Drill String and BHA Core

Drill String Components and their Purpose

Learning Objectives

By the end of this lesson, you will be able to:

✓ Identify drill string components and their suppliers
✓ Explain the purposes of the various drill string components
Drill String Components

- String Segments
  - Drill Pipe
  - Bottom-Hole Assembly (BHA)
    - Bit
    - Drill Collars
    - Heavy-weight drill pipe (HWDP)
    - Stabilizers
    - Crossovers
    - Other tools for directional control and measurement, formation evaluation, etc.

Purpose of Drill Pipe and BHA

- Purpose of Drill Pipe
  - Flow conduit for drilling fluid from the surface
  - Carry tension load of string weight
  - Transmit torque to BHA and bit

- Purpose of BHA
  - Flow conduit for drilling fluid from the surface
  - Weight on bit
  - Directional drilling control
Rotary Shouldered Connections

- As the pin is rotated, the pin threads engage the box threads and the pin advances down into the box until the shoulders engage.
- As shown in this animation, continued pin rotation as make-up torque is applied loads the shoulders in heavy compression as the pin is pulled into heavy tension.
- This make-up torque load ensures the shoulders will remain in contact under down hole conditions, creating an effective seal.
Rotary Shouldered Connection Thread Compound

- Thread compound for rotary shoulder connections, commonly called pipe dope, is a petroleum grease lubricant often with powdered metal.
- Most common metals as copper and zinc.
- Some dope formulations are metal free.
- Usually applied with a brush.
- Not the same as casing and tubing dope.

Crossover Subs

[Images of crossover subs in different configurations: Pin X Pin, Box X Pin, Pin X Box, Pin X Box, Box X Box.]
Thread Protectors

- **Three Types:**
  - **Cast Steel**
    - Machined threads and shoulders
    - Heavy-duty bails suitable for picking up and laying down a drill collar with the air hoist
    - Made from steel castings
      (30,000 psi yield [206842.7 kPa])
  - **Pressed Steel**
    - Light-duty protectors for shipping and storage
    - Non-load bearing threads
    - Do NOT weld a lifting bail on these protectors
  - **Plastic**
    - Light-duty protectors for shipping and storage
    - Do not rust
Drill Collars

- Built from one piece
- Collars have different:
  - Sizes (3-1/8" to 14" [0.07 m to 0.35 m])
  - Do not have Grades like normal DP
  - May be spiraled
  - May have slip and elevator recesses
- Connections have different:
  - Thread styles
  - Dimensions

Drill Collar Handling

- Since drill collars do not have OD upsets or shoulders, handling often requires a lift sub that can be used with drill pipe elevators or a lift plug or nubbin than can be used with drill collar elevators
Safety Clamp

Slips

Slip recesses provide a shoulder for slips to prevent loss of tools down hole; faster than using a safety clamp.

Elevator recesses provide a shoulder for elevators to lift against; faster than using a lift sub or nubbin.

Slip recesses provide a shoulder for slips to prevent loss of tools down hole; faster than using a safety clamp.
May not require safety clamp since slips have shoulder to prevent loss of string
- Can present a stress concentration and cause fatigue cracking in this area
Non-Magnetic Drill Collars

- Built from one piece
- Made from stainless steel material
- Used to prevent magnetic interference with directional survey tools – MWD tools are non-mag material

Non-Magnetic Drill Collars

- Non-mag drill collars have different:
  - Sizes (3-1/8" to 11" [0.07 m to 0.27 m])
  - Usually not spiraled
  - Usually no slip and elevator recesses
- Connections have different:
  - Thread styles
  - Dimensions
  - Often use saver subs – make-up torque is different than steel drill collars
- Other tools non-mag: HWDP, stabilizers
Stabilizers

- Integral Blade Stabilizer (IBS)
  - Used to control hole deviation based on stabilizer spacing along length of BHA and stabilizer diameter
  - String stabilizer is box x pin
  - Near-bit stabilizer is box x box
  - Spiral blades give more consistent support than straight blades
  - Hardfacing materials / TC inserts / diamond on blades to reduce wear
  - Usually machined from one piece
  - Sometimes blades are welded to tool body - weld cracking issues
  - Stabilizer integrated onto tool housing
Stabilizers

