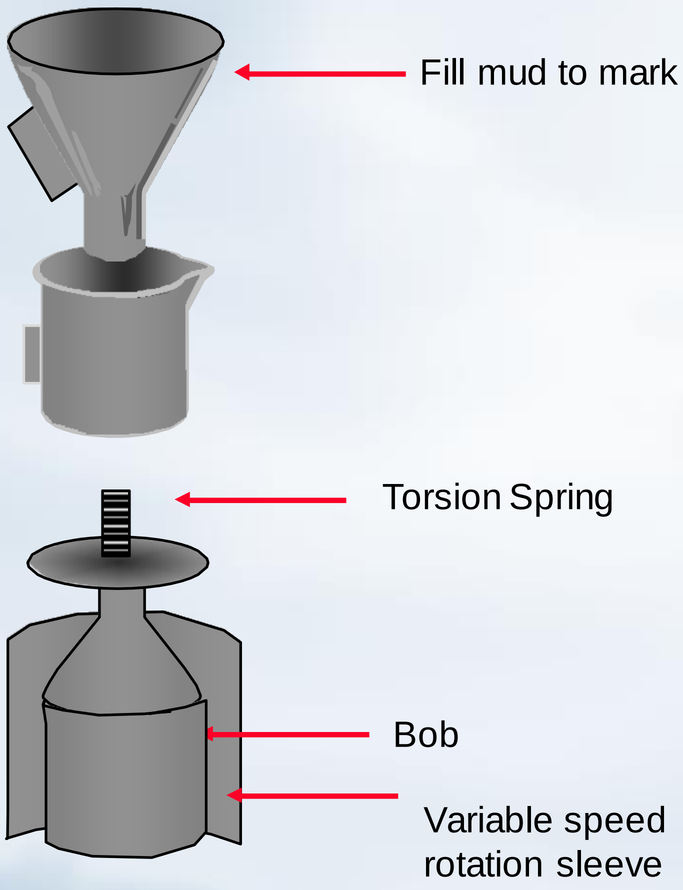
- ✓ The ability of drilling mud to suspend drill cuttings and weighting materials depends entirely on its viscosity otherwise, all the weighting material and drill cuttings would settle to the bottom of the hole as soon as circulation is stopped.
- ✓ The effects of increased viscosity can be felt by the increased resistance to fluid flow (increased pressure losses in the circulating system)

✓Several models have been developed to help understand the behaviour of different fluids in laminar flow

- Newtonian model - e.g. water, glycerine, oil
- Bingham Plastic Model - cement, flocculated fluids : high solids muds
- Power Law Model - low solids polymer muds, oil based muds

$$\text{Viscosity} = \frac{\textbf{shear stress (flow pressure)}}{\textbf{shear rate (flow rate)}}$$

INSTRUMENTS TO MEASURE VISCOSITY



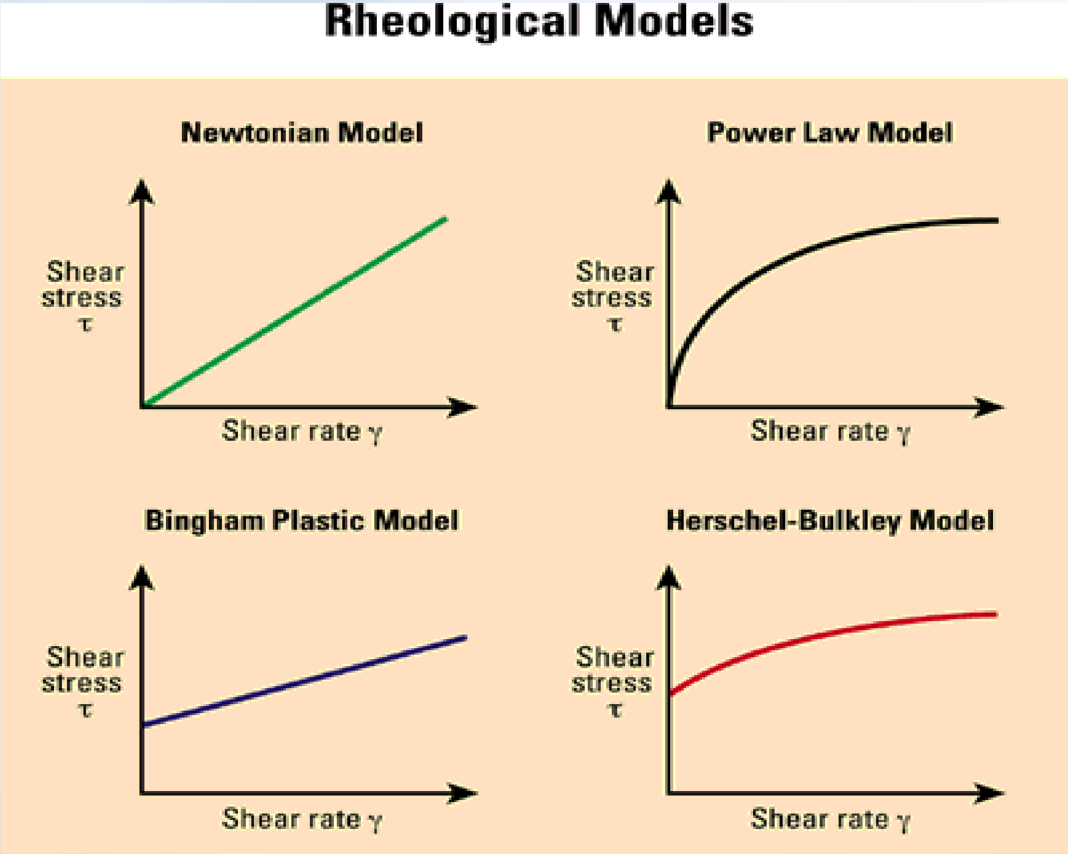
Marsh Funnel

- ✓Results are very temperature dependent
- ✓Used to give trends
- ✓Derrickman records results every 1/2 hour

Fann Viscometer

- ✓Can measure different shear stresses for different shear rates
- ✓Should be used with a heated cup to give readings at a set temperature
- ✓Also used to measure gel strengths

RHEOLOGY



✓Rheology is the study of how matter deforms and flows.

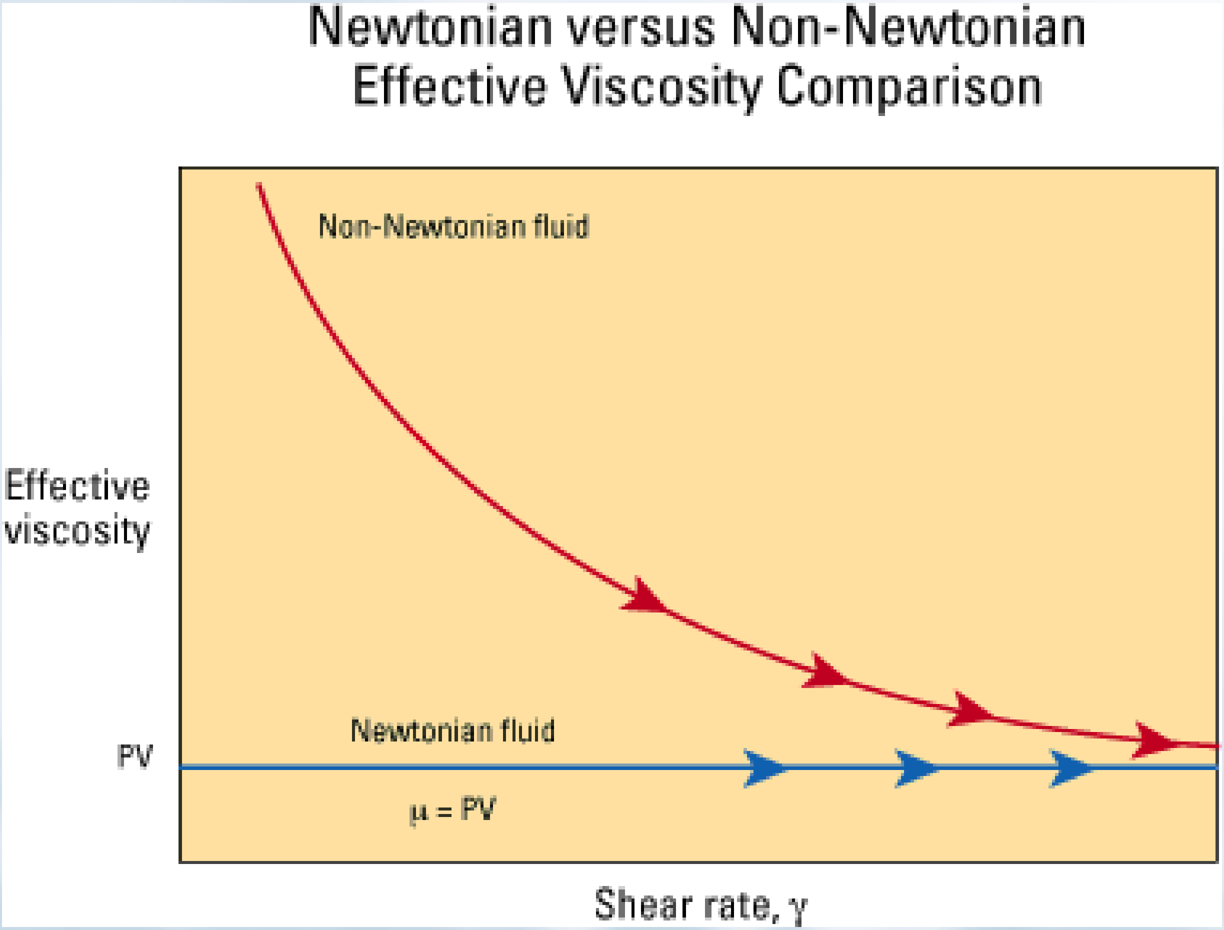
✓The rheological properties are plastic viscosity, yield point and gel strength.

✓Viscosity is Resistance to flow of a fluid and measured by cp (centipoise).

✓We have two kinds of Fluids:

- Newtonian
- Non-Newtonian

NEWTONIAN FLUID AND NON - NEWTONIAN FLUID



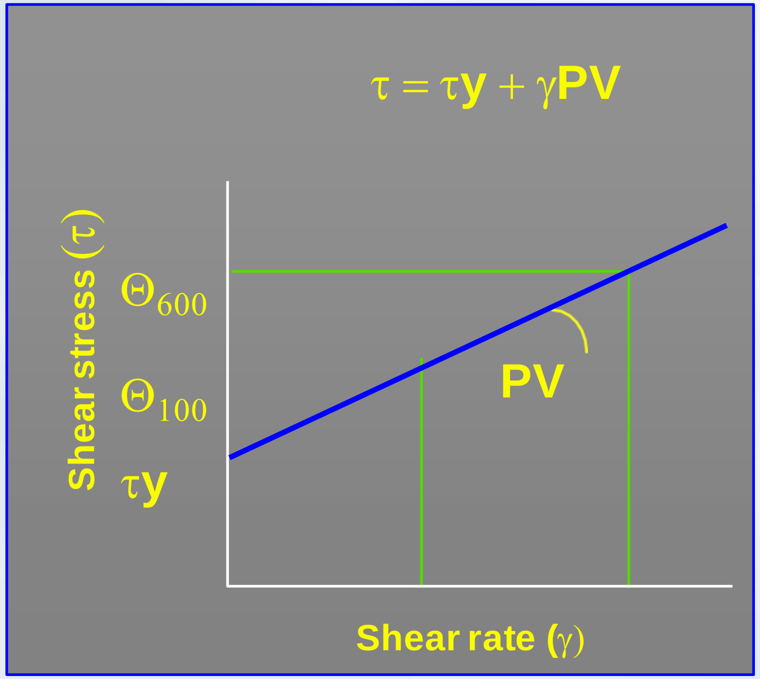
- ✓ **Newtonian Fluid:** A fluid that has a constant viscosity at all shear rates at a constant temperature and pressure, and can be described by a one-parameter rheological model. An equation describing a Newtonian fluid is given below.

$$\tau = k(\gamma)$$

Where τ = shear stress
γ = shear rate
k = viscosity.

- ✓ **Non Newtonian Fluid:** A fluid whose viscosity is not constant at all shear rates and does not behave like a Newtonian fluid. Within that group are several general types and rheological mathematical models to describe them.

BINGHAM PLASTIC MODEL



PV = 600 Q - 300 Q (cps)

- ✓ The plastic viscosity is due to the physical size and presence of any solids or emulsified droplets in the fluid.
- ✓ The PV should be as low as possible
- ✓ To reduce the PV reduce the solids

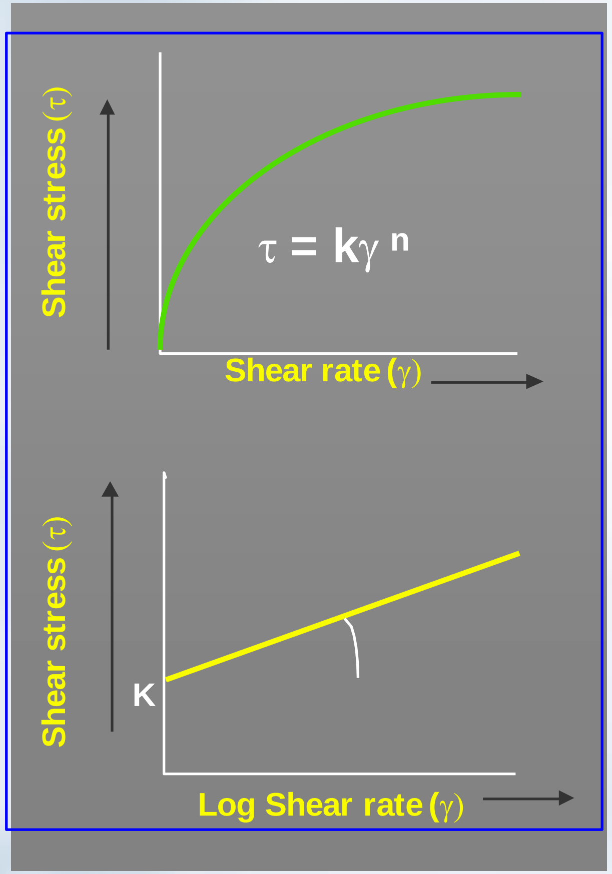
Yield Point = 300 Q - PV (lbs/100ft^2)

- ✓ The yield point is the viscosity due to the chemical attraction between the particles.
- ✓ To increase the YP add products with attractive forces.
- ✓ To reduce add products which reduce attractive forces

The PV for cements = (300 Q - 100 Q) / 1.5

- ✓ The high g forces generated by the 600 forces solids to the outside of the sleeve and distorts the reading

POWER LAW MODEL



$$n = 3.32 \log \frac{600\ \Theta}{300\ \Theta} \text{ (no dimensions)}$$

- ✓ n is the power law index and indicates the degree of non Newtonian behaviour
- ✓ n should be as low as possible, the effective viscosity decreases with shear rate
- ✓ low n values give flat flow profiles
- ✓ Additives with attractive forces reduce n

$$K = \frac{300\ \Theta}{511^n} \text{ (lbs/100ft}^2\text{)}$$

- ✓ k is the consistency index and indicates the viscosity of the liquid phase and solids content
- ✓ Anything which increases the low shear viscosity will increase k.

SHEAR RATES IN THE CIRCULATING SYSTEM

SECTION	RATE (S-1	FANN RPM

$$\text{Shear rate } (sec^{-1}) = \frac{120V}{D_h - D_p}$$

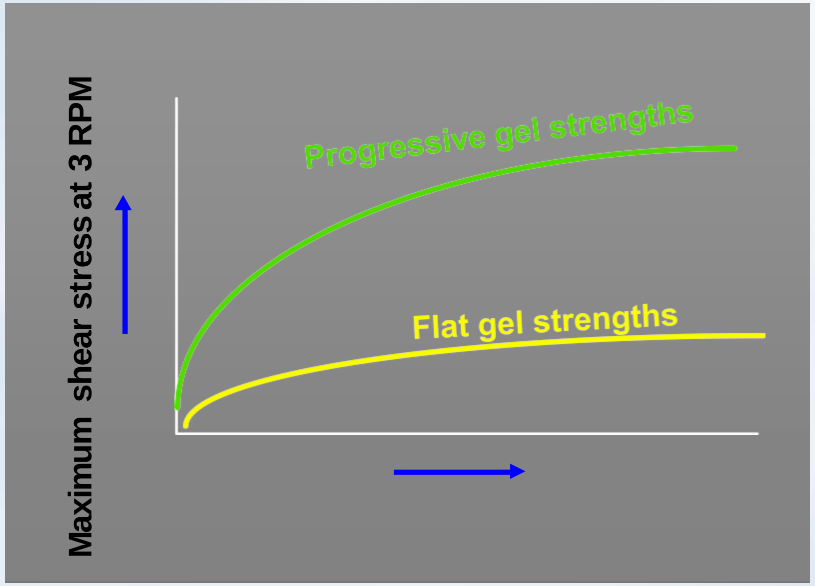
D is in mm, and V = velocity in cm/sec.

✓Monitor the shear stress of the fluid at the shear rates in the annulus

✓Pump Hi Vis pills regularly, if hole is not being cleaned increase shear stress for corresponding shear rate

✓Many operators request 3 and 6 RPM readings

GEL STRENGTHS



The Gel strengths refers to the increase in viscosity at zero shear rate

It is the measure of the attractive forces under static

conditions It is measured after :

– 10 seconds

– 10 minutes

– 30 minutes

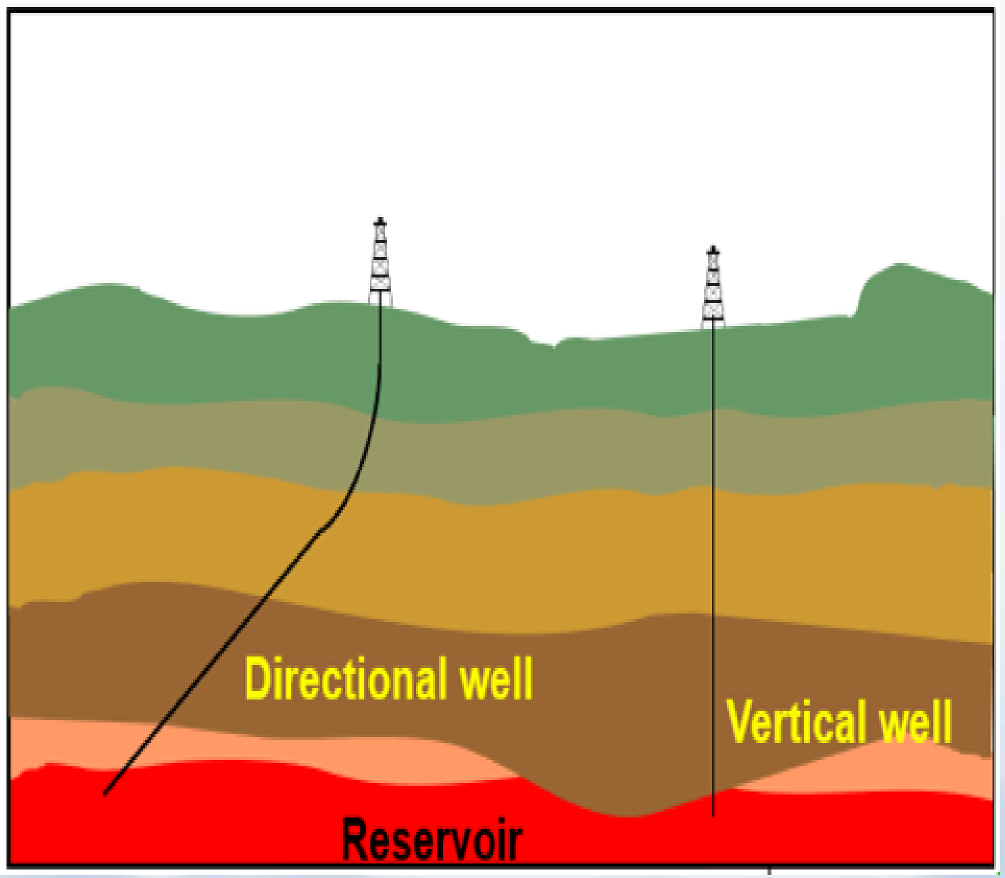
EFFECTS OF EXCESSIVE VISCOSITY

- ✓ Increased pump pressure
- ✓ Increased risk of swabbing / surging the hole
- ✓ Loss of mud at the shakers
- ✓ Poor efficiency of the solids control equipment
- ✓ Increased risk of fracturing the formation, especially with high gel strengths
- ✓ Poor mud removal for cementing operations

EFFECTS OF LOW VISCOSITIES

- ✓Poor hole cleaning
  - –Cuttings bed
  - –Hole fill
  - –Stuck pipe
  - –Cuttings degradation
- ✓Overloading of the annulus increasing the hydrostatic
- ✓Increased erosion if the fluid is in turbulent flow
- ✓ Barite sag or settlement

DIRECTIONAL DRILLING



✓Directional drilling is defined as an art and science involving deflection of a well bore in a specified direction in order to reach a predetermined objective below the surface of the earth.

✓The first controlled directional well was drilled in 1930 at Huntington Beach, California, USA. The well was drilled from an onshore location into offshore oil sands.

DEVIATION PROGRAMME

Directional drilling has now become an essential element in oilfield development, both onshore and offshore.

