Improving Drill String Safety and Reliability for MENA's Challenging Wells

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Agenda

• Drill String Overview
• Drill Pipe Terminology
• Overview of failures Modes
• Improving Safety by Failure Mitigation
  • Preventive Design for Overload
  • Mitigative Design for Fatigue
  • Dealing with H₂S
  • Protective Care & Handling
  • Differentive Evaluation
Drill Pipe Terminology

- Seamless tube per API 5DP/ISO 11961 (previously API 5D)
- Pin & Box Tool Joints per API 5DP/ISO 11961 (previously API 7)
- Connections per API 7-2/ISO 10424-2 or proprietary ones
SMYS (Specific Minimum Yield Strength)

- **A**: Elastic Limit
- **B**: API Minimum Yield
- **C**: Ultimate Tensile Strength
- **D**: Failure

- Stress = Force / Area
- $E = \frac{\text{Rise}}{\text{Run}}$
- Strain = Stress / $E$
- $E_{\text{steel}} \approx 30 \times 10^6 \text{ psi}$

### Stress (psi)

- **0.5% elongation of sample length**

### Strain

- **Run**
- **Rise**
Drill Pipe Body Grades

API grades:
- E 75 (SMYS = 75,000 psi)
- X 95 (SMYS = 95,000 psi)
- G 105 (SMYS = 105,000 psi)
- S 135 (SMYS = 135,000 psi)

Proprietary Sour Service Grades
Grant Prideco | Tenaris | Valourec
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- XD-95 / TSS -95 / CYX-95 | C-95S | VM-95 DP S (SMYS = 95,000 psi)
- XD-105 / TSS -105 / CYX-105 | C-105S | VM-105 DP S (SMYS = 105,000 psi)

Proprietary High Strength Sour Service Grades
Grant Prideco | Tenaris | Valourec
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- HS^3^125 (SMYS = 125,000 psi) | C-120 | VM-120 DP S (SMYS = 120,000 psi)

IRP Grades SS-95 & SS-105 and Proprietary High Strength Grades
Overview of Failure Modes: Tensile Overload

- **Cause?** Pull Exceeds Load Capacity
- **Tensile Capacity** = Cross Section × Material SMYS
- **Location?** Drill Pipe Body Usually (smallest cross-section) but also in connections.
Overview of Failure Modes: Torsional Overload

- **Cause?** Drilling torque exceeds torsional load capacity.

- **Torsional load capacity** is a function of steel envelope, geometry and material SMYS.

- **Location?** Usually in tool joints.

- **Boxes** become swelled and pins become stretched.
Overview of Failure Modes: Combined Tension-Torsion Failure

• Cause? Simultaneously applied tensile and torsional stresses exceed load capacity of joint.

• Where? Usually in the drill pipe body and sometimes in connections.
Overview of Failure Modes: Downhole Heating

- **Cause?**
  - Stuck string rotated without circulation.
  - Heat generated by friction downhole increases joint temperature beyond the critical temperature (~ 1400 F), changing steel’s microstructure & mechanical properties.

- **Where?**
  - Usually in pipe body, but can also occur in connections.
Overview of Failure Modes: Sulfide Stress Cracking (SSC)

Cause?
• H2S from formation releases its Hydrogens
• Hydrogen proton embrittles steel
• Embrittled steel cannot support cracks under loading leading to catastrophic failure.