**Integral Blade Stabilizer (IBS)**
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**Sleeve / Wear Pad Stabilizers**
- Same purpose as IBS
- Replaceable sleeves / wear pads
- Various treatments to blades for wear resistance
- Different diameters available
Stabilizers

- Roller Reamers
  - Same purpose as IBS
  - Reduced torque due to rollers but also less contact area
  - Various treatments to rollers for wear resistance
  - 3-point has three rollers per tool
  - 6-point has six rollers per tool
**Heavyweight Drill Pipe**

- Built from three pieces and welded together
  - Tube
  - 2 tool joints – box and pin
- Tubes have different:
  - Sizes (2-7/8” to 6-5/8” [0.07 m to 0.16 m])
  - Weights (based on style)
  - Do not have grades like normal DP
- Tool Joints have different:
  - Thread styles
  - Dimensions

---

**Heavyweight Drill Pipe (HWDP)**

- Longer, heavier tool joints
- Thicker wall tubes
- Center upset or spiral center section
Drill Pipe

- Built from three pieces and welded together
  - Tube
  - 2 tool joints – box and pin

- Tubes have different:
  - Sizes (2-3/8” to 6-5/8” [0.06 m to 0.16 m])
  - Weights (based on wall thickness)
  - Material strengths (Grade)

- Tool Joints have different:
  - Thread styles
  - Dimensions

Drill Pipe Grade

- The Grade of a DP tube indicates the API required Minimum Yield Strength for that material, typically expressed in psi

<table>
<thead>
<tr>
<th>Grade</th>
<th>Min. Yield Strength psi [kPa]</th>
<th>Max. Yield Strength psi [kPa]</th>
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<td>165,000 [1,137,634]</td>
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API Drill Pipe Marking Systems (Applicable since 1995)

Standard Weight Tubes
- No Markings
- Grade E-75
- Grade X-95
- Grade G-105
- Grade S-135

Heavy-wall Tubes
- Flat Only

API Marking System
Drill Pipe

Grade X-95?

Hardbanding

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Besides the standard drill string components including drill collars, stabilizers, heavy-weight drill pipe, crossovers, and drill pipe...

a large variety of specialty tools that are utilized in the BHA and the drill pipe segments of the drill string

In the BHA, several tools may be used that are designed to control the directional tendencies of the bit
Specialized BHA Tools

- **Vertical / Low Angle Applications**
  - Conventional Rotary
  - Conventional Motor
    - Positive displacement motor (PDM)
    - Turbine
  - Vertical Rotary Steerable System (RSS)

Vertitrak RSS
Automated Vertical Drilling System

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Specialized BHA Tools

- **Directional Applications**
  - Bent Housing Motor (PDM / Turbine)

Bent Housing
Power Section
Stabilizer
Bent Housing
Positive Displacement Motor

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Specialized BHA Tools

- Directional Applications (cont’d)
  - 2D Rotary Steerable System
  - 3D Rotary Steerable System
- Combination Applications
  - A PDM is used to drive an RSS and further expand its capabilities

Down Hole Measurement Tools

- Measurement While Drilling (MWD)
  - Directional surveying
  - Inclination
  - Azimuth – magnetic or gyro
  - Some with gamma ray, resistivity, vibration, temperature
Down Hole Measurement Tools

- Logging While Drilling (LWD)
  - Formation evaluation
  - Gamma Ray
  - Resistivity
  - Density
  - Temperature
  - Formation and Wellbore Pressure
  - Formation Fluid Types
  - Some with sonic and other sensors

- Telemetry
  - Mud pulse
  - Electromagnetic
  - Wired drill pipe
Learning Objectives

You are now able to:

✓ Identify drill string components and their suppliers
✓ Explain the purposes of the various drill string components
Drill String and BHA Core

Drill String Operation and Failure Prevention

Learning Objectives

By the end of this lesson, you will be able to:

- Determine drill string performance properties
- Diagnose drill string mechanisms
- Identify steps to prevent drill string failures
Considerations include:

- Hydraulics
- Torque and drag in the well
- Potential casing wear

**General Objectives**

- **Reduce time and cost**
  - No failures
  - Use current inventory
- **Efficient operations**
  - Optimum hydraulics
  - Reduced torque and drag
  - Avoid casing wear
- **Achieve directional objectives**

The string must be designed to meet the expected load requirements of the well and then utilized on the rig within that operational envelope.