The application of directional drilling can be grouped into the following categories:-

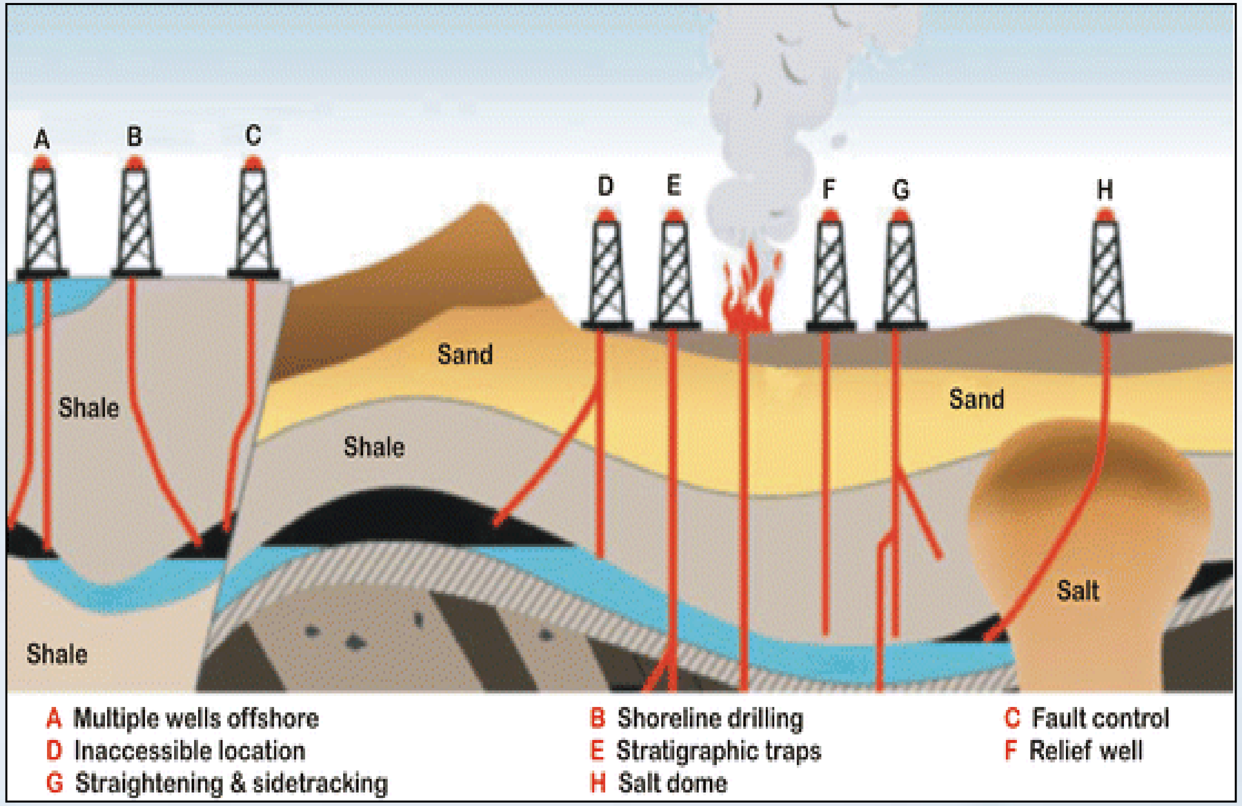
- ✓ Side tracking
- ✓ Drilling to avoid geological problems
- ✓ Controlling vertical holes
- ✓ Drilling beneath inaccessible locations
- ✓ Offshore development drilling,
- ✓ Horizontal drilling
- ✓ Relief well drilling.

DEVIATION PROGRAMME

Assuming that a target rig site has been selected, for directional planning considerations, the values that must be identified are as follows

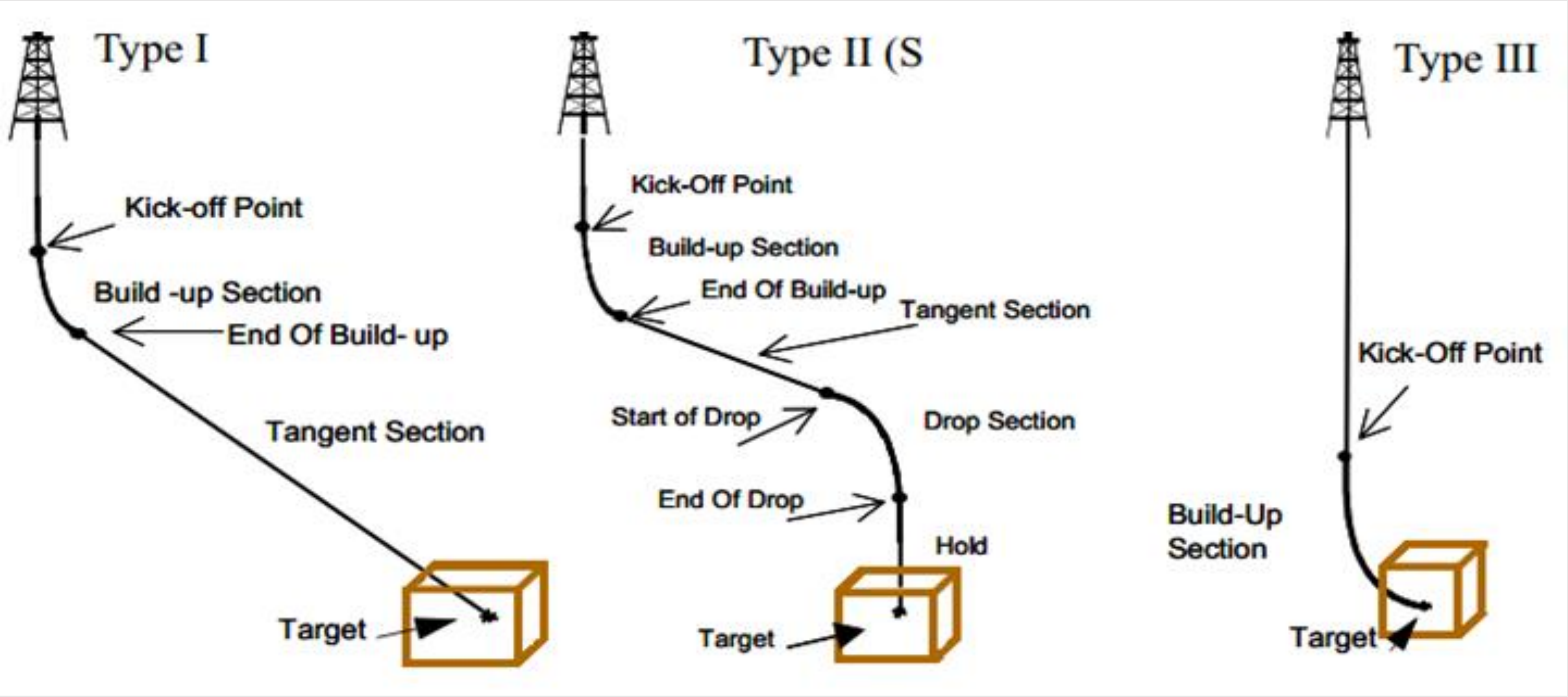
- ✓ Lateral or horizontal displacement from the target to a vertical line from the rig site.
- ✓ Kick off point (KOP)
- ✓ Desired build angle rate
- ✓ Final drift angle
- ✓ Plan type: Straight kick Vs Curve
- ✓ Desired drop angle rate in case of 'S' curve.

APPLICATIONS

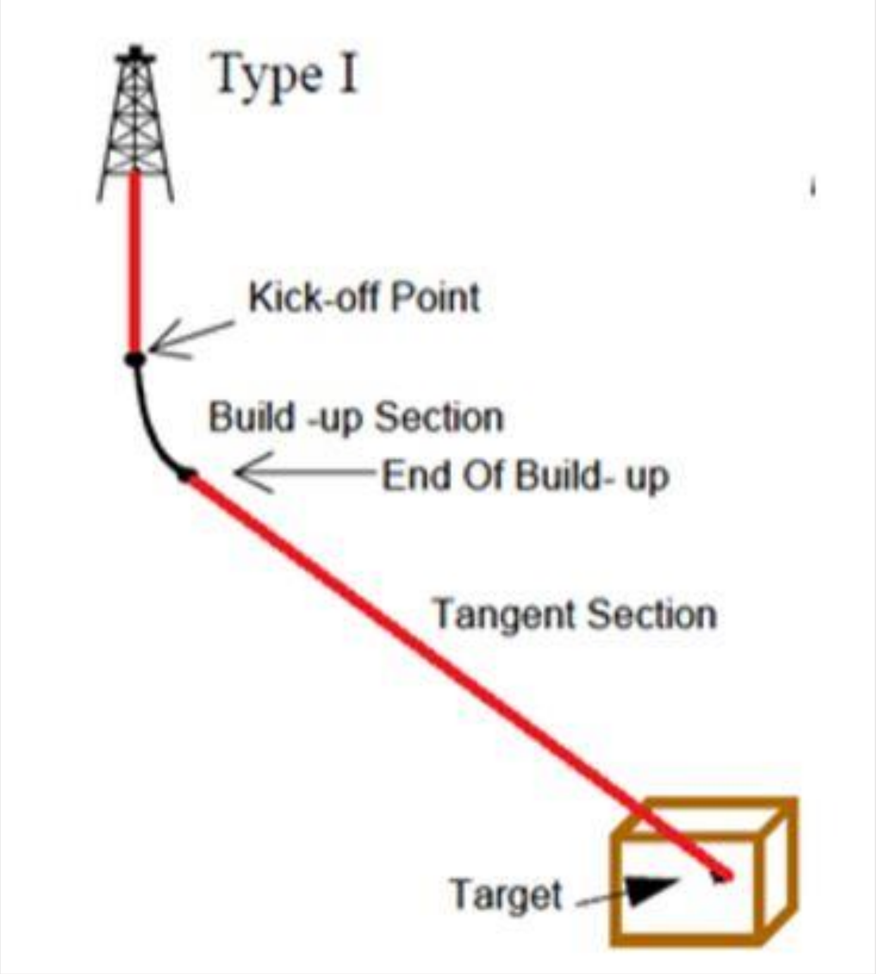


- ✓Sidetracking & Straightening
- ✓Inaccessible Locations
- ✓Multiple Exploration Wells from A Single Wellbore
- ✓Fault Controlling
- ✓Salt Dome Drilling
- ✓Relief Wells
- ✓Multilateral Wells
- ✓Horizontal Wells
- ✓Extended Reach Wells

TYPES OF DIRECTIONAL DRILLING WELL PROFILES



TYPE-1 (BUILD & HOLD) or L-TYPE



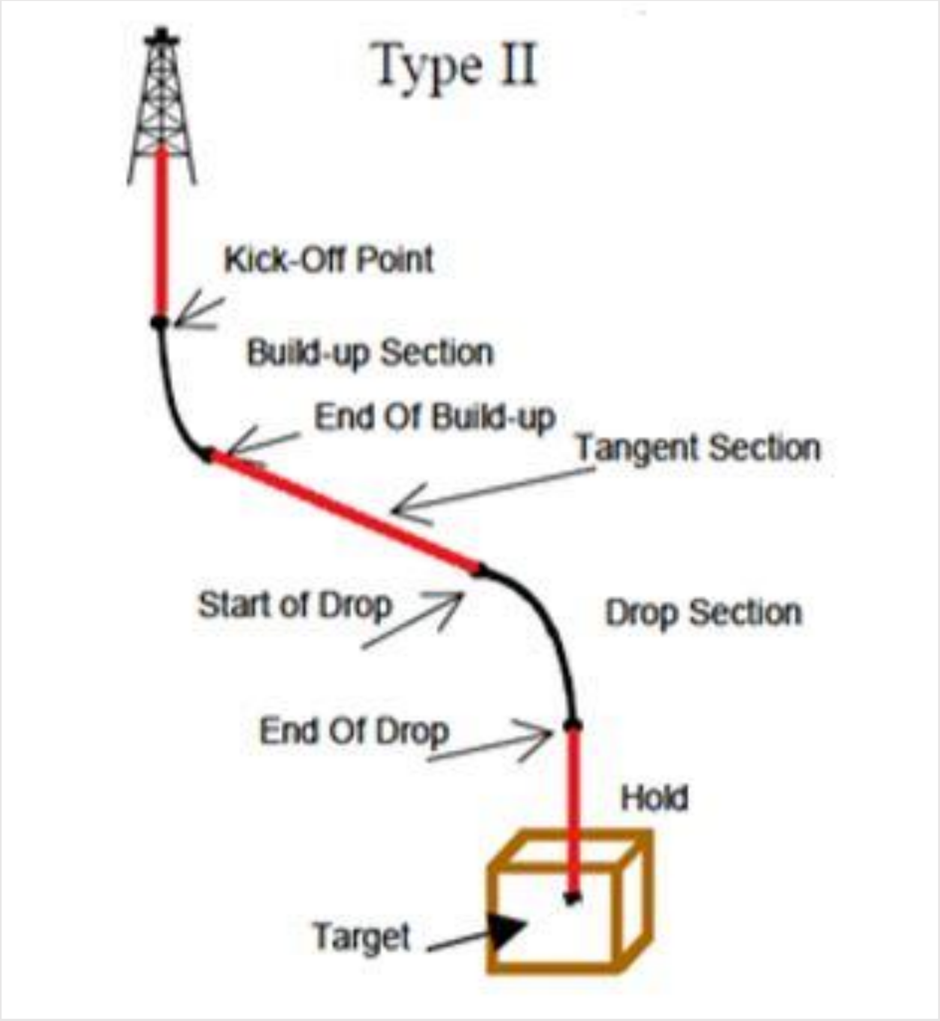
✓It is the most common and simplest.

✓The well is vertical until the KOP where it is kicked off and an angle is built.

✓When the desired inclination is reached, the well path is kept tangent or straight until the target is reached.

✓This can be applied where large displacements are required at relatively shallow depths.

TYPE-2 (BUILD, HOLD & DROP) or S-TYPE



✓It also called shaped wells.

✓The well is kept vertical until KOP and an inclination is built and the tangent section is drilled.

✓After the tangent section, a drop-off section is drilled where the inclination is reduced and the well path is almost vertical as it hits the target.

✓Used where target is deep but horizontal displacement is relatively small or multiple producing zones.

CLASSIFICATION OF WELLS

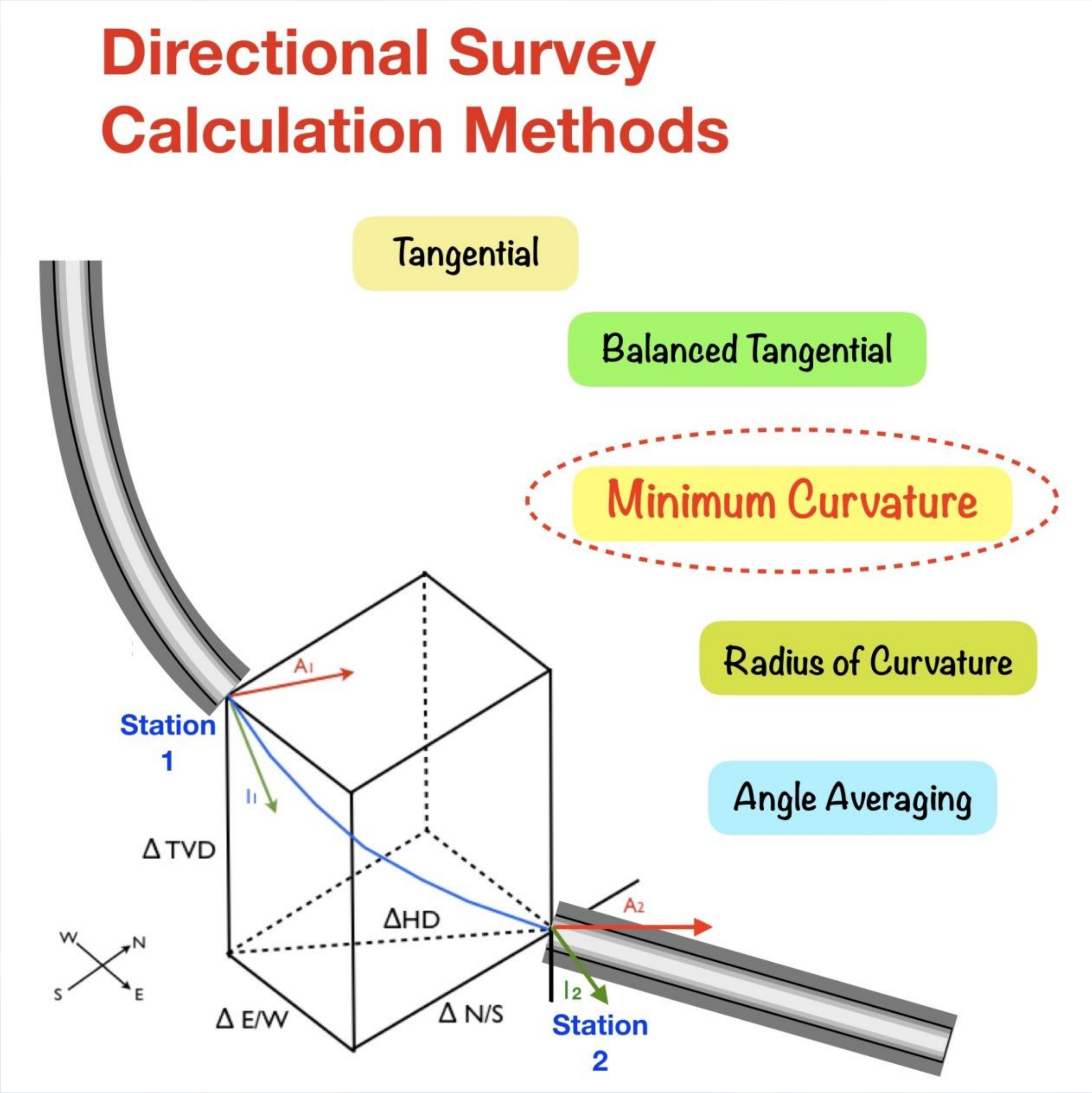
Pattern Classification	Degree of Difficulty	Relative Cost (% greater than vertical)
VERTICAL (reference)	Low	0.0
DIRECTIONAL		
Single-bend	Low	+ 25
Double-bend	Low to Medium	+ 50
Complex	Medium	+ 100
Extended-reach	Medium to High	+ 150
High-angle	High	+ 200
Slant	Low to Medium	+ 50
HORIZONTAL		
Short Radius	High	+ 200
Medium Radius	Medium to High	+ 150
Long Radius	High	+ 200

- ✓ Vertical wells – Inclination Angle < 5º
- ✓ Deviated wells – I < 60º
- ✓ Highly Deviated well – I > 60 º
- ✓ Horizontal well – I = 85 º - 90 º
- ✓ ERD – Long Horizontal departure

CLASSIFICATION OF WELLS

Pattern name	Short	Medium	Long
Turn radius	2–60 ft	300–800 ft	1000–3000 ft
Build rate	95–300 (°/100 ft)	7.2–19.1 (°/100 ft)	1.2–5.7 (°/100 ft)
Horizontal extension	100–800 ft	1500–3000 ft	2000–5000 ft
Devices and tools	Special rotary device	Approximate conventional rotary device and PDM	Conventional rotary device and PDM
Operation	Special	Approximate conventional	Conventional
Cost	High	Medium	Low
Trajectory survey	Oil-pipe conveyed	MWD or pumping	MWD or pumping
Controlled method	Whipstock	PDM tool	PDM tool
Logging	Non	Drill-pipe conveyed or down-	Drill-pipe conveyed or

DIRECTIONAL SURVEYING

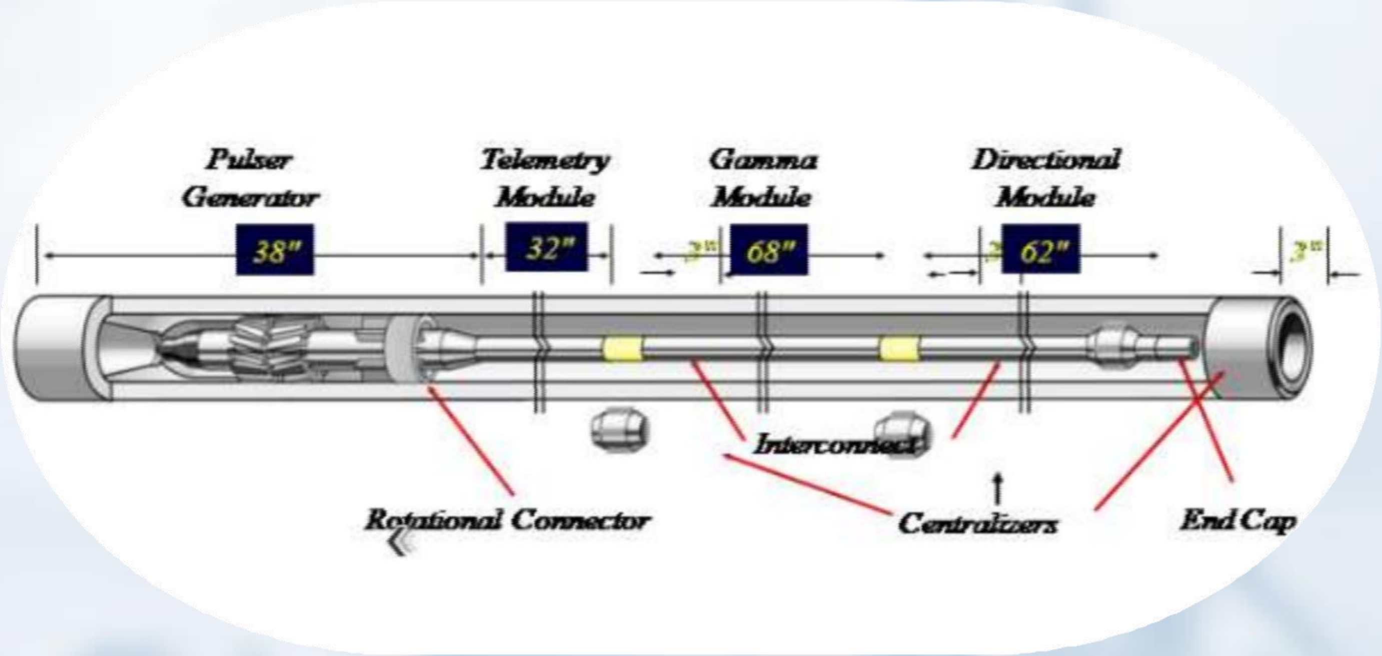


Single surveys can be performed during the drilling process to record inclination and hole direction. With directional drilling, single surveys can orient the deflection tool. The survey can be obtained during connections with a Measurement While Drilling (MWD) installed in the Bottom Hole Assembly (BHA) or lowering the survey instrument to the bottom of the hole, and taking the survey. Depending on the type of instrument used, inclination and hole direction information may be recorded and stored downhole in computer memory or transmitted to the surface. The transmitted or stored information is used in preparing the actual survey record. Surveying while drilling allows the driller to know the current position of the well and change the inclination and direction if required.

