Drilling & Well Construction Considerations

Presentation during NWTRB Deep Borehole Workshop, 10/20/2015

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Agenda

Drilling & Well Construction Considerations

– Bits
– Drillstring Vibrations
– Vertical Directional Drilling
– Stuck Pipe
– Isolation & Abandonment

Source: Deep Borehole Field Test: Characterization Borehole Science Objectives, Kuhlman et al., 2015
Hole-Making Response by Different Bits

Polycrystalline Diamond Compact (PDC) bit

Tri-cone Rock bit with Tungsten Carbide Inserts (TCI)

Different cutting action, different ROP response

Rate of Penetration of Various Bits in Crab Orchard Sandstone Water and 11 ppg Water-Base Drilling Fluid at 110 to 120 RPM

Full scale tests of 6” bits at 10,000 psi

ROP = Rate of Penetration
WOB = Weight on Bit

Source: Judzis et al., SPE/IADC 105885

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Bit Selection

<table>
<thead>
<tr>
<th>Formation Description</th>
<th>Unconfined Compressive Strength</th>
<th>Suitable for Milled Tooth?</th>
<th>Suitable for TCI?</th>
<th>Suitable for PDC?</th>
<th>Suitable for Diamond Impreg?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Soft</td>
<td>&lt; 4,000 psi</td>
<td>Yes</td>
<td>No*</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Soft</td>
<td>4,000 – 9,000 psi</td>
<td>Yes</td>
<td>No*</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Medium</td>
<td>9,000 – 15,000 psi</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Hard</td>
<td>15,000 – 22,000 psi</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Very Hard</td>
<td>&gt; 22,000 psi</td>
<td>No</td>
<td>Yes</td>
<td>Possibly</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Application of TCI is possible but would not be economically preferred

**Selection Methodology**

- Consider formation hardness and eliminate unsuitable bit types
- Consider bit economics using ROP, time savings, rig costs and bit prices
- Consider the requirements of special factors such as directional requirements
- Note that the operating envelope for PDC’s continues to expand

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Heterogeneous Formations: Kymera Bits

Kymera (Chimaera) Hybrid Bits:
• Recently developed bits that “marry” essential features of roller cones and PDC bits
• Meant to drill in relatively large-diameter hole in medium/hard formations (use of PDC) that are interspersed with high-strength stringers, e.g. chert (use of roller cone)

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Source: Pessier and Damschen, 2010
Dynamic Dysfunctions: Vibrations

- Drilling rock is a destructive process, using heavy, high inertia drilling components that are moving at high velocities
- Some level of vibration is always present in every drilling operation
- If uncontrolled, vibration leads to dysfunction (impaired/abnormal functioning)
  - Axial Dysfunction: Bit Bounce
  - Lateral Dysfunction: Whirl (Bit and/or BHA)
  - Torsional Dysfunction: Stick-Slip
- Results of dysfunction include:
  - Low / limited ROP (wasted energy, premature bit dulling)
  - Reduced bit life, increased number of bit runs and associated trips
  - Fatigue accumulation, wash-outs and twist-offs because of cyclic stresses
  - MWD / LWD failures due to high-G shock loading
- Dynamic dysfunction is the most limiting factor in achieving optimum ROP and minimizing bit runs

<table>
<thead>
<tr>
<th>Vibration Mode</th>
<th>Dysfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial</td>
<td>Bit Bounce</td>
</tr>
<tr>
<td>Torsional</td>
<td>Stick-Slip</td>
</tr>
<tr>
<td>Lateral</td>
<td>Bit Whirl</td>
</tr>
<tr>
<td></td>
<td>BHA Whirl</td>
</tr>
</tbody>
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Chaotic Whirl Vibrations


Video courtesy of Schlumberger, Inc.

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Tool rotating clockwise and progressing around the hole clockwise


Video courtesy of Schlumberger, Inc.

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Vertical Directional Drilling

Well dogleg severity and tortuosity will need to be minimized, which will require directional drilling techniques (downhole motors/turbines, rotary steerables, accurate surveying!) to keep the well as vertical as possible (e.g. DLS < 1 deg./100 ft)

Factors affecting bit trajectory

• Gauge and placement of stabilizers
• Diameter & length of (sections of) drill collars
• Weight on bit
• Rotary speed
• Bit type & bit gauge length
• Formation anisotropy and dip angle
• Formation hardness (& tendency to wash/break out)
• Flow rate
• Rate of penetration
Well Construction & Abandonment

Source: Deep Borehole Field Test Specifications, Sandia National Laboratories

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“Stuck canisters” is a particular concern when running waste canisters into an open hole that is not stable or has high (local) tortuosity – it does not take much to “wedge” a canister with a caving (0.25” – 0.9” radial clearance)
Well Isolation & Abandonment

Well Abandonment considerations:

- Offshore abandonments set a high standard for abandonments in general and are recommended as a minimum for nuclear waste disposal wells (250 CFR 1712-1717 & 1721)
- Barriers will need to be explicitly evaluated and possibly monitored continuously
- How safe is an “open-hole completion” around the waste canisters?
- Cement may not be the most versatile material to use in abandonments (see next slide)
- What about potential well re-entry and intervention?

Source: 250 CFR 1715
Plugs using Self Healing Materials

- Traditional Portland cement has many drawbacks:
  - It is sensitive to mud and formation fluid contamination
  - It does not bond particularly well to formations, particularly those that are clay-rich due to high-alkalinity, lime-based chemistry
  - It has low tensile strength
  - When (micro-)annuli, cracks or fractures are formed, Portland has no ability to re-heal them after its set time period
  - New materials should be explored – and are becoming available – that overcome many of these problems and are self-healing

Self Healing Cement
3 day compressive strength = 1100 psi @ failure
Failed sample retested at 21 days = 1200 psi
Conclusions and Recommendations

• The project needs a more detailed drilling program!
• The project would benefit technically and economically from bit-expertise and consideration of the latest in bit developments
• Harmful drillstring vibrations should be monitored (with downhole accelerometers and surface MSE) and mitigated
• Borehole quality, tortuosity and gauge are very important, and will require vertical directional drilling and excellent surveying techniques (e.g. continuous gyro)
• Stuck canister risk may exist in an unstable open hole or tortuous hole with high local dogleg severity, requiring risk mitigation
• Well abandonment and barrier installation / monitoring should be executed to the highest possible standard
• Self-healing alternatives of Portland cement should be explored for use in abandonment
Q & A
Optimum Drilling Beyond Efficient Drilling

Performance enhanced by redesigning to extend founder point

MSE Equation

\[
E_s = \frac{W}{A_b} + \frac{120\pi TN}{PA_b}
\]

In the Efficiency envelope the torque/ROP ratio is nearly constant, so MSE is nearly constant.

Optimum drilling is at the edge of the Efficiency envelope.