**Technical Objectives**

- Maximum Stress < Yield Stress
- Retard Fatigue
- Resist H₂S
- Optimize Hydraulics
**Maximum Stress < Yield Stress**

**Stress**
- Defined as load per unit of area
- Load may be the result of tension, torque, or pressure situations
- Load is applied over the cross-sectional area of the tool
- Might be expressed in:
  - pounds of load per square inch of cross-sectional area or pounds per square inch (psi)
  - Newtons of load per square meter of cross-sectional area (pascal or Pa)

**Strain**
- Describes deformation under stress
- Is a length measurement expressed as:
  \[ \epsilon = \frac{\Delta L}{L} \]
- Change in Length
- Original Length

**Keep Maximum Stress < Yield**

- Load creates Stress
- Stress creates Strain (deformation, elongation)
- Load exceeding Capacity → Stress exceeding Yield
- Stress < Yield creates elastic deformation
- Stress > Yield creates plastic deformation and failure - tension, torque, burst, collapse, simultaneous loads
- Manage operational loads to keep Stress < Yield
Keep Maximum Stress < Yield

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- Stress > Yield creates plastic deformation and failure – tension, torque, burst, collapse, simultaneous loads
- Manage operational loads to keep Stress < Yield

Take Action to Retard Fatigue

- Cyclic loading - rotation while bent or buckled
- Reduce stress:
  - less bending
  - less buckling
  - less tension
  - avoid vibration
- Reduce string RPM

\[
\text{Stress} = \frac{\text{Load}}{\text{Area}} = \frac{200 \, \text{kips}}{5 \, \text{in}^2} = 40 \, \text{ksi}
\]
Take Action to Retard Fatigue

- To combat fatigue, API material specifications require testing for toughness, which is a property that helps steels resist cracking.
- The test is called a Charpy V-Notch Impact Resistance test.
  - A standardized test that is often applied to drill strings, casing, marine risers, and other oilfield equipment.
- Fatigue:
  - Number 1 killer of drill strings worldwide.
  - Occurs over many load cycles – rotating the string while it is bent or buckled.
  - Cracking mechanism.
  - Cumulative – cannot ‘inspect it away’.
  - Not repairable in DP tubes.
  - May be repairable in BHA connections.

Resist H₂S

- Materials Selection
  - Lowest strength (hardness) to handle load.
  - Beware of specialty equipment.
**Resist H₂S**

- **Down Hole Environment**
  - Drill overbalanced
  - High pH for WBM plus scavengers
  - Use NAF where possible

  \[ H₂S \rightleftharpoons HS^- + H^+ \]

  \[ HS^- \rightleftharpoons S^- + H^+ \]

- Hydroxyl ions (OH⁻) from high pH environment react with hydrogen ion (H⁺) to form water (H⁺ + OH⁻ → H₂O)

- Metal ion in scavengers react with sulfide ion (S⁻) - examples are zinc (Zn⁺⁺) and iron (Fe⁺⁺) as follows:
  - Zn⁺⁺ + S⁻ → ZnS
  - Fe⁺⁺ + S⁻ → FeS
  - Both products are inert and reaction cannot be reversed

**Optimize Hydraulics**

- Flow rate / SPM requirements
- Pump pressure / HP requirements
- Hydraulic Horsepower at the bit (HSI)
- Annular Velocity (AV)
- Equivalent Circulating Density (ECD)
Drill String Failure Prevention

- Overload Mechanisms – *Applied Load generates stress > Yield Stress*
  - Tension
  - Torque
  - Combined Tension / Torque
  - Pressure – Burst / Collapse
- Cyclic Load Mechanisms – *Repeated cyclic loading leads to cracking*
  - Drill Pipe Tube Fatigue
  - BHA Connection Fatigue