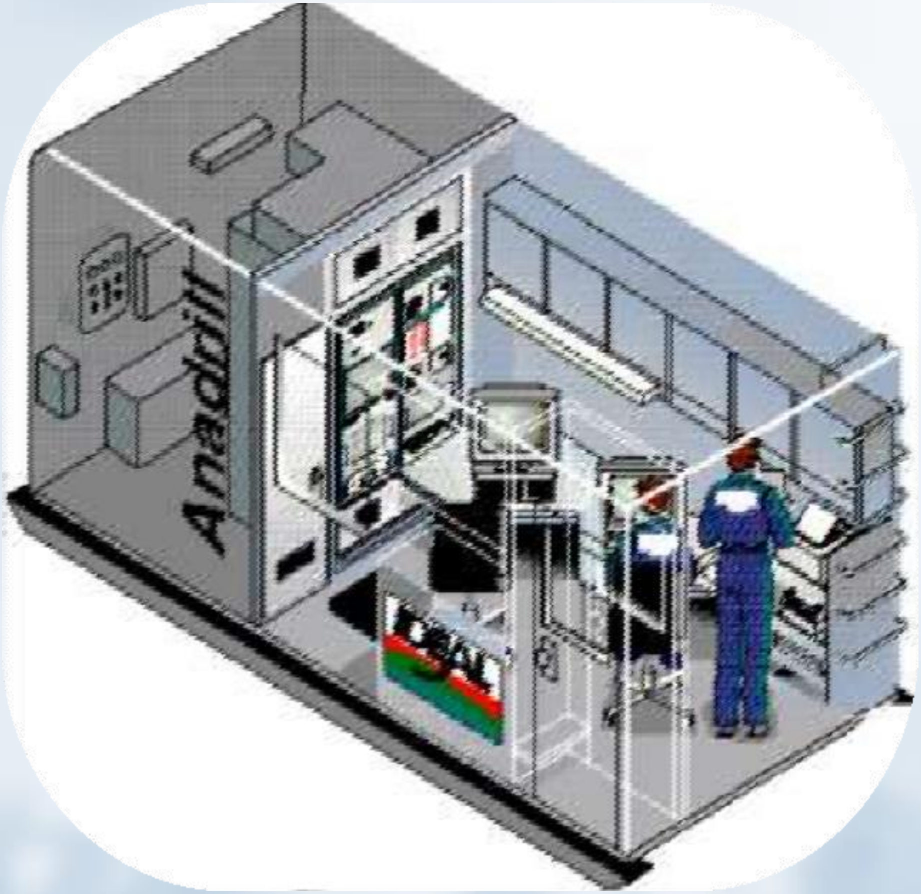
DIRECTIONAL SURVEYING

What is MWD?

Measurement While Drilling (MWD) systems measure formation properties (e.g. resistivity, natural gamma ray, porosity), wellbore geometry (inclination, azimuth), drilling system orientation (tool face), and mechanical properties of the drilling process.



MWD SURFACE SYSTEM



✓Surface sensors for measuring surface drilling parameters, as well as the well's depth.

✓A transducer at the surface to receive the measurement signals from the MWD tool.

✓A computer for decoding downhole data at the surface.

✓A computer for processing, storing, and using all of the data.

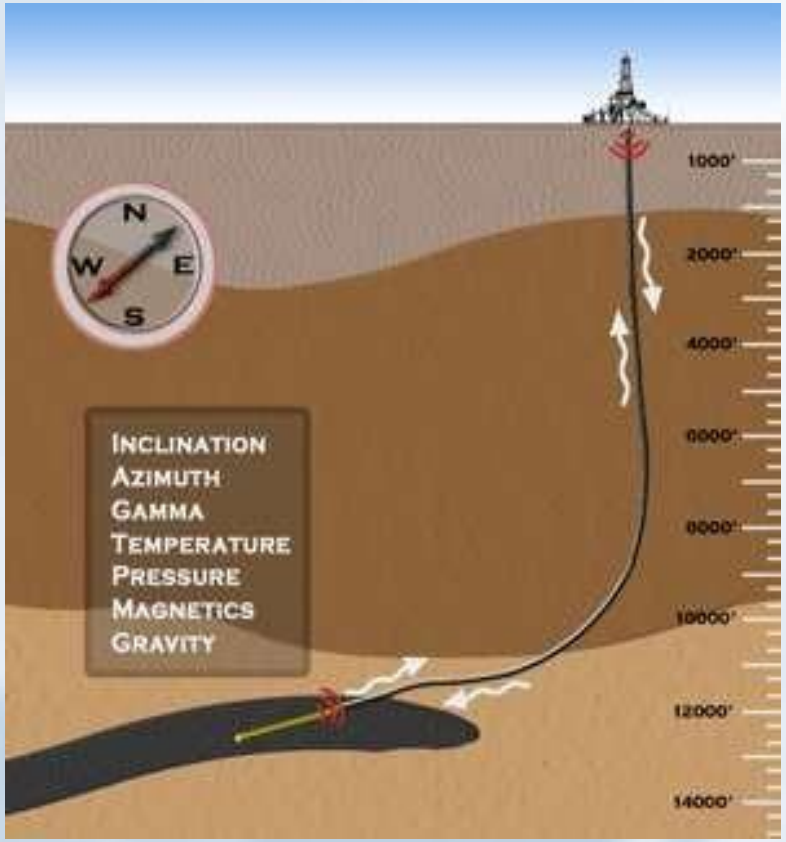
MWD SCREEN

✓It is to be noted that the MWD tool lies at about 20 m above the bit.

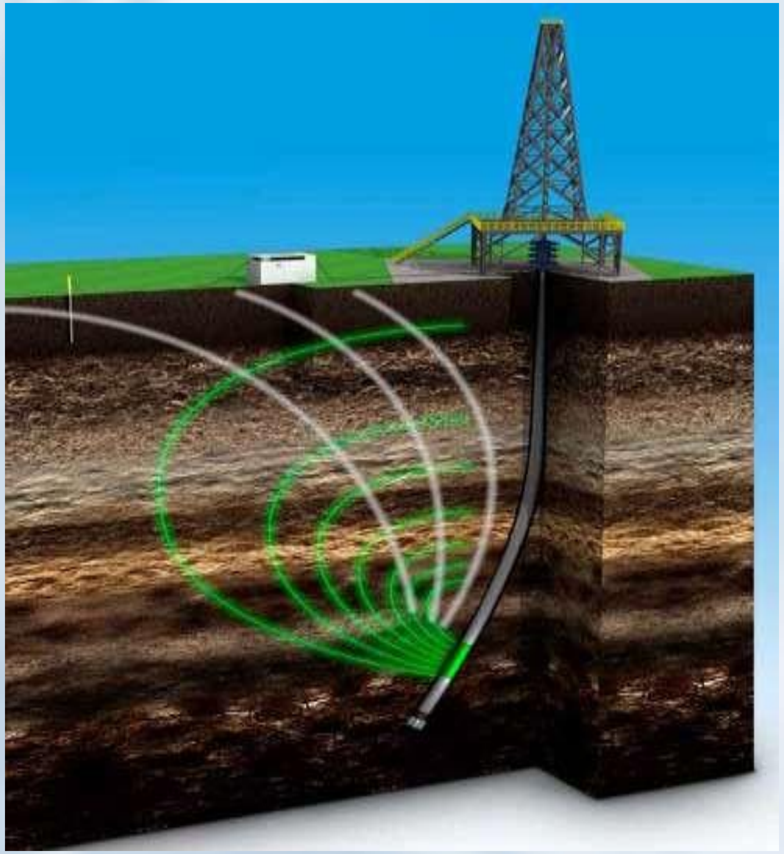
✓This distance between the MWD tool and the Bit is called the tool offset

HOW THE DATA IS TRANSFERRED?

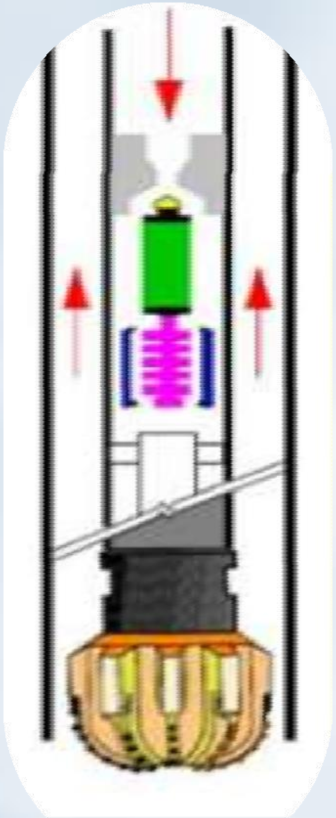
Mud Pulse Telemetry

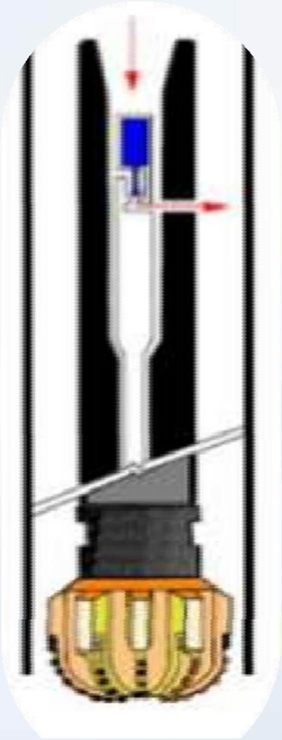


Electromagnetic Telemetry



MUD PULSE TELEMETRY





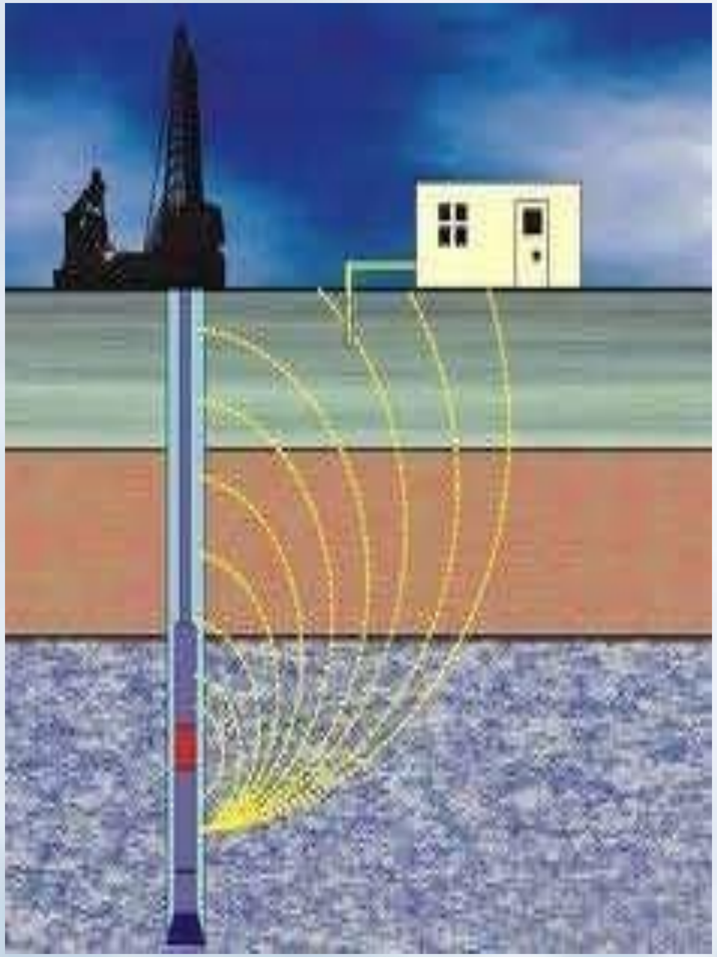
Positive mud pulse telemetry (MPT):

It uses hydraulic poppet valve to momentarily restrict mud flow through an orifice to generate increase in the pressure in form of positive pulse which travel back to the surface to be detected.

Negative MPT:

It uses a controlled valve to vent mud momentarily from the interior of the tool into the annulus .
This process generates a decrease in the pressure in the form of a negative pulse which travels back to the surface .

ELECTROMAGNETIC TELEMETRY



✓The EM does not use the drilling mud to send pressure waves.

✓The tool sends either a magnetic pulse or electrical current through the ground to the surface.

✓On the surface the data is received through ground antennas and the data is processed.

✓EM systems are significantly faster (10x) than conventional mud pulse

LOGGING WHILE DRILLING

DOWNHOLE DV MEASUREMENT

✓Logging while drilling (LWD) is closely related to MWD.

✓LWD provides formation measurements, while MWD provides drilling mechanics and survey measurements.

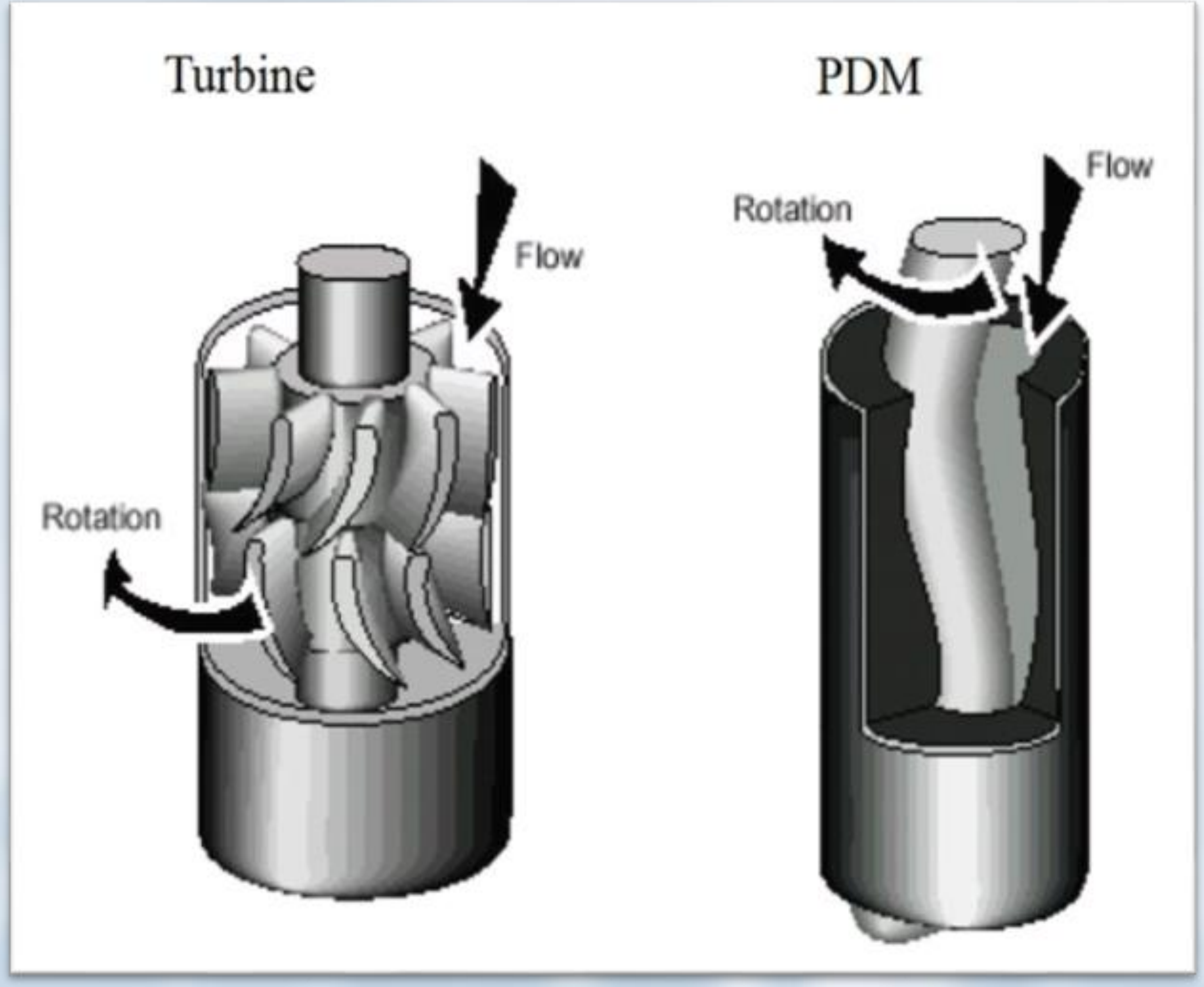
✓Lowered along with drill string during drilling instead of wireline

✓LWD tools now being used include electromagnetic resistivity, spectral gamma ray, lithology density and neutron porosity instruments housed in special drill collar.

✓The information collected are not transmitted via telemetry, but stored in a memory incorporated within the tool.

✓LWD tool also houses a power system like MWD tool.

MUD MOTORS

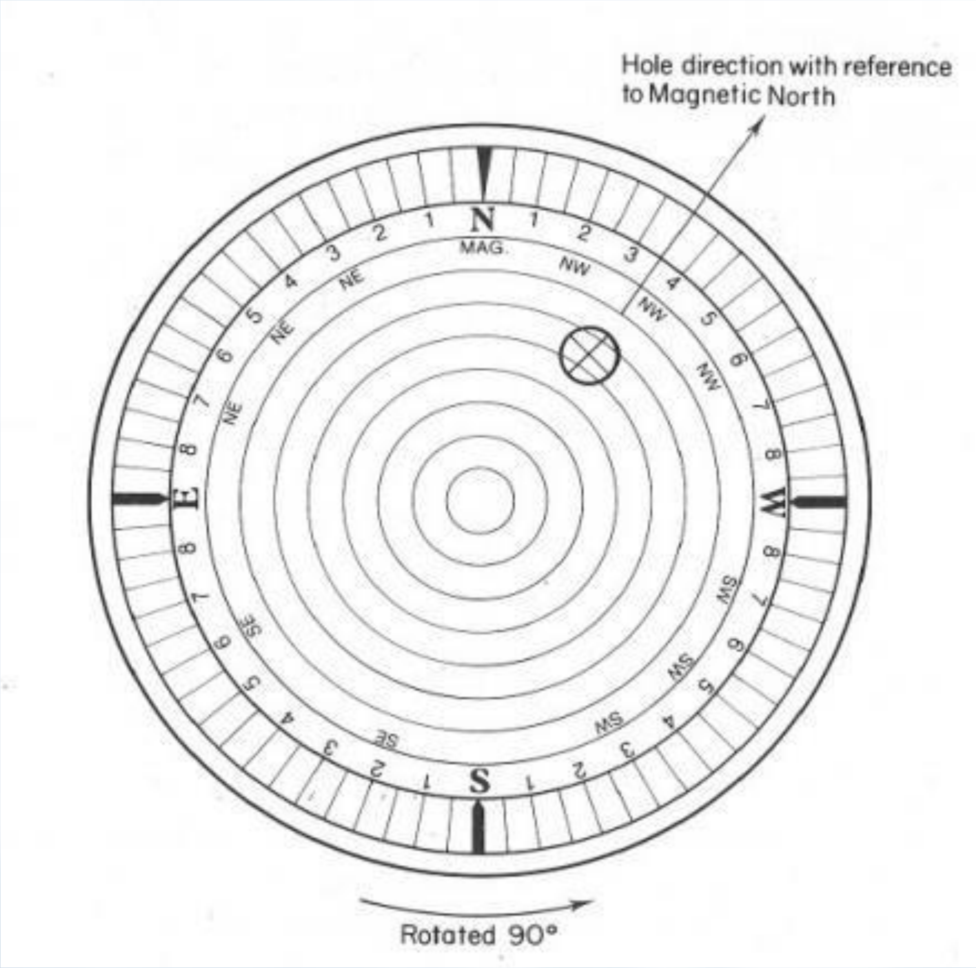


Type of Mud Motors:

✓Turbines

✓Positive Displacement motor

SURVEYING INSTRUMENTS



Instruments

✓Magnetic Single Shot

✓Magnetic Multi-Shot Major components:

✓Battery, camera, magnetic compass, pendulum assembly

✓Gyroscope

SURVEY CALCULATION METHODS

Survey data provide a pictorial image of the path of the well and the data are normally plotted on the same graph as that of the planned course

Most common methods

- ✓Tangential method
- ✓balanced tangential method
- ✓Angle averaging method
- ✓Radius of curvature method
- ✓Minimum curvature method
- ✓mercury method