Where?
• Point of highest stress & hardest steel
Overview of Failure Modes: Fatigue Failure

Cause?
- Drill pipe is put into compression
- Drill pipe buckles once its critical buckling load has been exceeded
- Rotation of buckled drill pipe induce cyclical loading which lead to residual stress
- Fatigue is irreversible and cumulative

Where?
- Usually in drill pipe body but also in connections
- Areas with point stress risers like slips areas or upsets areas
Drill String Design Process Overview

Determine expected load
- Torque
- Tension
- Fatigue (bending)
- Compression (buckling)
- Pressure

Select Drill string components (design)

Verify component condition

Set operating limits for rig team

Monitor condition during drilling

Economic issues
- Availability
- Logistics
- Cost

Rig issues
- Storage space
- Setback space
- Accuracy of load indicators
- Pump pressure/capacity
- Top-Drive output

Hole issues
- Hole cleaning
- Hole stability
- Hydraulics and ECD
- Casing wear
- Directional objectives

Other issues
- Jar placement
- Mud type and weight
- Etc.
- ...
Preventive Design for Overload

Grade Selection:
• Comfortable Safety Factor (SF)
• Adequate Margin of Over Pull (MOP)
• Select Purpose-built grades:
  • Drill Pipe:
    • API G-105 and S-135 not suitable for H₂S
    • Use high strength grades when no H₂S is present and going deeper than 16,000 ft
    • Use high strength sour service grades when drilling in H₂S and going beyond 16,000 ft
  • Heavy Weight Drill Pipe:
    • Do not use any of the API grades in H₂S

Connection Selection:
• Double Shouldered Connections (DSCs) offer 25% to 85% more torsional capacity, hence far less likely to get overtorqued
Mitigative Design for Fatigue

Grades:
- Select purpose-built grades with enhanced fracture mechanics
- Example: S-135T instead of S-135

Buckling Mitigation:
- Identify potential buckling areas along the string using string design simulators
- Select stiffer (thicker walled) components for those areas and repeat simulation

Connection:
- DSCs have greater resistance to bending and hence greater fatigue life.
- Select optimized geometry connections with fatigue resistant thread form
Better Understanding of SSC

**CHEMICAL EQUILIBRIUM PRODUCTS**

- **2 HYDROGEN ATOMS FORM 1 HYDROGEN GAS MOLECULE**
- **CRACK DUE TO H₂ GAS EXPANSION**
- **TINY HYDROGEN PROTONS PENETRATE THE STEEL**
- **EACH HYDROGEN PROTON CAPTURES AN ELECTRON & FORMS HYDROGEN ATOMS**
SSC Embrittlement Drivers

- pH
- temperature
- stress
- \( \text{H}_2\text{S} \) concentration
- pressure
Maximizing SSC Resistance

Minimize
- hardness

Minimize
- imperfections

Maximize
- martensite

Maintain
- A high mud pH
Dealing with H$_2$S

- Bulk stress and cyclic bending loads should be evaluated and minimized at well design stage
  - Apply comfortable safety factor on drill string design
  - Control dogleg severity
  - Over-engineer the drill string:
    - Select higher load rated tools
    - Use grades specifically designed for H$_2$S

- The effect of stress risers should be minimized when selecting string components
  - Use stress relief features on BHA (SRG, BB)
  - Use fatigue resistant thread form designs (SRT®, XT-F™, TurboTorque®)
  - Minimize slip cuts on pipe (low stress dies or SlipProof®)
NACE MR0175

recommendations:

1) Maintain the drilling fluid density to minimize formation fluid influx

2) Neutralize H$_2$S in the formation fluids by maintaining a mud pH of 10 or higher

3) Utilize sulfide chemical scavengers and/or corrosion inhibitors

4) Use oil-base drilling fluids
Protective Care & Handling - Running

Minimum distance
Protective Care & Handling - Lifting

Improper Handling Method

Recommended Handling Method
Protective Care & Handling - Slips

Slip Test

TOP CONTACT

FULL CONTACT

16-1/2''
Protective Care & Handling – Corrosion

Control Corrosion
Differentiative Evaluation

Shortcomings of bootlegged technologies:

• Unproven
• Not Interchangeable despite claiming to be
• Operators unwilling to take risks:
  • Safety
  • Legal:
    • IP
    • Trademark
  • Lack of adequate after sale support
• Limited to none geographical mobility
Last Slide, Really!

KEEP CALM AND ASK QUESTIONS