Drill String Failure Diagnosis

- Location, Orientation, and Appearance of Fracture
  - **Location**: Where in the string and where on the tool did fracture occur?
  - **Orientation**: How is the fracture surface oriented relative to the axis of the tool?
  - **Appearance**: Is fracture surface smooth or jagged? Is there evidence of plastic deformation?
Tension Failure

- **Cause:**
  - Pull exceeds load capacity and pipe parts

- **Location:**
  - Usually DP tubes
  - Sometimes connections

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Tension Failure

- **Prevention:**
  1. Confirm string capacity through inspection
  2. Prepare application specific design
  3. Calibrate load indicators
  4. Communicate limits to team
Drill Pipe Tensile Capacity

- Pure tension guideline – no torque
- Based on two criteria:
  - Tube cross-sectional area
    - Size, Weight, API Classification
  - Tube material Minimum Yield Strength
    - Grade

\[
\text{Tensile Capacity (lb)} = \text{Cross-Sectional Area of Tube (in}^2\text{)} \times \text{Strength of Steel in Tube (psi)}
\]

Tube Cross-sectional Area

- Premium Class and Class 2 tubes have both OD and wall thickness minimum values specified by API
- Measurements of OD and Wall Thickness are basic part of DP inspection
- Most recent values should be available on the rig

\[
\text{Cross-Sectional Area} = \frac{\pi (\text{OD}^2 - \text{ID}^2)}{4}
\]

where ID = OD – (2 x Wall Thickness)
API Used DP Classifications

- Class 1 (New) DP may have as little as 87.5% of ‘Nominal’ wall thickness.
- From the first trip in the hole until the tube wall is <80% of ‘Nominal’, the DP tubes are classed API Premium Class.

Drill Pipe Grade

- The Grade of a DP tube indicates the API required Minimum Yield Strength for that material, typically expressed in psi.

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<td>135,000 [9340,792]</td>
<td>165,000 [1,137,635]</td>
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Drill Pipe Tensile Capacity

- Tensile Capacity (lb) = Cross-sectional Area of tube (in²) x Strength of steel in tube (psi)

Example: 5” 19.5 ppf S-135 Premium Class
  - Min. tube OD = 4.85 in [0.12 m]
  - Min. Wall thickness = 0.290 in [0.007 m]
  - Cross sectional Area = 4.154 in² [0.002 m²]
  - Min. Yield Strength = 135,000 psi [930,792 kPa]

- Load Capacity = 4.154 in² x 135,000 psi
  - = 560,764 lbs [254,358 kg] (DS-1 4th Ed. vol.2 p.59 Table 3.8)

Tensile Design Factors

- Tensile Capacity (PT) at Yield = 560.8 K
- Allowable Load (PA) = 509.8 K
- Working Load (PW) = 409.8 K

Design Factor Example – 5” 19.5 ppf [29 kg/m] S-135 Prem. Class

<table>
<thead>
<tr>
<th>DFₜ</th>
<th>MOP</th>
<th>PT</th>
<th>PA</th>
<th>PW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>100K</td>
<td>560.8 K</td>
<td>509.8 K</td>
<td>409.8 K</td>
</tr>
</tbody>
</table>

(Where PA = PT/DFₜ and PW = PA – MOP)

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## So How Much Can I Pull?

<table>
<thead>
<tr>
<th>Class</th>
<th>Wall Thickness in [m]</th>
<th>Max. Tensile Load @ Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Nom.)</td>
<td>.362 [0.009]</td>
<td>712,070 [322,989]</td>
</tr>
<tr>
<td>1 (Min.)</td>
<td>.315 [0.008]</td>
<td>613,340 [278,206]</td>
</tr>
<tr>
<td>Premium (95% wall)</td>
<td>.344 [0.0087]</td>
<td>657,960 [298,445]</td>
</tr>
<tr>
<td>Premium (80% wall)</td>
<td>.290 [0.007]</td>
<td>560,764 [254,358]</td>
</tr>
<tr>
<td>2</td>
<td>.253 [0.006]</td>
<td>486,778 [220,798]</td>
</tr>
<tr>
<td>80% of Prem.</td>
<td>N / A</td>
<td>448,610 [203,486]</td>
</tr>
</tbody>
</table>
Torsional Failure