CLOSURE DISTANCE AND DIRECTION

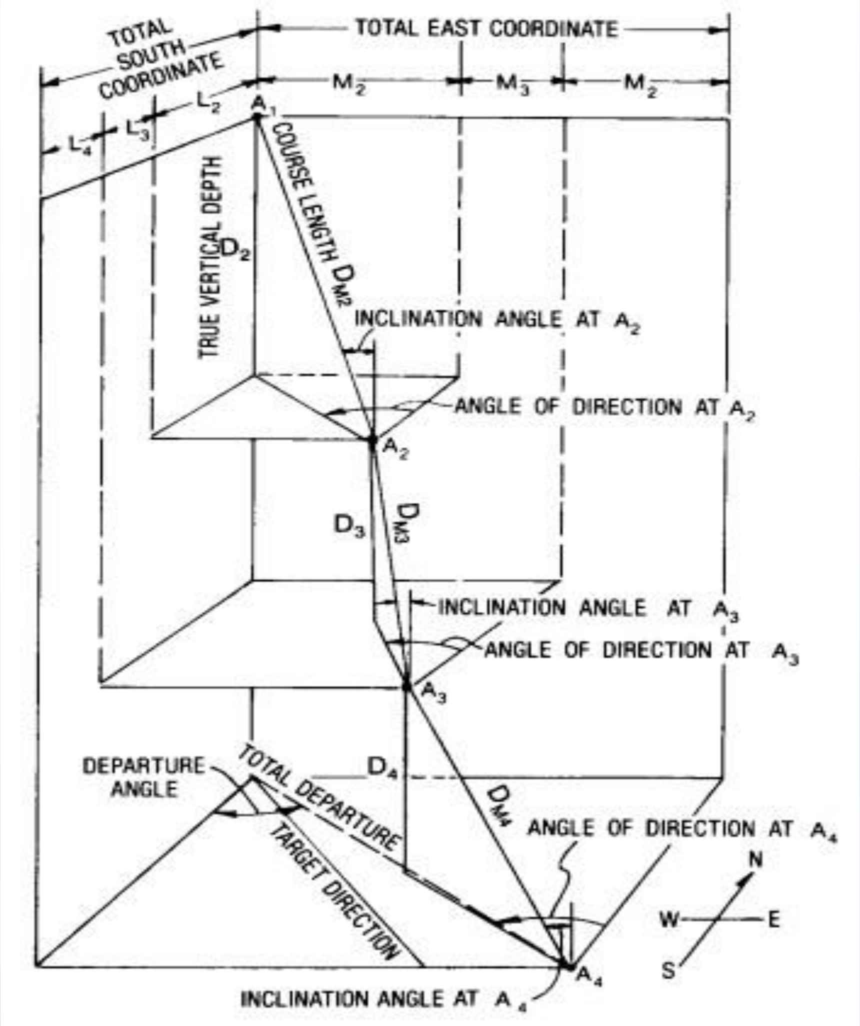
Total departure: Shortest distance from vertical wellbore to each station point

$$\tan \alpha = \frac{\Delta E}{\Delta N}$$

$$\text{Azimuth} = 360 \pm \alpha$$

$$\text{total departure} = \sqrt{(\text{total north})^2 + (\text{total east})^2}$$

$$\text{departure angle} = \text{arc tan}\left(\frac{\text{total east}}{\text{total north}}\right).$$



TANGENTIAL METHOD

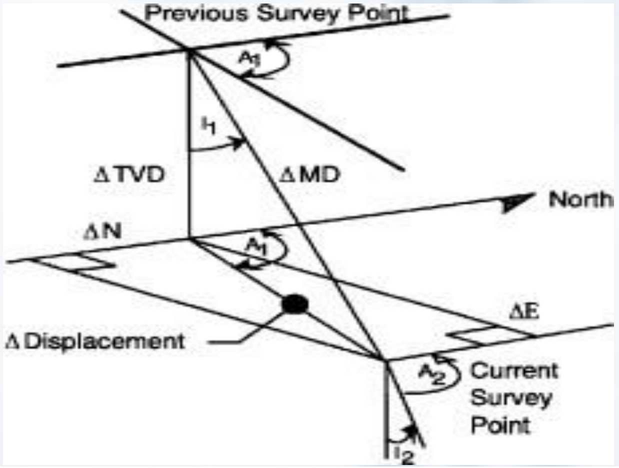
$$\Delta \mathrm{VD} = \Delta \mathrm{MD} \cos I_2$$

$$\Delta D = \Delta \mathrm{MD} \sin I_2$$

$$\Delta \mathrm{E} = \Delta D \sin A_2 = \Delta \mathrm{MD} \sin I_2 \sin A_2$$

$$\Delta \mathrm{N} = \Delta D \cos A_2 = \Delta \mathrm{MD} \sin I_2 \cos A_2$$

ΔMD = increment of course length
ΔVD = increment of true vertical depth
ΔD= increment of horizontal displacement or departure
ΔE= increment of easting co-ordinate
ΔN = increment of northing co-ordinate



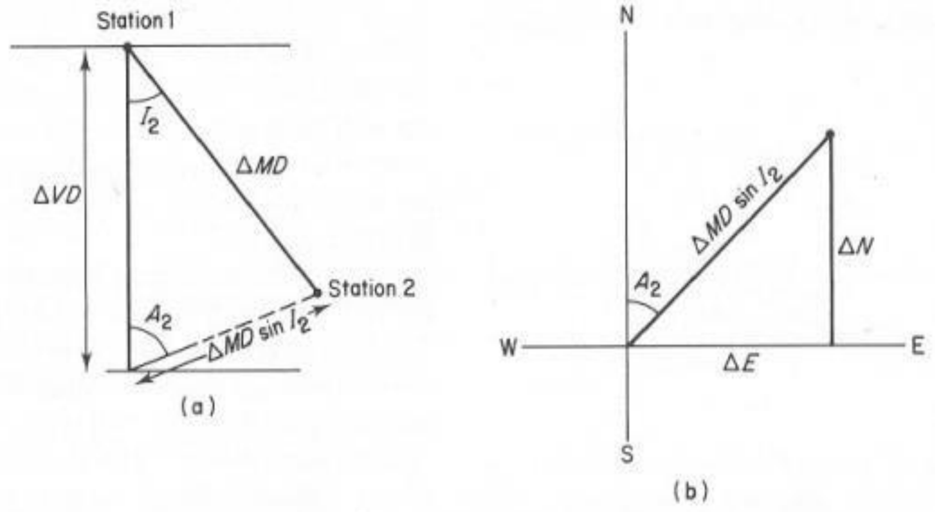


Fig. 8.28. Tangential method: (a) vertical section; (b) plan view.

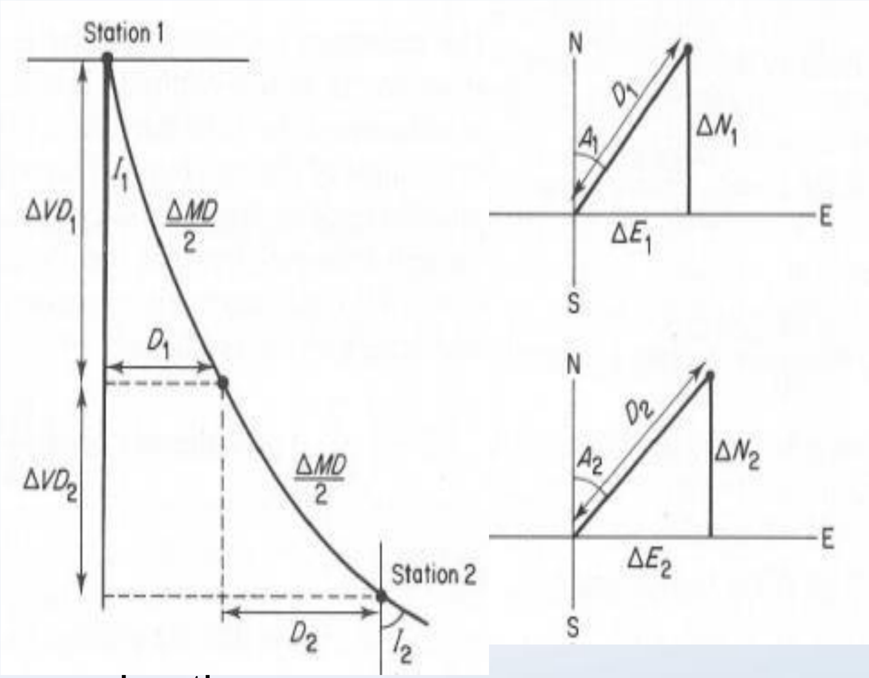
ANGLE AVERAGING METHOD

$$\Delta D = \Delta MD \sin\left(\frac{I_1 + I_2}{2}\right)$$

$$\Delta VD = \Delta MD \cos\left(\frac{I_1 + I_2}{2}\right)$$

$$\Delta E = \Delta MD \sin\left(\frac{I_1 + I_2}{2}\right)\sin\left(\frac{A_1 + A_2}{2}\right)$$

$$\Delta N = \Delta MD \sin\left(\frac{I_1 + I_2}{2}\right)\cos\left(\frac{A_1 + A_2}{2}\right)$$



ΔMD= increment of course length
ΔVD= increment of true vertical depth
ΔD= increment of horizontal displacement or departure
ΔE= increment of easting co-ordinate
ΔN= increment of northing co-ordinate

✓Inclination angles and direction angles are averaged and used for the calculation of departure, total vertical depth, and easting and northing increments

Assumption:

✓Wellbore course is a straight line tangent to the average angle

✓This method is simple and provides accurate means of calculating wellbore surveys when two survey points are not too far and apart and there is no large change in azimuth at low angles

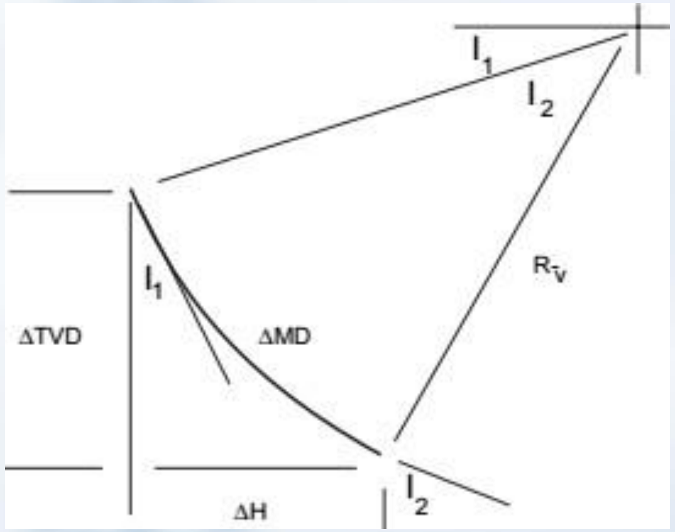
RADIUS OF CURVATURE METHOD

✓Vertical Projection:

Taking a vertical section through the well path, by "unwrapping" the cylinder (Arc length of MD and a change of inclination from I_1 to I_2)

✓Radius of curvature of segment $= \dfrac{1}{\text{rate of change in inclination}}$

$$R = \frac{1}{\frac{I_2 - I_1}{\Delta MD}} = \frac{\Delta MD}{I_2 - I_1}$$



$$Rv = \frac{180 \cdot \Delta MD}{\pi(I_2 - I_1)}$$

$$\Delta TVD = Rv\,(\sin I_2 - \sin I_1)$$

$$\Delta H = Rv\,(\cos I_1 - \cos I_2)$$

ΔMD= increment of course length

*Δ*VD = increment of true vertical depth

ΔD= increment of horizontal displacement or departure

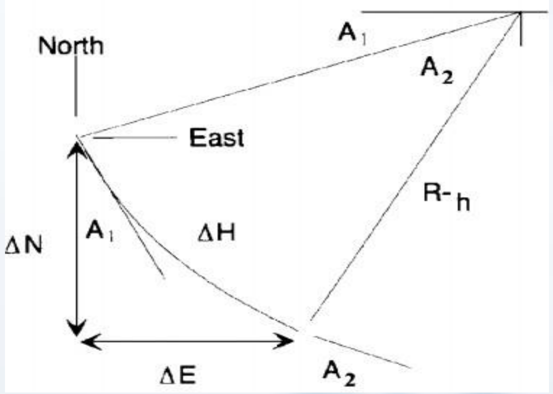
ΔE= increment of easting co-ordinate

ΔN= increment of northing co-ordinate

RADIUS OF CURVATURE METHOD

✓ **Horizontal Projection:**

Consider a horizontal projection of the well bore, having a radius of curvature Rh to find the North and East displacements



$$R_h = \frac{180 \cdot \Delta H}{\pi(A_2 - A_1)}$$

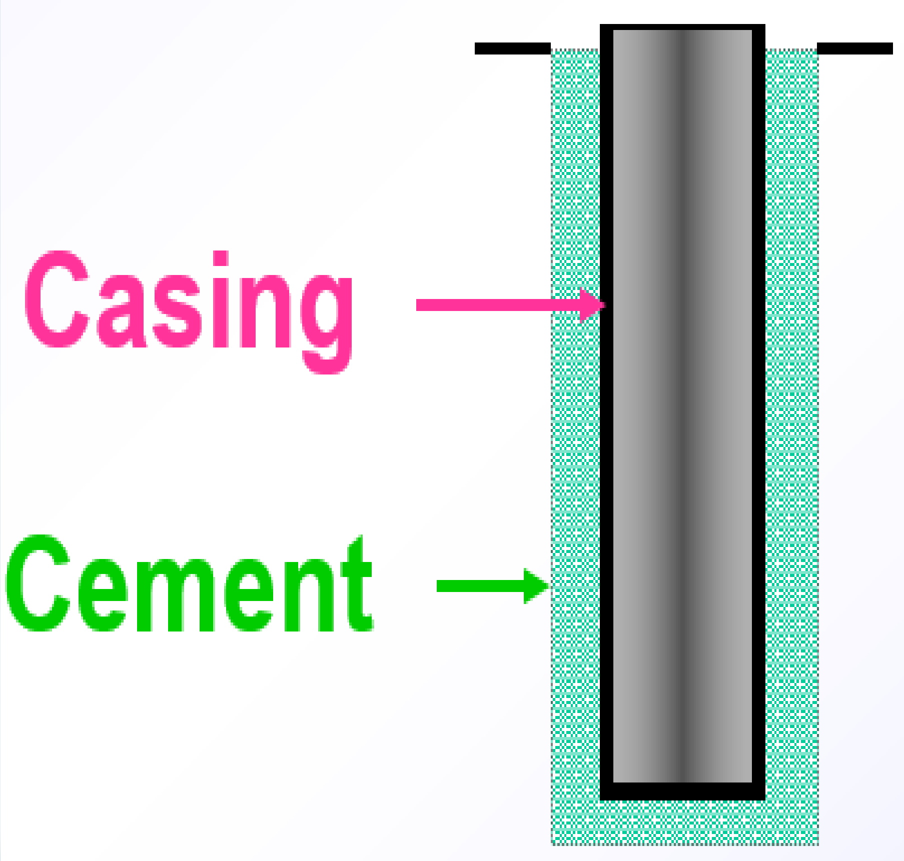
$$\Delta North = R_h\ (\sin A_2 - \sin A_1)$$

$$\Delta East = R_h\ (\cos A_1 - \cos A_2)$$

Average angle method is quite accurate when the well curvature is small and stations are close together

Radius of curvature method is accurate for stations spaced far apart, and with higher rates of curvature

WHAT IS CASING ?



✓Casings are tubular goods run in a wellbore after drilling the hole. They have various sizes to suit the different hole sizes used in each section of the drilling operation.

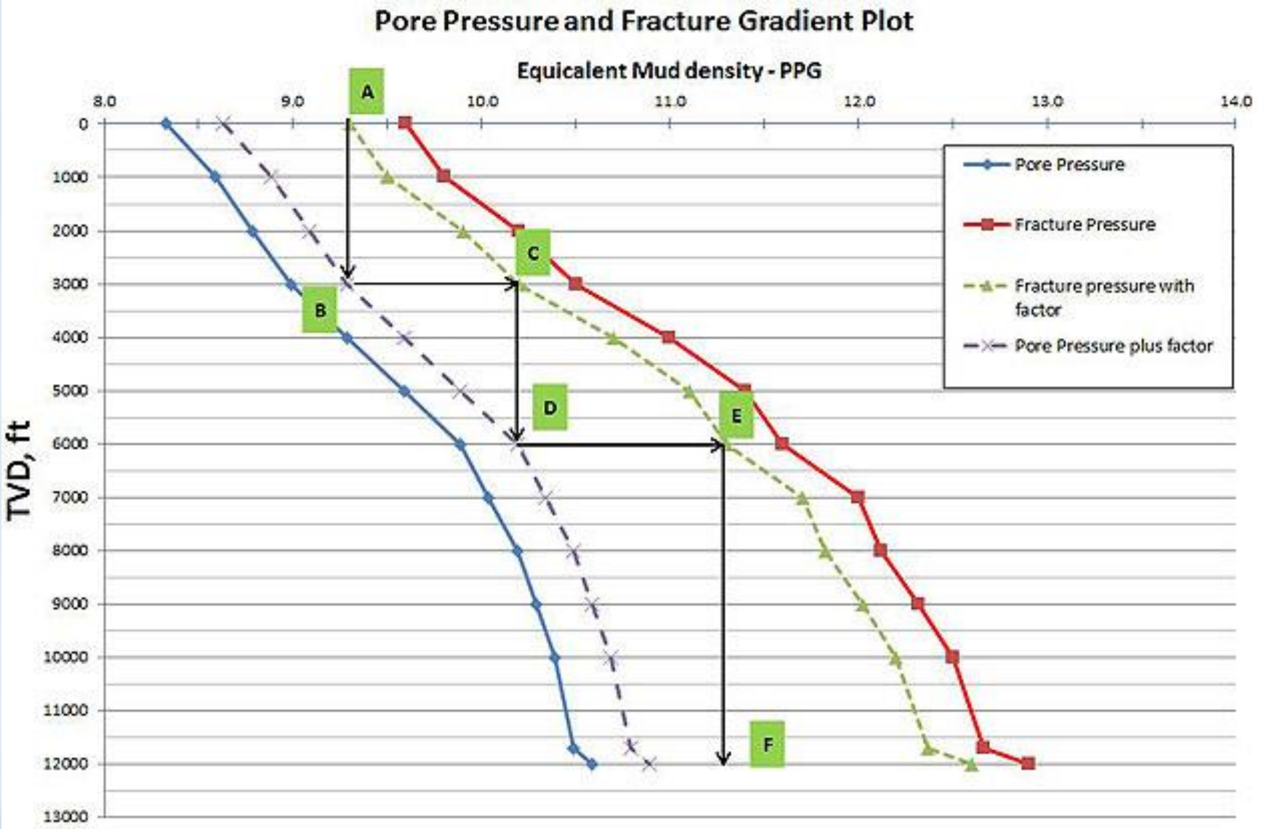
✓Normally, casing will be cemented in a wellbore.

✓Typically, casing is terminated on surface at the casing hanger. Liners do not reach surfacebut are suspended within the string of previous casing

WHY RUN CASING IN HOLE?

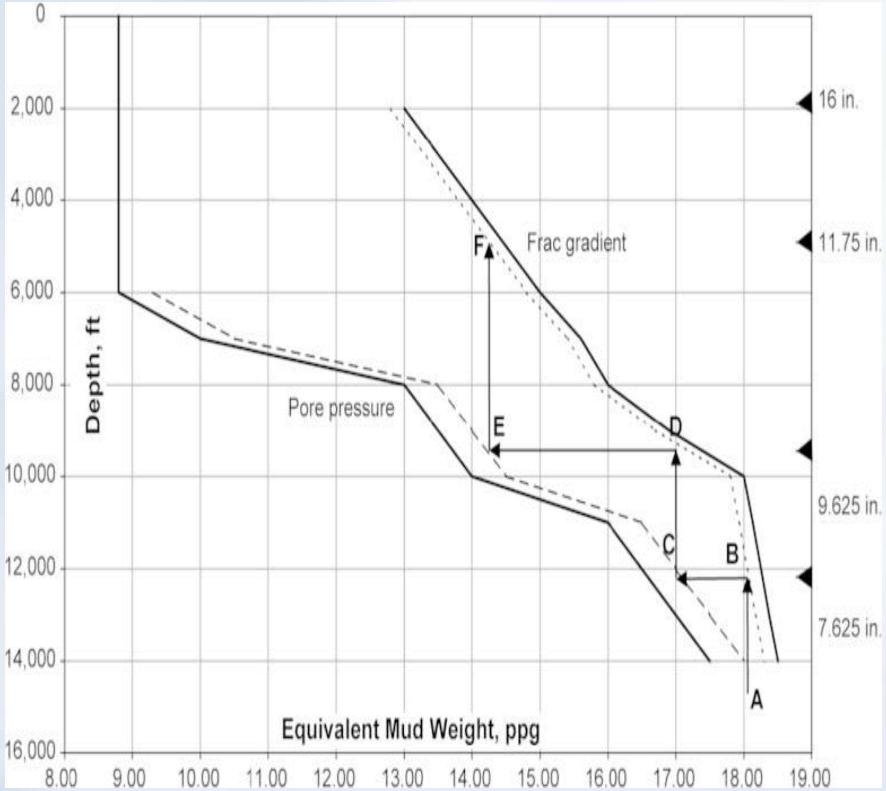
- ✓To prevent the hole from caving in (keep it open due to sloughing or swelling)
- ✓To protect fresh water zones from contamination.
- ✓To prevent water migration to producing formation.
- ✓To isolate porous formations with different pressure regimes
- ✓To provide a production conduit & confine production to the wellbore.
- ✓To provide a foundation for the wellhead/BOP
- ✓To control pressures during drilling
- ✓To provide an acceptable environment for subsurface equipment in producing wells
- ✓To enhance the probability of drilling to total depth (TD) e.g., you need 14 ppg to control a lower zone, but an upper zone will fracture at 12 lb/gal, What do you do?

CASING SEAT SELECTION



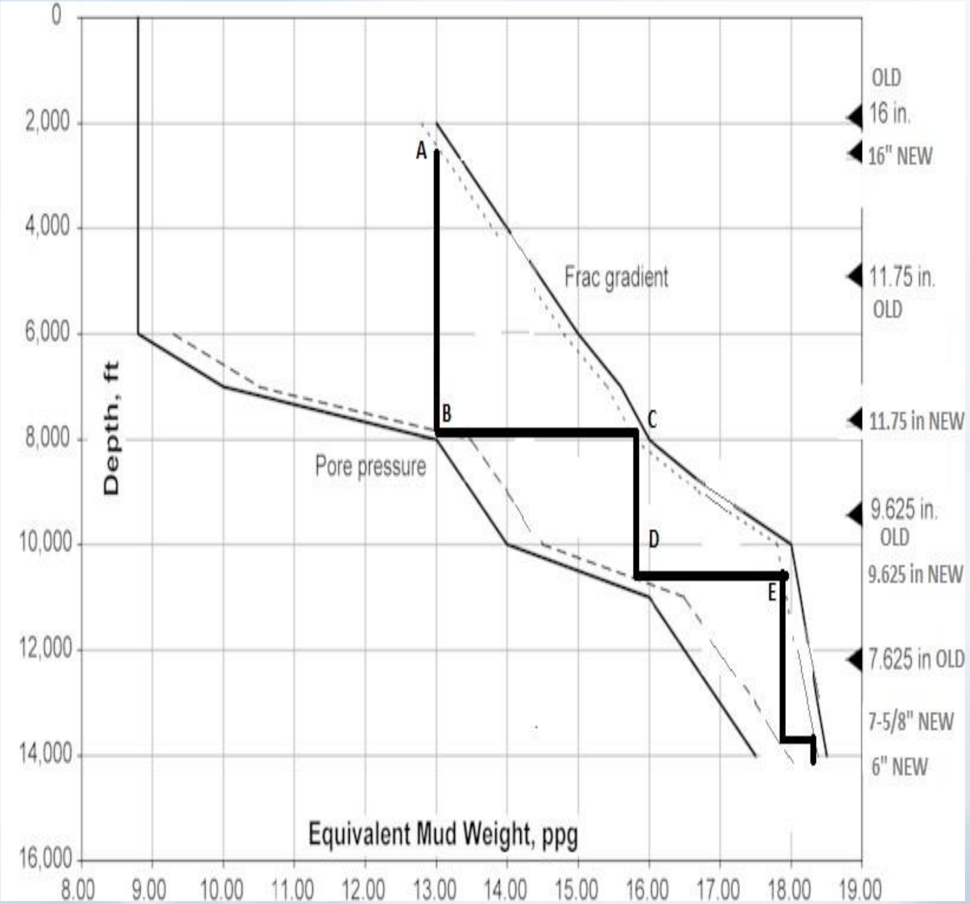
- For the casing setting depth determination, pore pressure and fracture gradient are normally described in PPG
- The first step of casing seat design is to apply the safety margin to the PP-FG plot.
- Usually a 0.5 ppg for safety for both pore pressure and fracture gradient are applied.
- You need to add the safety factor into formation pressure and subtract it from the fracture gradient.

BOTTOM UP APPROACH FOR DESIGN



- ✓ This is the standard method for casing seat selection.
- ✓ From Point A (the highest mud weight required at the total depth), draw a vertical line upward to Point B.
- ✓ A protective 7 $^{5}/_{8}$-in. casing string must be set at 12,000 ft, corresponding to Point B, to enable safe drilling on the section AB.
- ✓ To determine the setting depth of the next casing, draw a horizontal line BC and then a vertical line CD.
- ✓ In such a manner, Point D is determined for setting the 9 $^{5}/_{8}$-in. casing at 9,500 ft.
- ✓ The procedure is repeated for other casing strings, usually until a specified surface casing depth is reached.

TOP DOWN APPROACH



- ✓ From the setting depth of the 16-in. surface casing (here assumed to be at 2,000 ft), draw a vertical line from the fracture gradient dotted line, Point A, to the pore pressure dashed line, Point B.
- ✓ This establishes the setting point of the 11¾-in. casing at about 8000 ft.
- ✓ Draw a horizontal line from Point B to the intersection with the dotted frac gradient line at Point C; then, draw a vertical line to point D at the pore pressure curve intersection. This establishes the 9 $^{5}/_{8}$-in. casing setting depth at about 10,500 ft.
- ✓ This process is repeated for the casing at TD.

EXAMPLE WELL PP-FG DATA – FOR WELL PLANNING

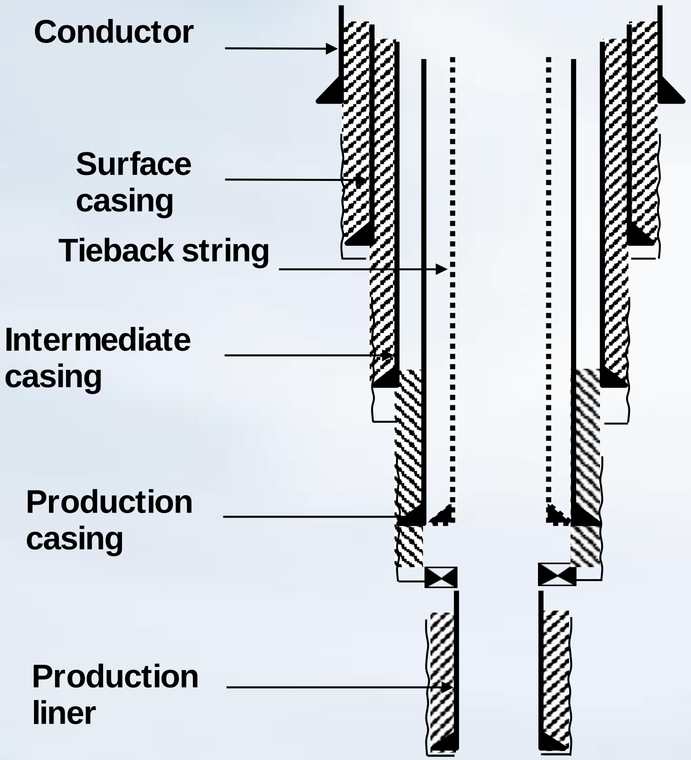
MD ft	TVD ft	Pres psi	PP ppg	0.5 ppg SM
5724.00	5724.00	2619.30	8.80	9.30
7783.50	7783.00	3844.80	9.50	10.00
9843	9842	5271.38	10.3	10.80
11202	11200	6173.44	10.6	11.10
13302	13300	7676.76	11.1	11.60
14583	14580	8870.47	11.7	12.20
160120	16017	9994.61	12	12.50
16159.00	16156.41	10091.07	12.01	12.51
16176.99	16174.45	10097.94	12.01	12.51
16233.95	16231.40	10125.77	12.00	12.50
16302.98	16300.43	10156.70	11.98	12.48
16315.98	16313.44	10162.30	11.98	12.48
16825.97	16823.42	10595.56	12.11	12.61
16967.98	16965.43	10762.98	12.20	12.70
17557.0	17554.4	11172.8	12.24	12.74
18337.1	18331.1	11939.2	12.53	13.03
18869.1	18848.0	12044.8	12.29	12.79

20313.1	20183.8	13055.0	12.44	12.94
20702.0	20545.3	13263.0	12.41	12.91
20811.1	20646.9	13309.5	12.40	12.90
20816.1	20651.5	13311.4	12.40	12.90
20826.1	20660.8	13316.0	12.39	12.89
21473.0	21264.6	13371.1	12.09	12.59
21657.1	21436.2	13595.0	12.20	12.70
22383.0	22109.5	14096.9	12.26	12.76
22403.0	22128.1	14104.4	12.26	12.76
22595.0	22305.3	14180.8	12.23	12.73
22623.0	22331.1	14192.2	12.22	12.72
22730.0	22429.7	14585.0	12.50	13.00
23740.0	23360.1	16272.6	13.40	13.90
23913.1	23519.2	16334.5	13.36	13.86
24104.0	23694.3	16410.2	13.32	13.82
24175.0	23759.2	16559.8	13.40	13.90
25701.0	25132.9	18320.0	14.02	14.52
25705.0	25136.6	18320.0	14.02	14.52
Depth	TVD	LOT	fit-tvd-bml	LOT-SM
9147	9147	13.6	3351	13.10
16017	16017	14.2	10221	13.70
21830	21600	15.3	15804	14.80
25850	25600	15.6	19804	15.10

Data For PP-FG as provided by G&G staff.

Plot the PP-FG graph. Based on this plot, do the bottoms up and top down casing design to select casing shoe.

CASING SCHEMATIC



Functions

✓**Conductor (20”-30”)** to protect loose, near surface formations and enables circulation of drilling fluid

✓**Surface casing (13-3/8”- 20”)** to provide blowout protection and prevent loss circulation

✓**Intermediate casing (9-5/8” - 16”)** to isolate unstable hole section and loss circulation, low pressure and production zones (often set in the transition between normal to abnormal zone)

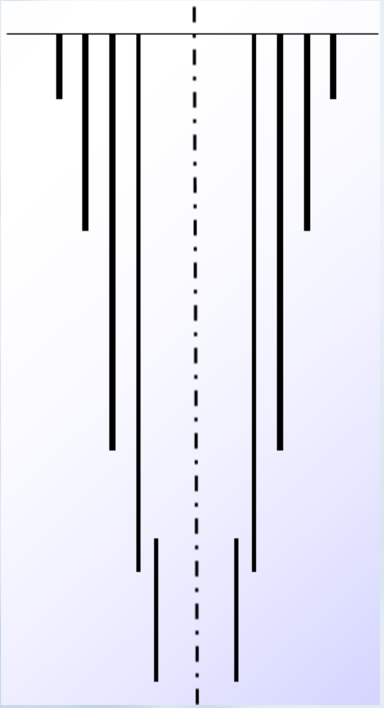
✓**Production (4-1/2”-9-5/8”)** to isolate production zone and contains formation pressure in the event of tubing leaks

✓**Liner (4-1/2” - 13-3/8”)** to improve hydraulic performance during deep drilling and to allow the use of larger tubing above the liner top

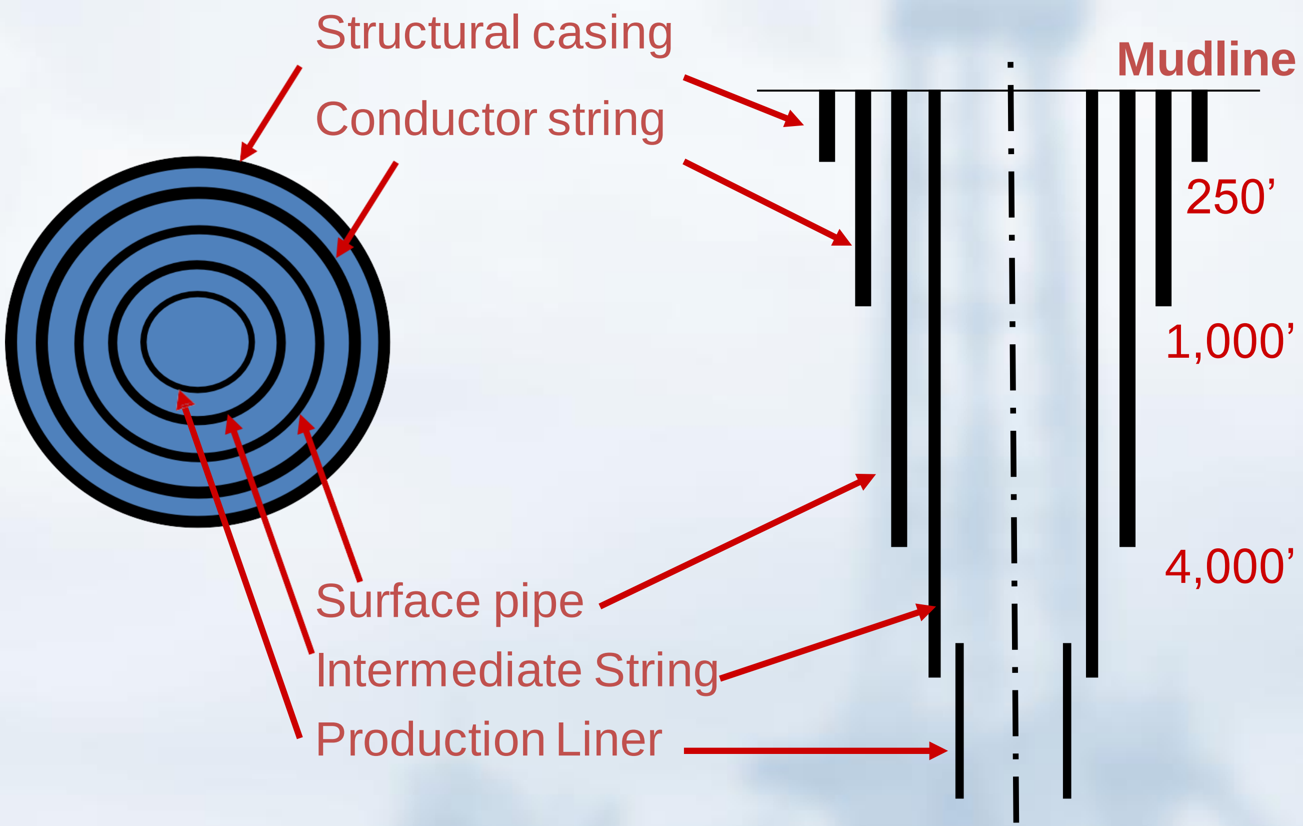
✓**Tieback string** to provide additional pressure integrity from the liner top to the wellhead

EXAMPLE HOLE AND STRING SIZES (IN)

Hole Size		Pipe Size
36”	Structural casing	30”
26”	Conductor string	20”
17 1/2	Surface pipe	13 3/8
12 1/4	Intermediate String	9 5/8
8 3/4	Production Liner	7

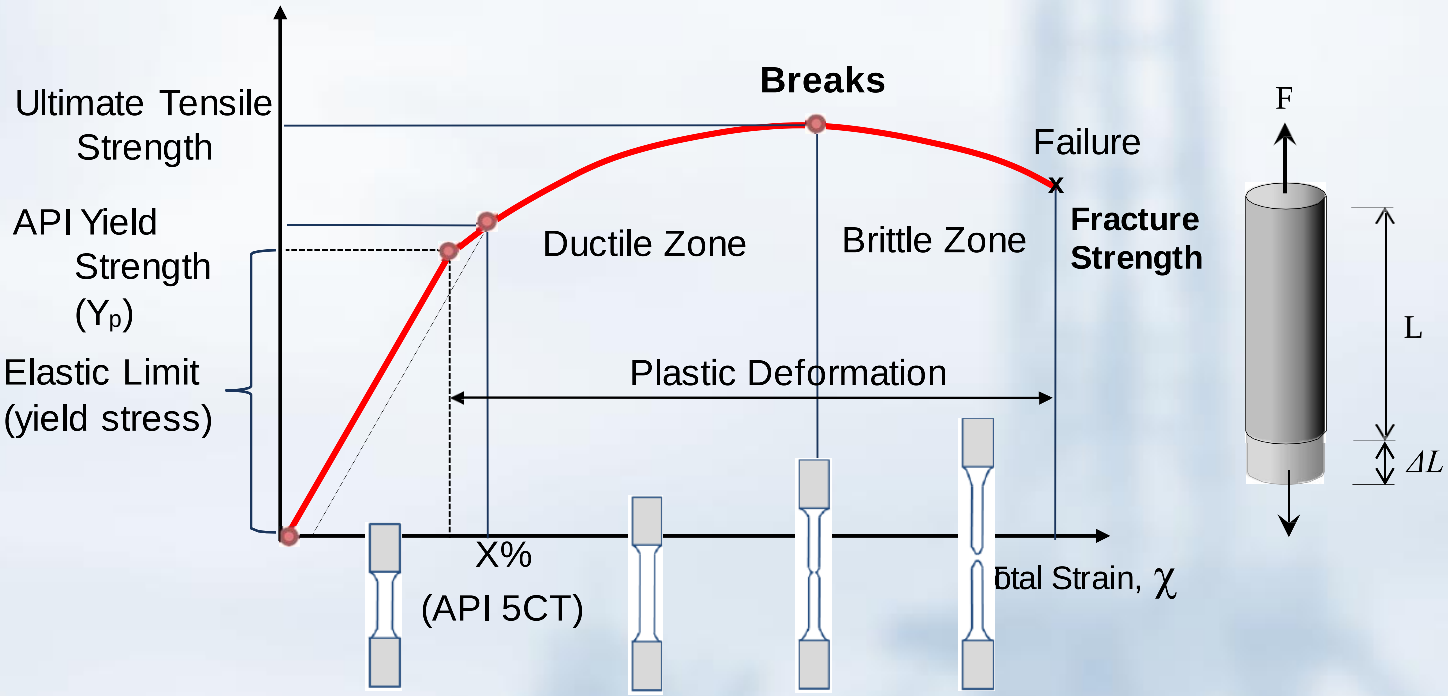


EXAMPLE HOLE AND STRING SIZES (IN)



YIELD STRENGTH (Y_P) DESIGN BASIS

- ✓ Based on uniaxial tension or compression test on specimen prepared to specifications Load against elongation
- ✓ API Yield Strength based on stress at specific strain (API Spec 5CT)



YIELD STRENGTH (Y_P) DESIGN BASIS

- API minimum yield strength (Y_p) defined by specified percentage total strain under load

$Y_p \leq 95$ psi	X = 0.50 %
$95 \leq Y_p \leq 110$ psi	X = 0.60 %
$110 \leq Y_p \leq 125$ psi	X = 0.65 %

- Equivalent to ~0.2% permanent plastic strain

YIELD CRITERIA OVERVIEW

✓**Stress applied < yield strength:**
Elastic, recoverable deformations
Volumetric change, no shape change

✓**Stress applied ≥ yield strength but < fracture strength:**
Plastic, irreversible deformations (molecular re-arrangement)
Stress and strain are no-longer proportional → yield criteria
Shape change, no volumetric change
Yield driven by shear stresses, atomic bonds breaks and re-form in new positions

✓**Stress applied reaches fracture strength (UTS):**
Atomic planes separation
Broken atomic bonds are not allowed to reform in new positions

CASING DESIGNATIONS

When ordering casing, we should specify the following:

- ✓Pipe Grade refers to the pipe's yield strength by a letter and a 2 or 3 digit number e.g. [N80, K55, H40]
- ✓The letter selected defines the metallurgy and production method (K is seamed, J is seamless, L is seamless and heat treated)
- ✓The Numerical Code indicates the minimum yield strength in psi (N80 has a minimum yield strength of 80,000 psi).
- ✓The Yield strength is used to determine the minimum value of pipe Burst and Collapse resistance and the tensile strength.
- ✓Weight: refers to weight per unit length of tubular [47.0 lb/ft, 29.0 lb/ft]
- ✓Size: refers to the outside diameter of tubular [13 3/8”, 9 5/8”]
- ✓Connection: the coupling used to connect the tubulars [Buttress, VAM, LT&C]
- ✓Range: refers to average length of tubular joint [API:R1 = 16 to 25 ft, R2 = 25 – 34 ft and R3=35 – 45 ft]

EXAMPLE CASING DESIGNATIONS

Most Common Grades	Minimum Yield Strenght (PSI)	Ultimate Tensile Strength (PSI)
H-40	40,000	60,000
J-55	55,000	75,000
K-55	55,000	95,000
C-75	75,000	95,000
L-80	80,000	95,000
N-80	80,000	100,000
C-90	90,000	100,000
C-95	95,000	105,000
P-110	110,000	125,000
V-150	150,000	160,000
	$\uparrow$ $\boxed{Y_P}$	$\uparrow$ $\boxed{U_P}$

CASING CONNECTIONS

✓The casing joint is externally threaded on both ends of the pipe.

✓The single joints are joined by an internally threaded coupling, to form the connection.

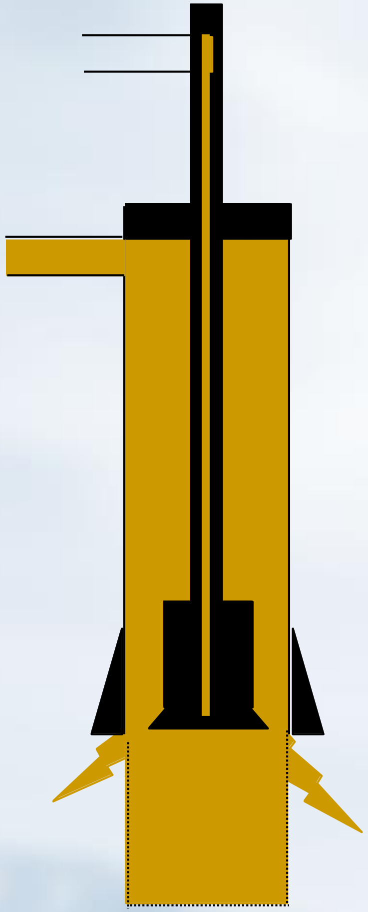
✓The coupling can be made with several varying outer diameters.

✓Casing connections should satisfy several functional and operational requirements.