- Rotary-shouldered connections as used to join drilling tools into desired drill string configurations.
- By API recommended practice, tool joints are the weak link in torque. As a consequence of their position near the top of the string, they are also exposed to the highest torque loads in the string.
- As a result, the focus shifts from the drill pipe tube for tension failure prevention to the tool joint for torsional failure prevention.

Torsional Failure

- A properly made up tool joint provides both an effective seal to prevent the connection from leaking and a shoulder through which drilling torque loads can be conveyed.
- Make up torque loads the pin and box shoulders in compression as it simultaneously loads the pin neck in tension.
- The make up torque is specified to achieve a targeted level of stress in the connection.
Torsional Failure

- Tool joint make up stops when applied make up torque achieves that stress level in either the box or the pin, whichever occurs first. But if the torque load on the connection exceeds this value, stress goes up.
- If the stress exceeds yield of the material, plastic deformation occurs.
- The box may swell outward, called “belling the box”, and the pin may stretch.

Torsional Failure

- Typically one or the other of these occurs, whichever component is weaker.
- Depending upon connection dimensions, a “box weak” connection would yield the box first and a “pin weak” connection would likewise yield the pin first.
Torsional Failure

- Basic inspection services will provide dimensional information on the connection to ensure it was manufactured correctly and that it has not been plasticly deformed in previous use.
  - These dimensions, box OD and pin ID especially, determine the torsional load capacity of that connection.
- A design and operational plan allows comparison of the torque load predictions for the well with the torque load capacity of the drill string.
- Load indicators on the rig, in this case the top drive torque indicator and make up torque sensors in the pipe handling system, should be calibrated so that the applied loads can be monitored and controlled at a level within string capacity.
- The safe operating load envelope for the drill string must be communicated to the team on the rig.

Torsional Failure

- Torque Load generates stress that exceeds Yield Stress
- Plastic Deformation
  - Belled Boxes
  - Stretched pins
- Connection Failure
- Connection Leak
### Tool Joint Dimensions

Based Upon: 5” 19.50 ppf [29 kg/m] NC 50 Drill Pipe (ID: 4.276” [0.108 m])

<table>
<thead>
<tr>
<th>Grade</th>
<th>Tube MYS psi [kPa]</th>
<th>Tool Joint MYS psi [kPa]</th>
<th>Tool Joint OD in [m]</th>
<th>Tool Joint ID in [m]</th>
<th>Weight ppf [kg/m]</th>
</tr>
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<tbody>
<tr>
<td>E-75</td>
<td>75,000 [517,106]</td>
<td>120,000 [827,370]</td>
<td>6-5/8 [0.168]</td>
<td>3-3/4 [0.095]</td>
<td>21.37 [31.8]</td>
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<td>95,000 [655,001]</td>
<td>120,000 [827,370]</td>
<td>6-5/8 [0.168]</td>
<td>3-1/2 [0.088]</td>
<td>21.90 [32.5]</td>
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<td>3-1/4 [0.082]</td>
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<td>2-3/4 [0.069]</td>
<td>22.59 [33.6]</td>
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MYS = Minimum Yield Stress  
ppf = Pounds per foot

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As the pin bore gets smaller, the pin end tool joint gets heavier; this results in heavier average weight per foot.

None of these joints of drill pipe weighs 19.5 ppf [29 kg/m], even though that is the name the industry applies to it.

In this drill pipe case, the actual weight of Grade S with API-recommended tool joints is more than 3 ppf [4.4 kg/m] heavier than the name we use to describe it.

Be careful to choose the correct actual weight of the pipe when doing load calculations or the results could end in errors.