API CONNECTIONS

	Connection Name
Tubing	Nom-Upset Threaded & Coupled (NUE)
	External-Upset Threaded & Coupled (EUE)
	Integral (IJ)
Casing	Short Round Thread (STC)
	Long Round Thread (LTC)
	Buttress Thread (BTC)
	Extreme-Line Thread (X-Line)

KICK TOLERANCE (KT)



- ✓ KT define as **maximum kick size which can be tolerated without fracturing the previous casing shoe** or
- ✓ **Maximum allowable pore pressure for next section TD or maximum allowable mud weight** which can be tolerated without fracturing shoe
- ✓ KT depends on
  - **Maximum Kick Size**
  - **Max Formation/Pore Pressure**
  - **Maximum mud wt, Surface Pressure,Leak Off test**
  - **Other factor – Density of invading fluid & the circulating temperature**
- ✓ Example of KT
  - ✓(Based on operator standards)

HOLE SIZE (inch)	KICK VOLUME (bbl)
6"and smaller	10-25
8.5"	25-50
12¼"	50-100
17.5"	100-150
23"	250

- ✓ When to calculated
  - ✓After LOT, prior to drill ahead, Change M.wt,drillstring

KICK TOLERANCE OPERATIONAL VARIABLE

- ✓ LOT less than plan i.e Fracture Gradient less than expected
  - ✓ Open hole can not be drilled to planned depth
  - ✓ Cement Plug need to place to artificially strengthen the shoe (if FG <15ppg)
- ✓ LOT/FG > than plan i.e OH section can be drilled further than planned depth
- ✓ While drilling high porous and permeable zones (1-3darcies)
- ✓ Using low technology kick detection
- ✓ Several transition zones with increasing pore pressure are expected in the same open hole section are encountered
- ✓ Drilling from MODU (Semi/DP)
- ✓ **Kick Intensity** – It is the different between the maximum anticipated formation pressure and planned mud weight. For example, the planned mud weight is 13.0 ppg and the possible kick pressure is 13.5 ppg. Therefore, the kick intensity is 0.5 ppg (13.5 – 13.0).
- ✓ A zero kick intensity (swabbed kick scenario) should be used for a know area where you have less uncertainty about an overpressure zone.

KT PLANNING CONSIDERATIONS

During the initial well planning stage, a preliminary determination of kick tolerance for casing design purposes is made on the following basis:

- ☑ Single bubble of a dry ideal gas @ 0.1 psi/ft.
- ☑ Formation strength based on shoe LOT which is assumed to be a formation representative of the shoe placement location. For the avoidance of doubt, if the shoe is in a clear shale, then use shale strength, if the shoe is in a silty or dirty sand area where there is no clear distinction of formation type, or formation type cannot be confidently assured, a weaker LOT corresponding to those formations is to be assumed.
- ☑ Kick is circulated out using the Drillers Method.
- ☑ ECD and temperature effects are ignored.
- ☑ Gas solubility, dispersion and migration are ignored
- ☑ Influx pressures as per below

Influx Pressures for Kick Tolerance

Well Type	Influx Pressure
Early Field Life Development wells	☑ Swab kick based on planned MW
Mid to Late Field Life Development wells	☑ Drilled kick which is based on the planned mud weight with a kick intensity equal to the virgin pore pressure.
Exploration wells	☑ Drilled kick where drilling MW is chosen to address the most likely pore pressure and kick intensity based on maximum predicted MW. If confidence in pore pressure prediction is especially weak, a premium higher than maximum MW can also be chosen, but that value needs to have some form of a logical basis.

KT CALCULATION (WIPER TRIP)

Kick Tolerance Calculation

wipertrip.com

Shoe Depth (ft) - TVD	1640.4
Formation Strength (ppg)	17.625
Safety (psi)	
Frac Pressure at shoe (psi)	1503
MW (ppg)	14.9225
Kick Intensity (ppg)	0.5
Pore Pressure EMW (ppg)	15.4
Drilling Depth (ft) - TVD	4592
Bottom Hole Pressure (psi)	3683
Gas Gradient (psi/ft)	0.1
Hole Size (inch)	12.25
DP OD (inch)	5
Ann Cap at Shoe (bbl/ft)	0.121
Inclination at Shoe (deg)	0.5
Cos (incl. at shoe)	1.000
Open Hole Height (ft)	2952

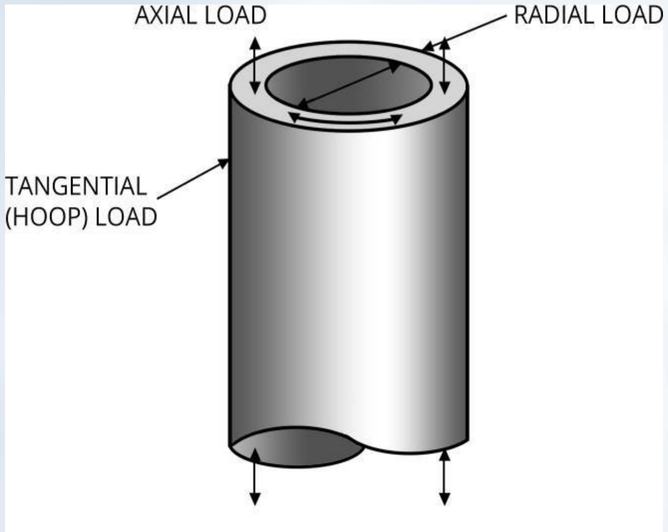
BHP = Frac Pressure at shoe + P (gas) + P (mud)
P (gas) = Gas gradient * H (gas)
P (mud) = Mud Gradient * H (mud)
H(mud) = Open Hole Height - H(gas)

BHP- FracP Shoe	2179
OH height * Gmud	2290
Ggas - Gmud	-0.68
H(gas) Shoe	164.4
L(gas) Shoe	164.4

Vol Gas at shoe (bbl)	20
Vol Gas at TD (bbl)	8

Drilling Kick

CASING DESIGN



TRIAXIAL LOADING ON CASING

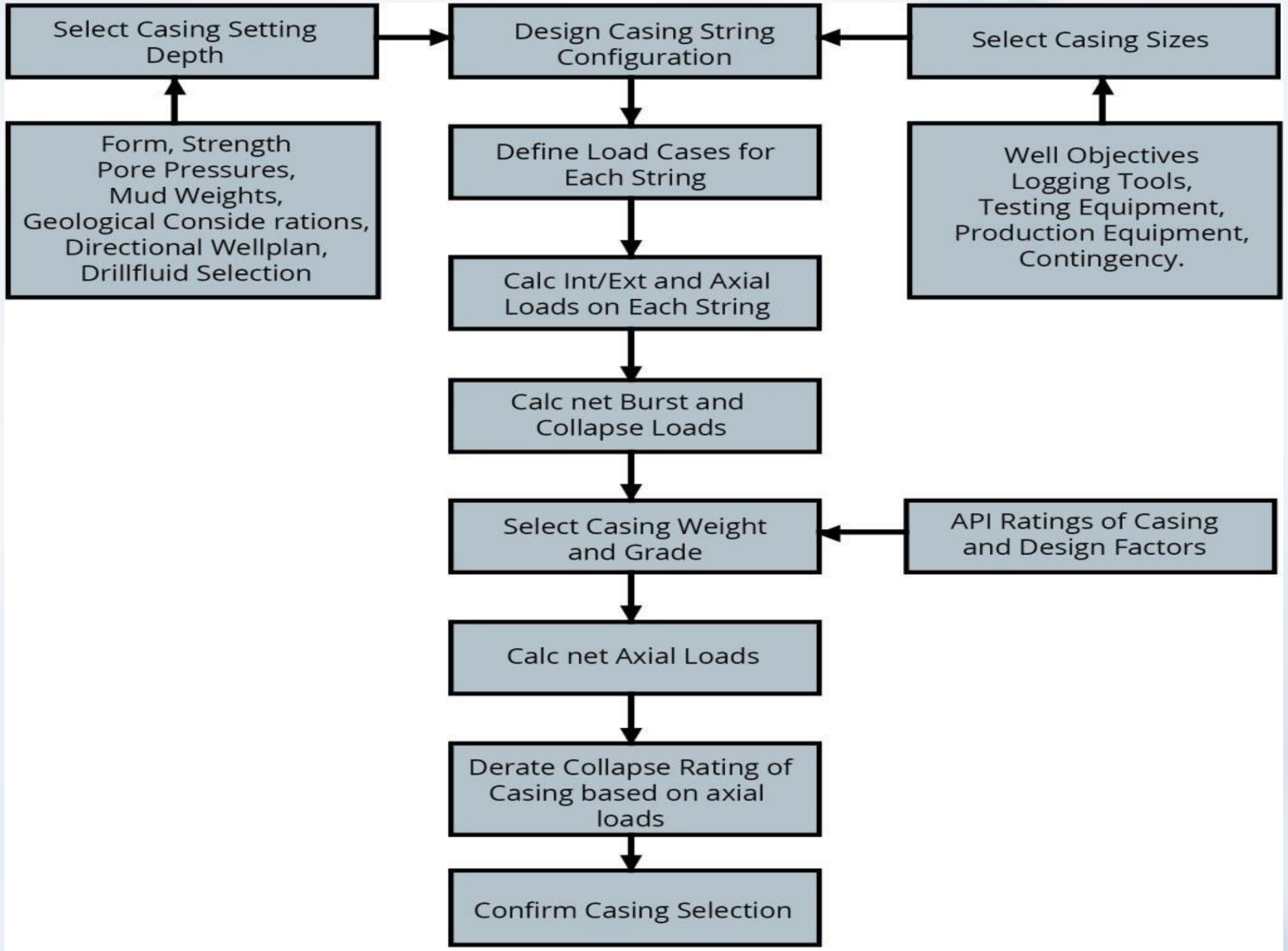
Secondary considerations in casing design:

- ✓ Triaxial stress
- ✓ Buckling
- ✓ Wear
- ✓ Internal and external corrosion
- ✓ Loading during pressure testing
- ✓ Loading during reciprocation

CASING DESIGN

- **Sources of Tubular Loads**
- **Tension**
  - ✓ String Weight
  - ✓ Friction
- **Compression**
  - ✓ Buoyancy
  - ✓ Setting weight
  - ✓ Reservoir compaction
- **Burst and Collapse**
  - ✓ Fluid pressure
  - ✓ Fluid expansion
- **Bending**
  - ✓ Buckling
  - ✓ Hole deviation
  - ✓ Doglegs

CASING DESIGN

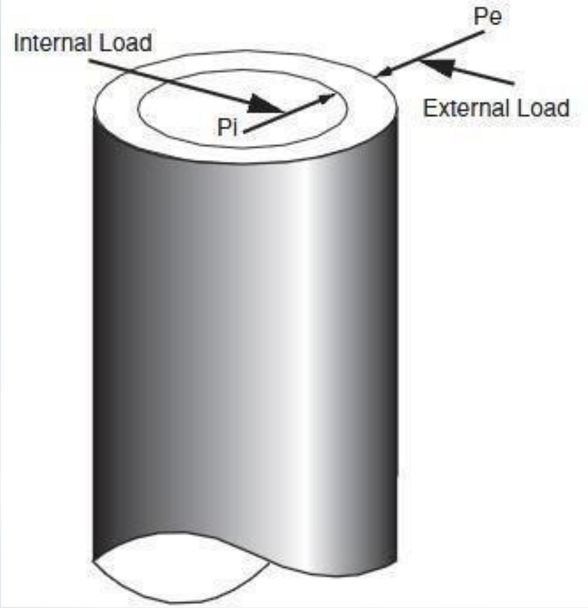


Casing Design Process

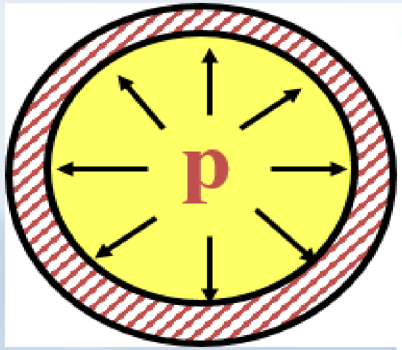
TYPICAL INDUSTRY DESIGN FACTORS

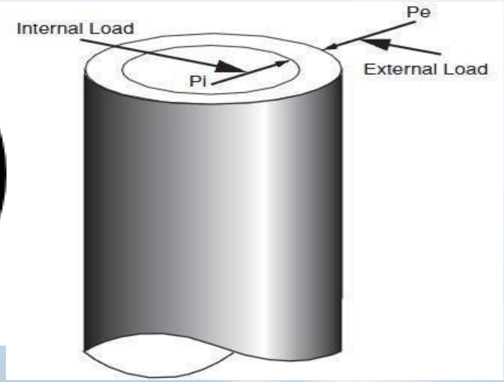
Load Type	Design Factor
Uniaxial Burst	1.1 – 1.25
Collapse	1.0 – 1.1
Axial	1.3 – 1.6

CASING DESIGN-BURST FAILURE



Internal press > External press → Burst





✓ Internal Yield Pressure for Pipes & Couplings

•The casing will experience a net burst loading if the internal radial load exceeds the external radial load.

API Burst Resistance

- Called API min internal yield pressure (MYIP)
- Barlow Equation
- Wall thickness tolerance
- Effect of Axial Load
- Wear/corrosion

CASING DESIGN-BURST

Example 1

Design a 7” Csg. String to 8,000 ft.

Pore pressure gradient = 0.6 psi/ft Design factor, N_i=1.1

1. Calculate probable reservoir pressure

$$p = 0.6\frac{psi}{ft} * 8,000 \quad ft = 4,800 \ psi$$

2. Calculate required pipe internal yield pressure rating

$$p_i = p_{res} * N_i = 4,800 * 1.1 = 5,280 \ psi$$

CASING DESIGN-BURST

3. Select the appropriate casing grade and wt. from the Halliburton tables:

Burst Pressure required = 5,280 psi

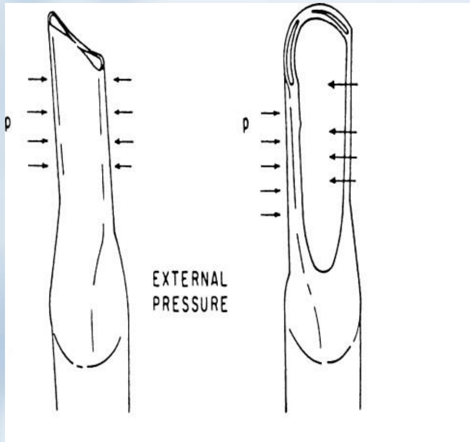
7”, J-55, 26 lb/ft has BURST Rating of **4,980 psi** 7”, N-80, 23 lb/ft has BURST Rating of **6,340 psi** 7”, N-80, 26 lb/ft has BURST Rating of **7,249 psi**

Can use N-80 Csg., 23 lb/ft

Size O.D. In.	Grade	Wt. Per Ft. With Cplg., Lb.	Inside Dia. In.	Thread & Cplg. Drift Dia. In.	Thread & Cplg. O.D. of Cplg. In.	Extreme Line Drift Dia. In.	Extreme Line O.D. of Box In.	** Col'pse Resis-tance PSI
7	*F-25	17.00	6.538	6.413	7.656	——	——	1,100
	H-40	17.00	6.538	6.413	7.656	——	——	1,450
	H-40	20.00	6.456	6.331	7.656	——	——	1,980
	J-55	20.00	6.456	6.331	7.656	——	——	2,270
	J-55	23.00	6.366	6.241	7.656	6.151	7.390	3,270
	J-55	26.00	6.276	6.151	7.656	6.151	7.390	4,320
	K-55	20.00	6.456	6.331	7.656	——	——	2,270
	K-55	23.00	6.366	6.241	7.656	6.151	7.390	3,270
	K-55	26.00	6.276	6.151	7.656	6.151	7.390	4,320
	C-75	23.00	6.366	6.241	7.656	6.151	7.390	3,770
	C-75	26.00	6.276	6.151	7.656	6.151	7.390	5,250
	C-75	29.00	6.184	6.059	7.656	6.059	7.390	6,760
	C-75	32.00	6.094	5.969	7.656	5.969	7.390	8,230
	C-75	35.00	6.004	5.879	7.656	5.879	7.530	9,710
	C-75	38.00	5.920	5.795	7.656	5.795	7.530	10,680
	N-80	23.00	6.366	6.241	7.656	6.151	7.390	3,830
	N-80	26.00	6.276	6.151	7.656	6.151	7.390	5,410
	N-80	29.00	6.184	6.059	7.656	6.059	7.390	7,020
	N-80	32.00	6.094	5.969	7.656	5.969	7.390	8,600
	N-80	35.00	6.004	5.879	7.656	5.879	7.530	10,180
	N-80	38.00	5.920	5.795	7.656	5.795	7.530	11,390

CASING DESIGN-COLLAPSE FAILURE

- ✓ The casing will experience a net collapse loading if the external radial load exceeds the internal radial load.
- ✓ Operational Calculation application –
  - ✓ Hydrostatic Loading during Cementing, Losses
  - ✓ Casing Evacuation

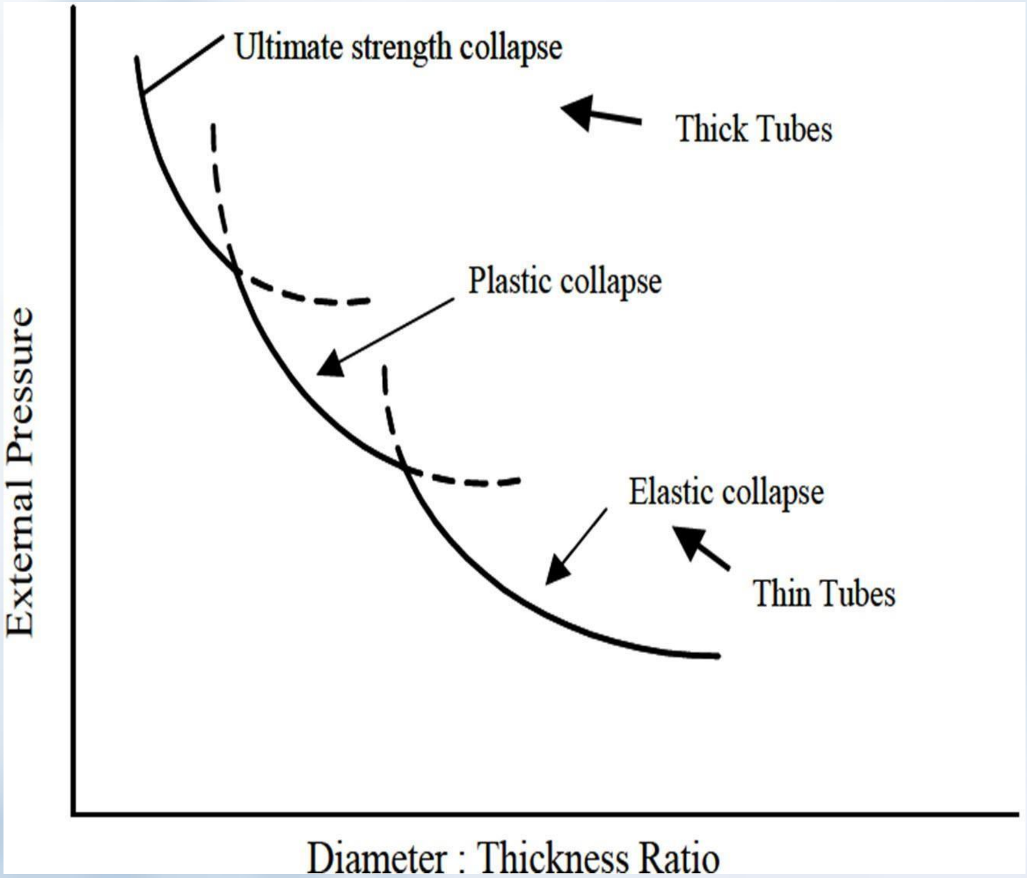


COLLAPSE FAILURE FROM EXTERNAL PRESSURE

COLLAPSE BEHAVIOR

- ✓ For thin wall pipes the collapse pressure results from a
- ✓ *stability* failure
  - ✓ Similar to failure of long columns
  - ✓ Occurs at stresses < yield strength
  - ✓ Can be calculated using Euler instability formula

- ✓ For between thin and thick wall pipes no analytical method exists
  - ✓ Empirical test values must be used
  - ✓ Partial plastic yielding before snap-through failure



Collapse Failure Modes

COLLAPSE FAILURE TYPES

✓ Yield collapse (analytical)

- Based on yield at inner wall using Lamé thick wall elastic solution
- Does not represent a “collapse” pressure
- In thick wall pipes ($D/t < 15$), hoop stress will exceed material yield strength before collapse failure occurs

✓ Plastic collapse (empirical)

- Based on empirical data from 2488 tests of K-55, N-80 and P-110 seamless casing
- No analytic expression accurately models this collapse behavior
- A,B,C factors derived by statistical regression analysis resulting in 95% confidence level that 99.5% of all pipes manufactured to API specifications will fail at a collapse pressure higher than the plastic collapse pressure

✓ Elastic failure (numerical)

- Based on theoretical elastic instability failure
- Criterion is independent of yield strength
- Applicable to thin wall pipe ($D/t > 25$)

✓ Transition failure (analytical)

- Generated because the plastic min equation and the elastic equation did not intersect
- Numerical curve fit between the plastic and elastic regime

CASING DESIGN CRITERIA

Burst Loading Criteria

The burst loading criteria for each casing type vary and are tabulated in Table 1 .

Casing	Internal Loading	External Loading
Surface and Intermediate Casing	The greater of: • Hole and casing evacuated to gas from TD (maximum pressure at TD less gas gradient from TD to surface). OR • Hole and Casing evacuated to gas from casing shoe (maximum pressure at shoe less gas gradient from shoe to surface). OR • Test pressure required.	Hydrostatic column of mud behind the casing to TOC + pore pressure for the entire cement column.
Production Casing or Liner. Burst is only a consideration for liner if the packer is set in the liner.	The greater of: • Hole and casing evacuated to gas from next hole TD, if applicable (maximum pressure at TD less gas gradient from TD to surface). OR • Production-Tubing Wellhead Leak (formation pressure at TD less gas gradient + packer fluid hydrostatic).	Hydrostatic column of mud behind the casing to TOC + pore pressure for the entire cement column. Formation pressure at packer depth.

Burst Loading Criteria

CASING DESIGN CRITERIA

Collapse Loading Criteria

The design loads for each casing string are tabulated in

External Loading			Internal Load
Running / Cementing	**Drilling**	**Production**	
The greater of: • Hydrostatic of mud behind casing. OR • Hydrostatic of cement slurry. OR • Seawater. OR • Combination of all the above.	The greater of: • Hydrostatic of mud behind casing. OR • Pore pressure behind cement. OR • Seawater. OR • Combination of all the above.	Not applicable.	Assume hydrostatic down to a level where the column of mud equals formation pressure.

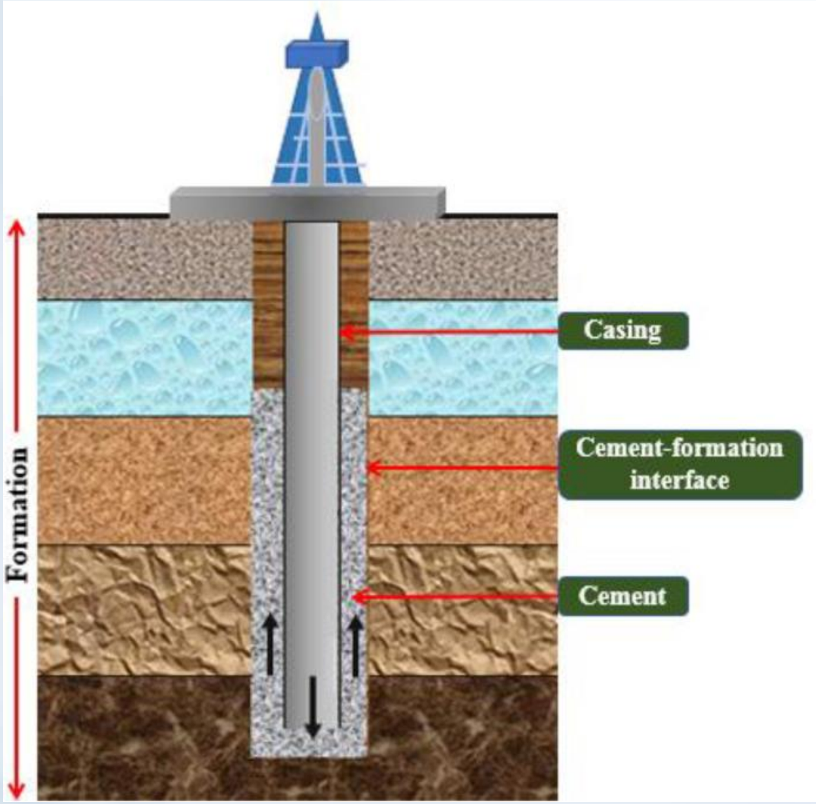
Collapse Loading Criteria - Surface and Intermediate Casing

CASING DESIGN CRITERIA

External Loading			Internal Load	
Running / Cementing	**Drilling**	**Production**	**Drilling**	**Production**
The greater of: • Hydrostatic of mud behind casing. OR • Hydrostatic of cement slurry. OR • Seawater. OR • Combination of all the above.	The greater of: • Hydrostatic of mud behind casing. OR • Pore pressure behind cement. OR • Seawater. OR • Combination of all the above.	The greater of: • Hydrostatic of mud behind casing. OR • Pore pressure.	As for intermediate casing.	The greater of: • Perforations plugged resulting in gas hydrostatic from TD-RT. OR • Reduced hydrostatic due to gaslift or Nitrogen injection into production Casing.

Collapse Loading Criteria - Production Casing

OILWELL CEMENTING



One of the most important factors in well completion is obtaining an effective primary cement job. A defective cement job will adversely affect all remaining operations.

There are two general classifications of oil well cementing:

- ✓ **Primary Cementing**
  - ✓ supports the casing
  - ✓ restricts the movement of formation fluids behind the casing
  - ✓ seals off zones of lost circulation (fractured formation)
  - ✓ protects the casing from shock loads during the drilling of deeper sections
  - ✓ protects casing from corrosion

OILWELL CEMENTING

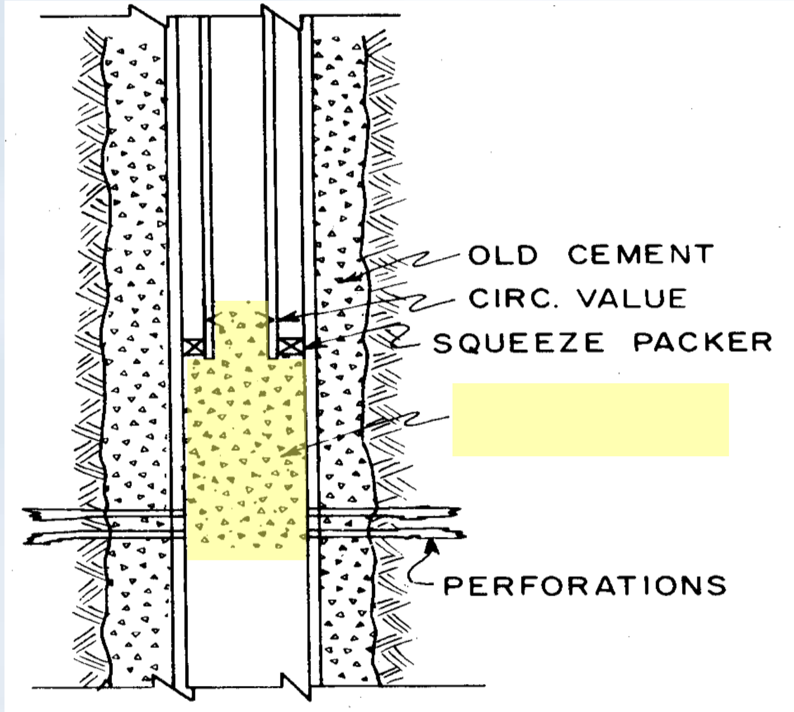
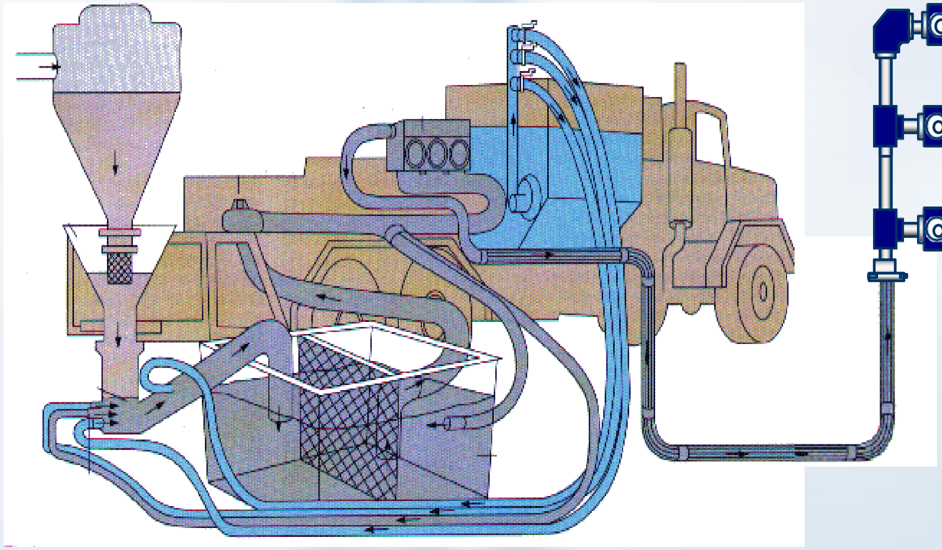


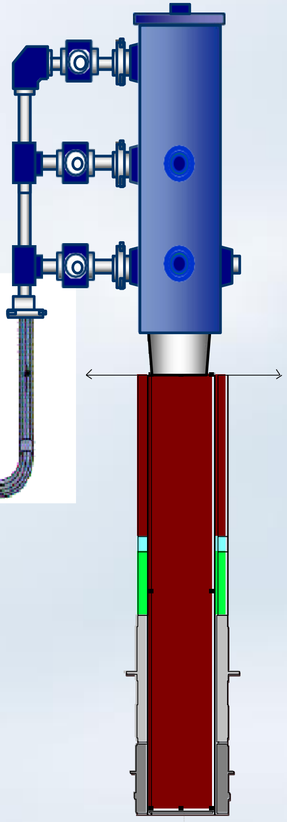
Fig. 3.14—Squeeze-cementing technique.

Secondary or remedial cementing

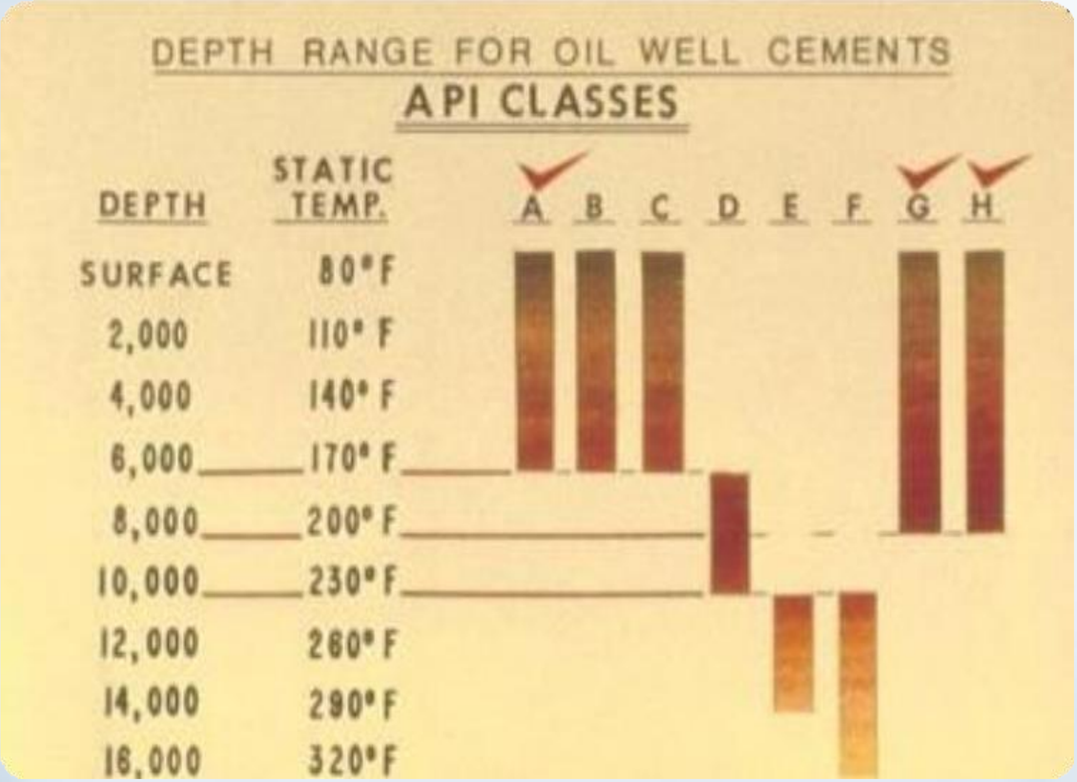
- ✓ **Isolation squeeze**
  - ✓ Cement slurry is circulated into the annulus through perforations.
  - ✓ Supplementing a faulty primary job
  - ✓ Extending the casing protection above the cement top
- ✓ **Plug back cementing**
  - ✓ The hole is plugged by cement.
    - ✓ Abandonment of the hole
    - ✓ Sidetracking the hole
    - ✓ Seal off lost circulation
    - ✓ Shutting off of water or gas encroachment

OILWELL CEMENTING





OIL WELL CEMENTS



- ✓ The principal differences between construction and oil well cements are that:
- ✓ No aggregate is added to the oil well cements.
- ✓ Large volumes of water are used in oil well cements in order to permit the cement slurry to be pumped.

CEMENT BY CASING TYPES & COVERAGE

Casing	Top of Cement	Coverage
Conductor / Surface	1. Surface or sea floor	1. Exploration wells shall only be cemented to seabed level to facilitate cutting and retrieval of casings. On Development wells to reduce corrosion: 1. Annular space between the casing and formation shall be filled back to surface. 2. If no cement returns observed, a grout job shall be performed.
Intermediate	1. 500ft above all hydrocarbon and abnormal pressure zones 2. 500ft above the previous casing shoe.	1. If zonal isolation is required, the cement shall fill the annular space between casing and hole to at least 500ft above the zones to be isolated. 2. If zonal isolation is not required, the cement shall fill the annular space between the casing and hole to at least 500ft above the previous casing shoe.
Production	1. 500ft above the uppermost producible hydrocarbon zone or 2. 500ft above the previous casing shoe depth.	1. The cement height shall cover at least 1/3 of the total measured length of the production casing to provide casing stability.
Liner	1. Top of liner lap	1. Liner strings shall generally be cemented from the shoe to the top of the liner lap.

CEMENTING EQUIPMENT

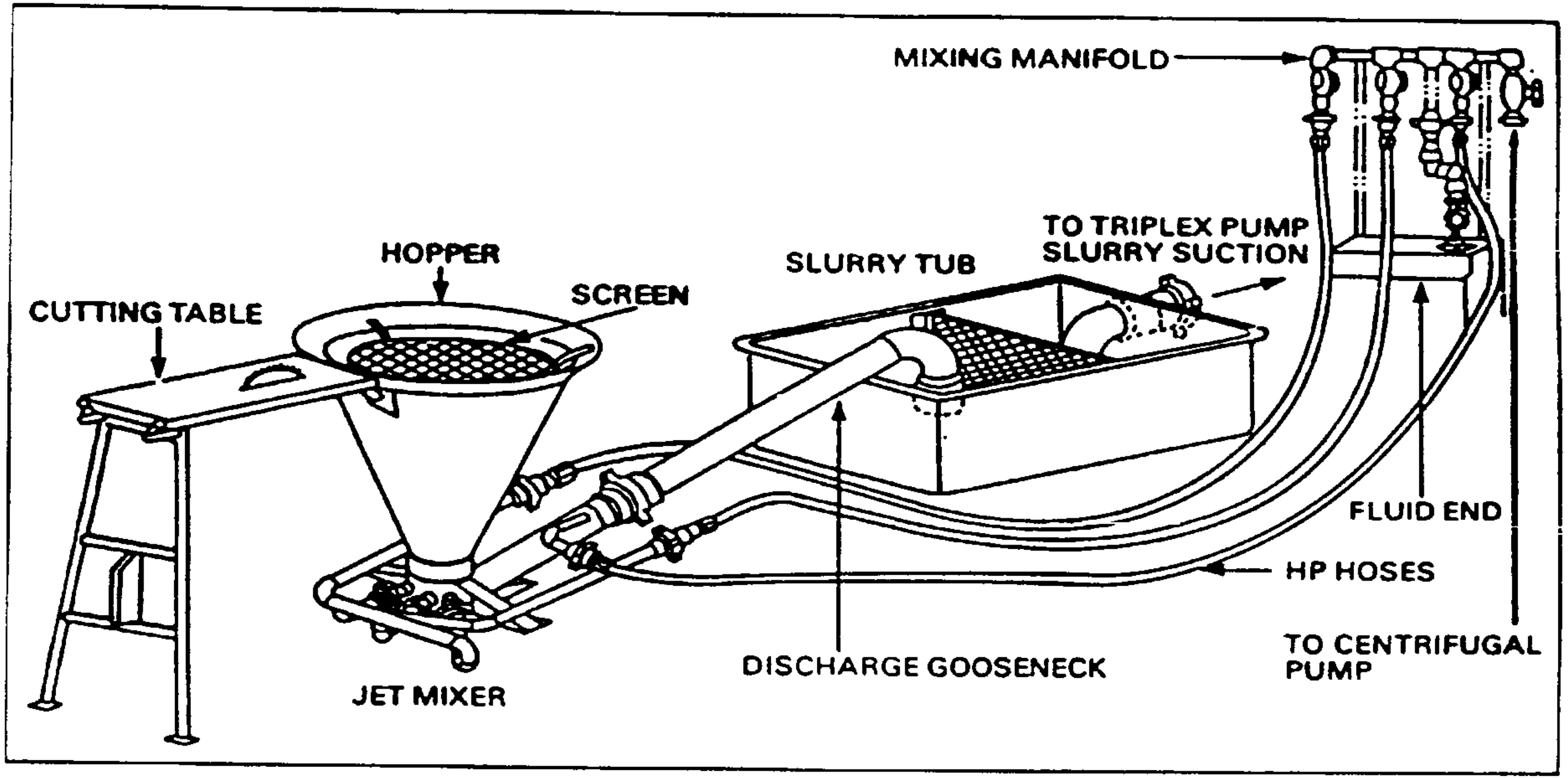
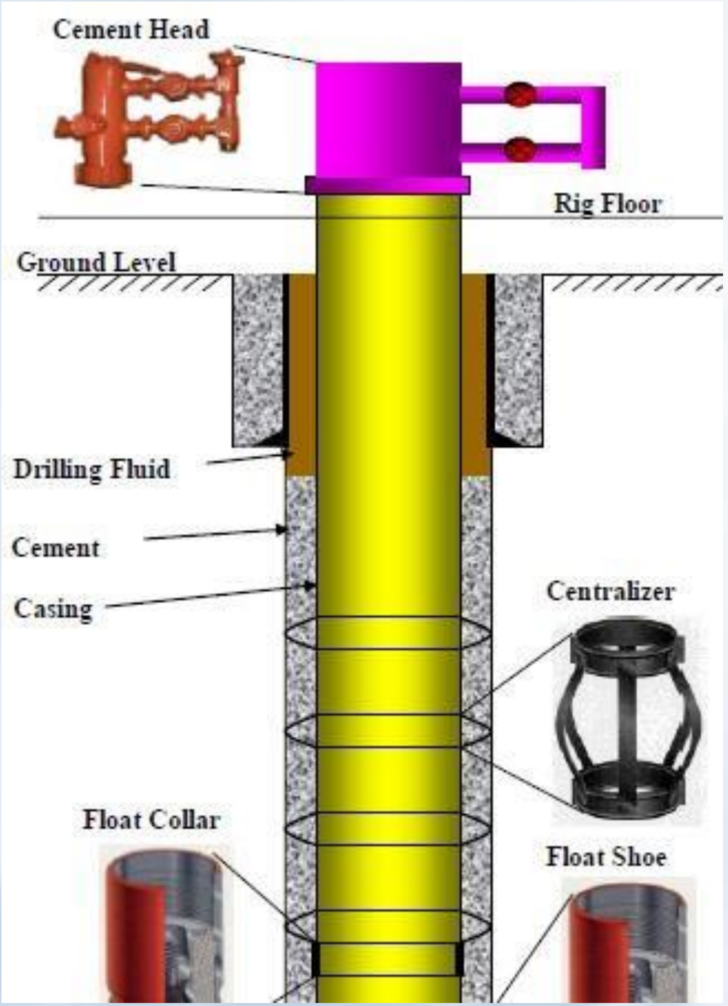


FIG. 13. 30

CEMENT EQUIPMENT



Common cementing equipment includes

- ✓ Floatshoe
- ✓ Floatcollar
- ✓ Centralizers
- ✓ Cementing head
- ✓ Scratchers
- ✓ Well-bore Wipers
- ✓ Top and Bottom plugs