MYS = Minimum Yield Stress  
ppf = Pounds per foot
NC50 Tool Joint Dimensions

- Smaller Pin ID = More Cross-sectional Area
- More Cross-sectional Area = More Pin Strength
- More Pin Strength = Higher Make Up Torque

6-5/8" [0.168 m] Box OD
3-3/4" [0.095 m] Pin ID (Sized for Grade E tube)
3-1/2" [0.088 m] Pin ID (Sized for Grade X tube)
3-1/4" [0.082 m] Pin ID (Sized for Grade G tube)
2-3/4" [0.069 m] Pin ID (Sized for Grade S tube)

Tool Joint Dimensions

- Based Upon: 5" 19.50 ppf [29 kg/m] NC 50 Drill Pipe (ID: 4.276" [0.108 m])

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MYS = Minimum Yield Stress
ppf = Pounds per foot
How are Tool Joint Dimensions Determined?

- **API Torsional Strength Guidelines:**
  - TJ should be the weak link in torque capacity of string
  - TJ strength @ Yield should be 80% of Tube strength @ Yield
  - So, if the Tube Yields @ 50,000 ft-lb [74,408.1 kg/m] torque, the Tool Joint should Yield at 40,000 ft-lb [59,526.5 kg/m] (50,000 * 0.8)
  - YIELD means TJ stress due to torque > 120,000 psi
  - Also, as the strength of the Tube changes, the strength of the recommended TJ will change
  - Make Up Torque is 60% of TJ Torsional Strength @ Yield
  - So, if TJ Yield @ 40,000 ft-lb [59,526.5 kg/m], then Make Up Torque @ 24,000 ft-lb [35,715.9 kg/m] (40,000 * 0.6)
  - And Make Up Torque stress is 60% of Yield Stress:
    \[(120,000 \text{ psi} [827,370.8 \text{ kPa}] @ Yield) * 0.6 = 72,000 \text{ psi} [496,422.5 \text{ kPa}] @ \text{Make Up Torque}\]

### Make Up Torque Changes as Dimensions Change

<table>
<thead>
<tr>
<th>Dimensions (in)</th>
<th>NC50</th>
<th>NC60</th>
<th>NC120</th>
<th>NC150</th>
<th>NC175</th>
<th>NC200</th>
<th>NC220</th>
<th>NC245</th>
<th>NC275</th>
<th>NC300</th>
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**Make Up Torque at Premium Class Minimum tool joint OD** is MUCH LESS than **Make Up Torque when New**

Ref.: T.H. Hill Standard DS-14th Ed

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### What Tool Joint Dimensions Should I Use?

- Choose dimensions so that Make Up Torque (MUT) will be higher than expected operating torque
- The tube grade DOES NOT GUARANTEE the dimensions of the attached tool joints
- Make sure you have dimensions from most recent inspection
  - *Premium Class may not be good enough*
  - *Be aware of impact of box weak condition*
- Make appropriate tradeoffs between torque capacity and hydraulics restrictions
- Consider Make Up Torque adjustments and high friction pipe dope

**NOTE:**

- Bold Type face means connection is BOX WEAK
- Normal type face means connection is PIN WEAK
High Torque Connections

- Double-shoulder configuration more popular:
  - GP HT
  - GP XT / XT-M
  - GP GPDS
  - Tenaris NKK DSTJ
  - VAM EIS
  - VAM Express
  - VAM X-Force
- Variable taper / TPI / threadform

High Torque Connections

- High Torque (HT)
  - NC threadform
  - 4 threads / inch
  - More taper
- Xtreme Torque (XT)
  - Proprietary threadform
  - 3-1/2 threads / inch
  - Less taper
High Torque Connections

- GP TurboTorque
- Double starting thread
- >2x make up speed
- Higher torque than 2nd Gen DS connections
- Better hydraulics
- Better fatigue life
- 130 ksi TJ material with good toughness values

High Torque Connections

- VAM X-Force
- Unique threadform
- Very coarse threads per inch for fast makeup

You may want to PAUSE a moment to review the image in detail.
Learning Objectives

You are now able to:

☑ Determine drill string performance properties
☑ Diagnose drill string failure mechanisms
☑ Identify steps to prevent drill string failures