FLOAT SHOES

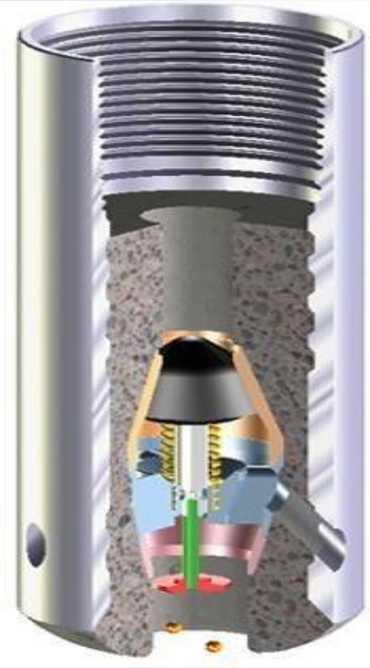
Ball valve

Poppet Valve

with Down Jet

FLOAT SHOES

Self-Filling Float Shoes



Automatic Fill-up Float Shoe with Actuated Valve

Float Shoe Cement Nose with Flapper Valve and Automatic Fill-up

FLOAT COLLARS

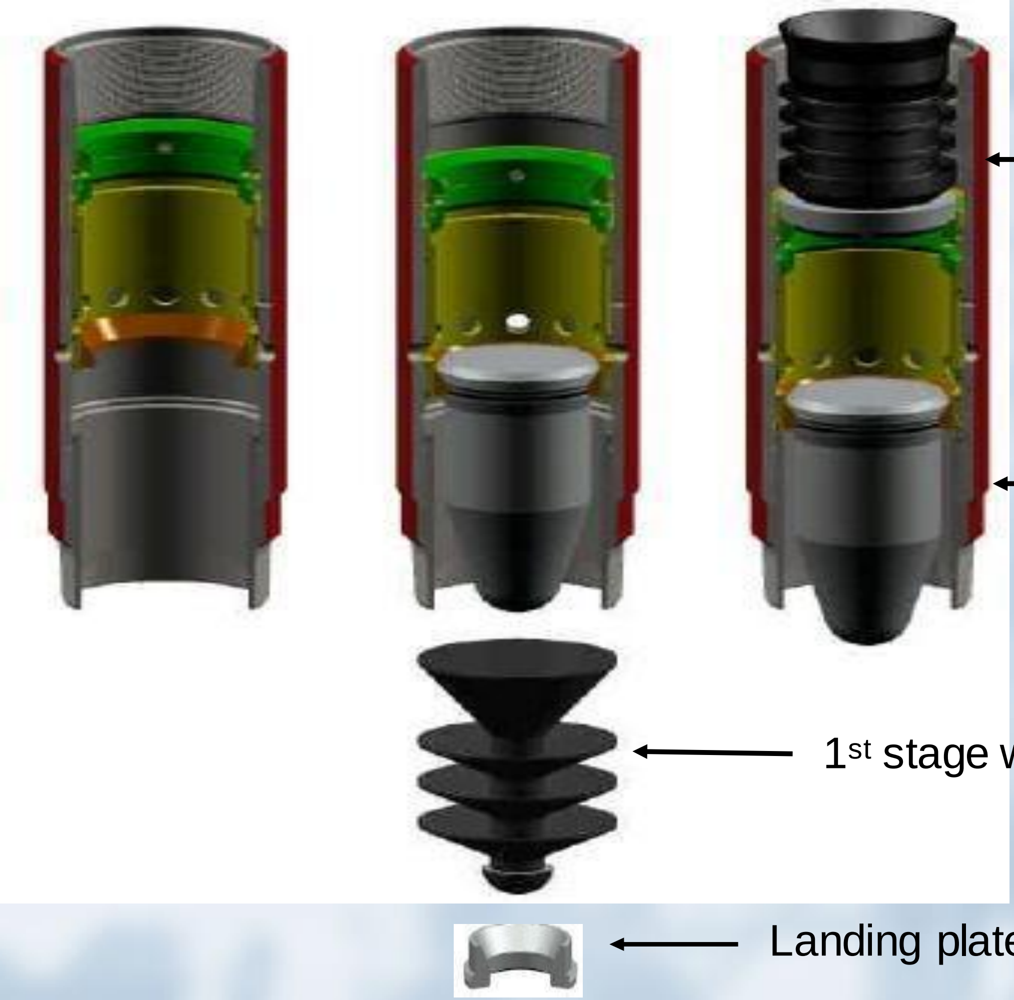
Float Collar - Ball Valve

Float Collar - Sure Seal

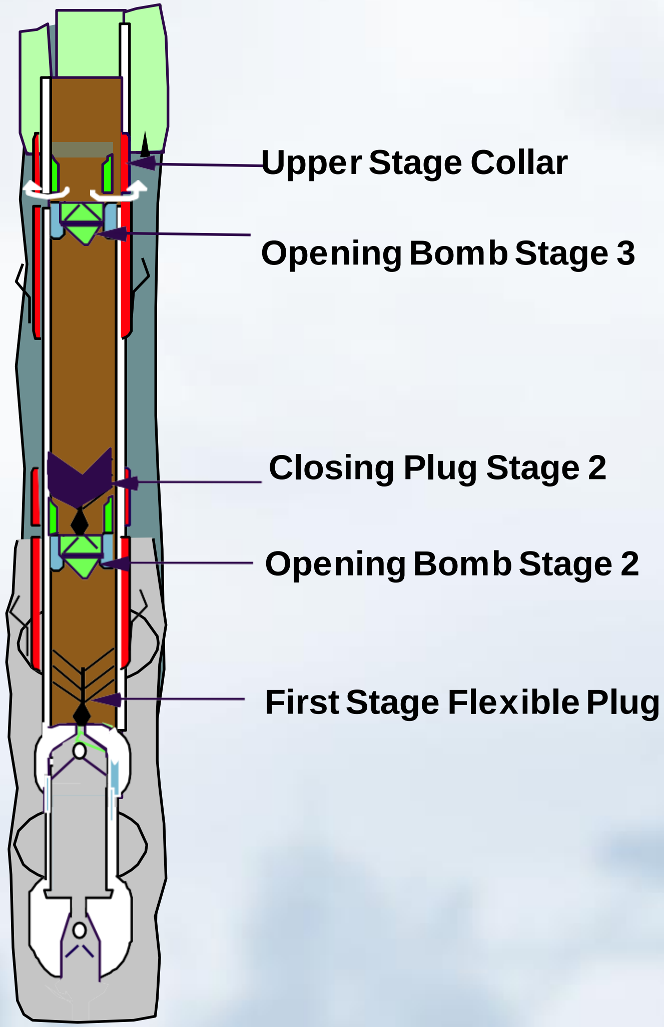
Float Collar – Flapper Valve

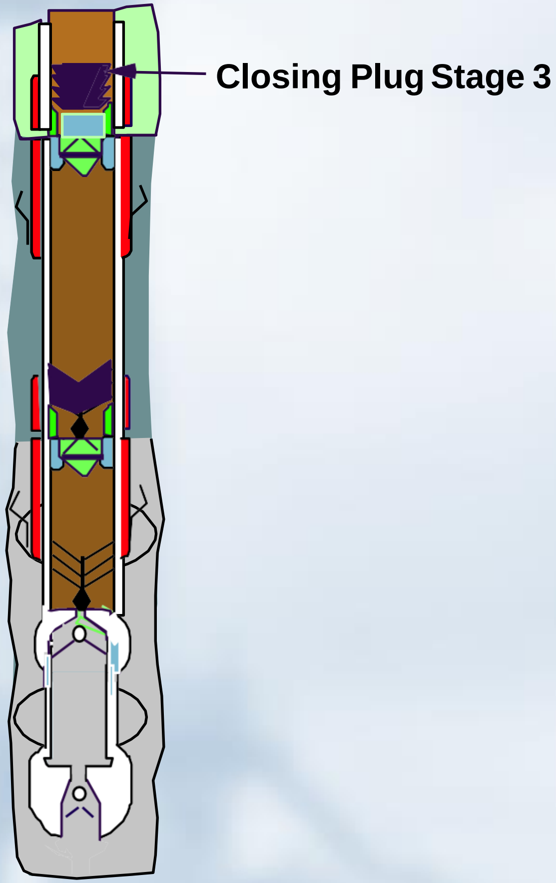
1-3 Casing joints above the shoe to reduce contamination around the shoe

TWO STAGE CEMENTING



THREE STAGE CEMENTING OPERATION





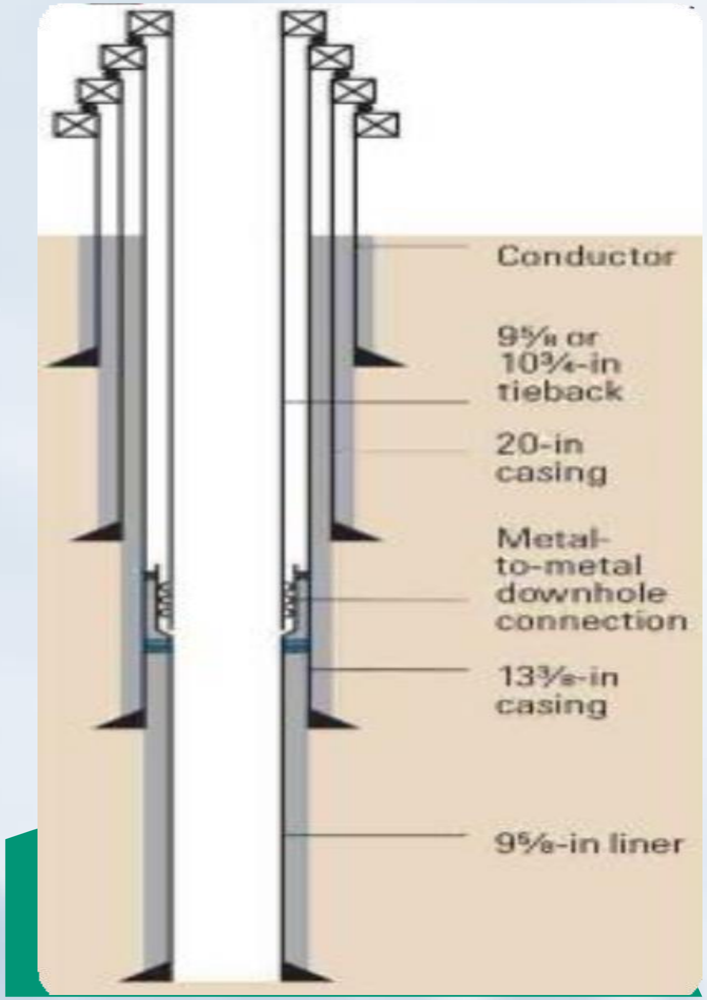
CONSIDERATIONS AFTER CEMENTING

- After cement hardens, releasing pressure on the casing permits it to contract so that the bond with the cement may be loosened.
- Release of pressure on the casing before the cement sets eliminates this problem.
- Pressure is made to bleed off if the back pressure valve in the casing string is holding satisfactorily.

Deepwater Cementing Objectives

- Long term hydraulic isolation in Deepwater cementing operations:
- Strict slurry density control at surface and downhole conditions
- Adequate rheology for optimal mud displacement
- Fast gel and compressive strength development
- Minimal shrinkage and low permeability
- Engineered set cement mechanical properties

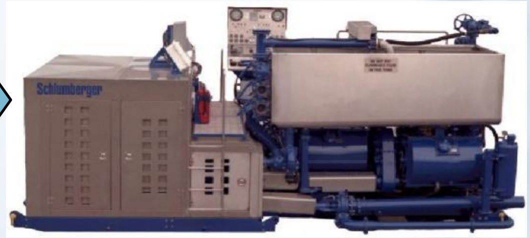
DEEP WELL LINER CEMENTING



- ✓Deep wells usually start with 20 to 30-inch conductor casing and are ultimately completed with 5, 5-1/2 or 7- inch liners.
- ✓In some of the deep wells, it is common to set two liners (a drilling liner & a production liner) before reaching the ultimate drilling objective.
- ✓The wear and tear on the intermediate liner during drilling often requires the setting of a tie-back string before the well is completed.
- ✓The tie-back string stabilizes and reinforces the intermediate liner and intermediate casing, which may have been weakened during the drilling process.

EQUIPMENT OFF-SHORE

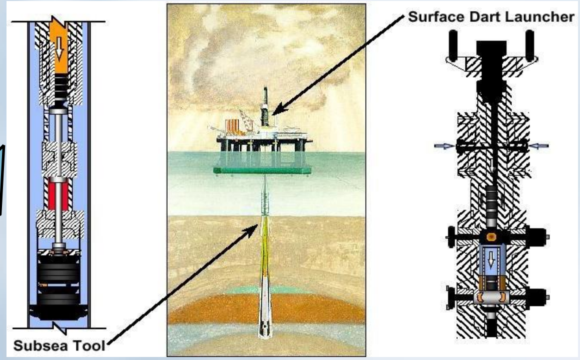
LAS
Liquid Additive System



CPS
Cement Pump Skid

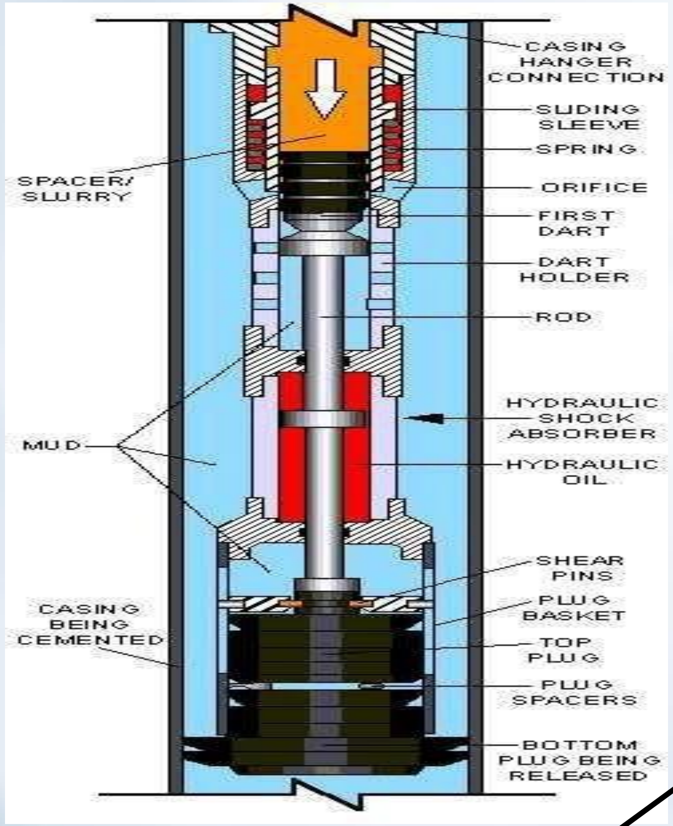
Batch Mixer

Slurry Chief
Mixing System

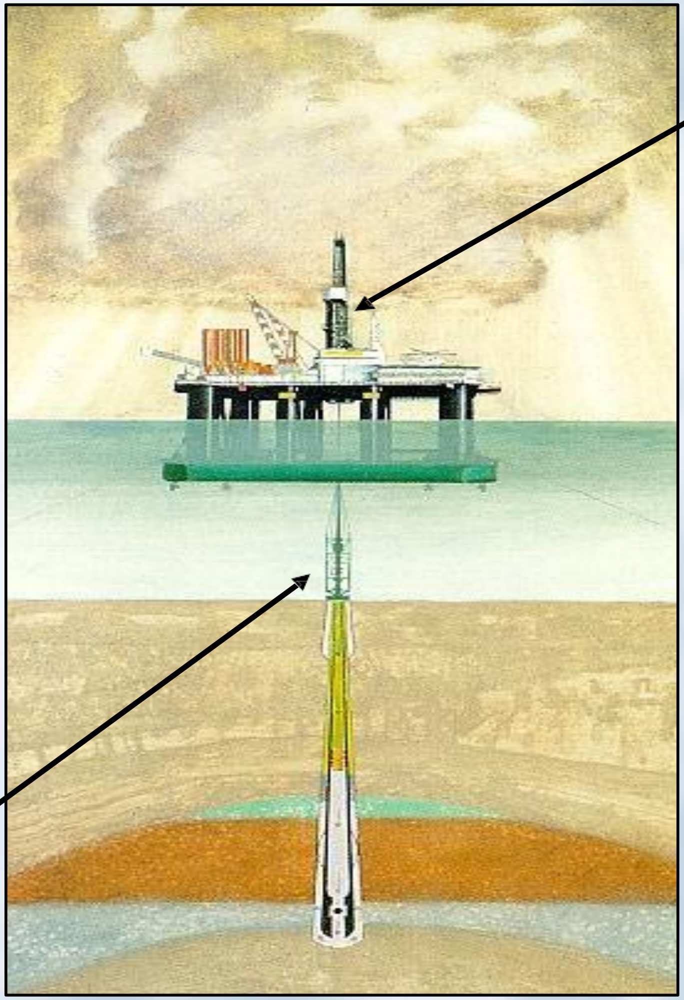


Cement Head
(Sub Sea System)

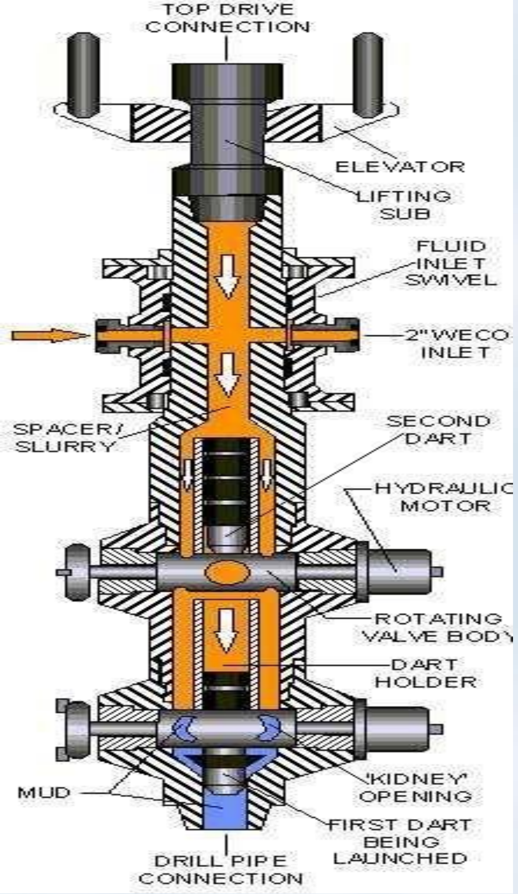
DEEPSEA SYSTEM



Subsea Tool



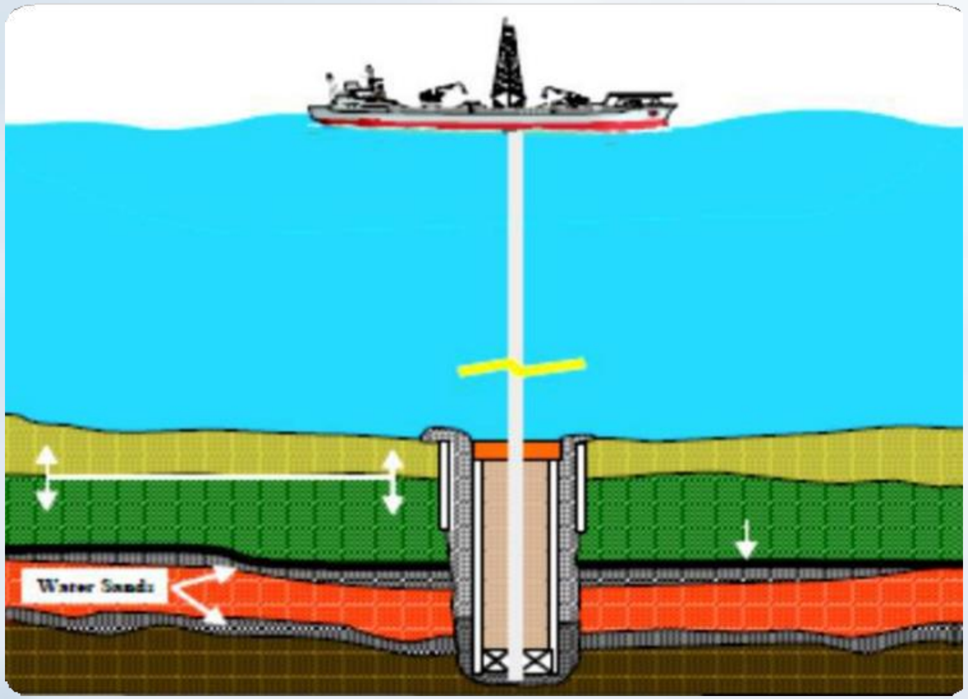
Surface Dart Launcher



CEMENTING PROGRAM

Hole size	Casing Size	FC Depth	Shoe Depth	Pump rate (BPM)	Spacer bbl / ppg	Cement type	Additives	Yeild	Cement (saks)	Cement (ft3)	Cement bbl / ppg	Spacer bbl / ppg	Dart displace by (bbls)	Displacement bbl/ppg
26	22		8549			Foam Cement			5354					
21.5	17.875	12298	12352	5 / 10	100 / 12	Premium Joppa	0.07 ez flo, 3 gphs D-Air 300L, 3 gphs HR-6L 4.35 gal/sac mixing water	1.08	1216	1313	234 / 16.4	15 / 12	10 / 10.6	360/10.6
19	16	15571	15665	5 / 10	100 / 13.5	Premium Joppa	0.07 ez flo, 0.25% D-Air 300L, 5 gphs HR-6L 4.42 gal/sac mixing water	1.08	1825	1971	351 / 16.4	15 / 13.5	172 / 12.1	1635 / 12.1
16.5	13.625	18978	19250	5 / 10	100 / 15	Premium Joppa	0.07 ez flo, 0.25% D-Air 3000, 1.8 lbs/sk Kcl, 10 gphs SCR-100L 4.3 gal/sac mixing water	1.08	1905	2057	366 / 16.4	15 / 15	1619 / 14.3	2146 / 14.3
14	11.875	25630	25784	5 / 11	100 / 15	Premium Joppa	0.07 ez flo, 0.25% D-Air 3000, 1.8 lbs/sk Kcl, 5 gphs SCR-100L, 10 gphs Halad 344EXP, 4.42 gal/sk mixing water	1.08	850	918	163 / 16.4	20 / 15	510 / 14	760 / 14
10.625	-	-	29800	6 / 11	50 / 15	Premium Joppa	0.07 ez flo, 0.3 gal/sk D-Air 3000L, 6 gphs HR-6L, 3 gphs HR-25L, 4.32 gal/sk water	1.07	468	501	89.2 / 16.4	5 / 15	-	735 / 14.4

DEEPWATER CEMENTING CHALLENGES



✓**Shallow water / gas flow:** High flow rates can be cause to washout craters, large enough to seriously jeopardize well integrity. If not properly handled, this can lead to high water flows through the cemented annulus of the shallow surface casing.

✓**Low seabed temperature:** For 20" and 30" surface casing sea bed temperatures can range between 4 – 12 deg C, depending upon the water depth. The slurry properties like thickening time, transition time, time to achieve early compressive strength and rheology of cement slurry have a retarding effect and tends to elongate the above parameters.

✓**Low Fracture gradient :** The fracture gradient in deep water wells are very low. Consequently, low weight cement slurries are used for surface casing jobs (30" and 20").

CEMENTING IN DEEPWATER

Slurry design should include following considerations:

- Use of Low density cement slurry / optimized lightweight cementing system.
- Cement slurry should have High gel strength and less transition time (critical hydration period).
- Cement slurry should have additives to control gas migration.
- Cement slurry should have sufficient early CS /controlled fluid loss and nil free water.

Microspheres or hollow spheres (glass or ceramic spheres), when added to the cement system, allow reduction of the cement density without additional mix water, thereby improving the compressive strength development properties at low temperature. The typical range of slurry density with the application of microspheres is 8.5 to 14 ppg. The performance properties can be adjusted with accelerators and anti-gas migration additives.

Thank You for your undivided attention !

We are now open to questions.