Agenda

- Introduction to Schlumberger
- Modeling of Drilling Dynamic
- Simulation Implementation
- Challenge
Introduction to Schlumberger

Schlumberger

Founded in 1926 from Wire Line Logging...

Now we are the World’s No.1 oil and gas field services company.

From pore to pipeline
What is our value and future direction?

What’s our values?
- People
- Technology
- Profit

Our Transformation:
- Reliability
- Efficiency

Digital Transformation

Where does Schlumberger develop its industry software?
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Modeling of Drilling Dynamics

How does well drill?

BHA: Bottom Hole Assembly.
Drilling Activities and Its Challenges

Offshore Drilling

Control Parameters:
- WOB: Weight On Bit
- RPM: Revolutions Per Minute

How can we determine the optimum zone?
Modeling to Dynamic Behavior of Drill String

Mathematic Model:
- Governing Equation:
  \[ \sigma_{ij, j} + \bar{f}_i - \rho u_{i,j} - \mu u_{i,j} = 0 \]
  \[ \epsilon_{ij} = (u_{i,j} + u_{j,i}) / 2 \]
  \[ \sigma_{ij} = D_{ijkl} \epsilon_{kl} \]
- Boundary Condition:
  \[ u_i = \bar{u}_i \]
  \[ \sigma_{ij} n_j = \bar{T}_j \]

FEM Model:
- Governing Equation:
  \[ M \ddot{U}(t) + C \dot{U}(t) + F_{int}(t) = Q(t) \]
- where
  \[ M = \sum_{\epsilon} M^\epsilon \]
  \[ C = \sum_{\epsilon} C^\epsilon \]
  \[ F_{int} = \sum_{\epsilon} F_{int}^\epsilon \]
  \[ Q = \sum_{\epsilon} Q^\epsilon \]

Algebra Equation:
- \[ AX = B \]
- where
  \[ A = c_0 M_{i,j} + c_i C_{i,j} + K_{i,j} \]
  \[ X = \Delta U \]
  \[ B = Q_{i,j} - F_{f,i,j} - M_{i,j} \dot{U}_i - C_{i,j} \dot{U}_i - C_{i,j} U_{i,j} \]
Finite Element Matrix

Block Triangular Matrix

\[
A = \begin{bmatrix}
K_{11} & K_{12} & \cdots & K_{19} \\
K_{21} & K_{22} & \cdots & K_{29} \\
\vdots & \vdots & \ddots & \vdots \\
K_{91} & K_{92} & \cdots & K_{99}
\end{bmatrix}
\]

\[
X = \begin{bmatrix}
x_1 \\
x_2 \\
\vdots \\
x_9
\end{bmatrix}, \quad B = \begin{bmatrix}
b_1 \\
b_2 \\
\vdots \\
b_9
\end{bmatrix}
\]

Beam Element Matrix by 12X12 values

Buckling Behavior Under High WOB

Newton Iteration for Geometric and contact nonlinearity
Message Passing Interface (MPI) is a standardized and portable message passing system designed by a group of researchers from academia and industry to function on a wide variety of parallel computers.

Remark: Use MPI for parallel computing.
There are 4 procedures:

1. Factorization:
   \[ A^{0\text{cpu}} = LDL^T, \ A^{1\text{cpu}} = LDL^T, \ A^{2\text{cpu}} = UDU^T, \ A^{3\text{cpu}} = UDU^T \]

2. Forward Substitution:
   \[ Y^{0\text{cpu}} = (L)^{-1} B^{\text{first}}, \ Y^{1\text{cpu}} = (A^{1\text{cpu}})^{-1} B^{1\text{cpu}}, \ Y^{2\text{cpu}} = (A^{2\text{cpu}})^{-1} B^{2\text{cpu}}, \ Y^{3\text{cpu}} = (U)^{-1} B^{3\text{cpu}} \]

3. Solve small equation:
   \[ A^{\text{small}} X^{\text{small}} = B^{\text{small}} \]

4. Backward Substitution:
   \[ X^{0\text{cpu}} = (DL)^{-1} Y^{0\text{cpu}} ..., \ X^{3\text{cpu}} = (DU)^{-1} Y^{2\text{cpu}} \]
I-DRILL Service

Engineering service that provides interpretation of IDEAS® simulations, correlation with field data and recommendations.

Analysis types:
1. Bit/Mill
2. Underreamer
3. Bit- Underreamer balance
4. Durability Analysis
5. BHA Comparison
6. WOB & RPM recommendations
7. Cause of Vibrations Analysis
8. Failure Analysis
9. Post i-DRILL Analysis
10. Drilling System Check
Field Application

A Case Study:

Integrated Drilling Approach Saves Shell USD 1.1 Million, Achieves Record 275-ft/h ROP Salt Drilling Performance

Data-driven BHA design delivers 52% ROP increase compared with best offset well, deepwater Gulf of Mexico

CHALLENGE
Maximize penetration rates while delivering maximum borehole quality in salt drilling operation in deepwater Gulf of Mexico.

SOLUTION
Work with Schlumberger drilling experts to identify, evaluate, and deploy the technologies, processes, and workflows that will achieve the operator’s objectives.

RESULTS
- Reached section TD 1.4 days ahead of AFE, saving USD 1.1 million.
- Achieved an ROP of 275 ft/h (84 m/h), 52% faster than the best offset well.
- Drilled 4,230 ft [1,289 m] in one day compared with an average 2,000 ft [607 m] per day in the best offset well.

"[This job] sets the bar for future development—here and for our whole organization."

John Cook
Drilling Superintendent
Shell

Maximize drilling performance in deepwater salt section
Shell was drilling in the Atwater Valley field of the deepwater Gulf of Mexico. The campaign’s next well, Deep Sleep, would involve salt drilling. A similar well in a comparable field achieved an ROP of 180 ft/h (55 m/h) over 14,025 ft (4,275 m) that served as the performance benchmark to exceed. Shell challenged Schlumberger to deliver an integrated drilling solution that would achieve faster ROP, maintain a high-quality wellbore, and set new best practices for salt drilling in the area.

Implement engineered drilling approach to operate at high parameters
Shell collaborated with Schlumberger experts in Houston to investigate salt drilling KPIs across the Gulf of Mexico and to evaluate the drilling systems and workflows used in previous successes in the region. The highest-performance runs were drilled with 50,000- to 60,000-lbf (222,411- to 256,693-N) weight on bit (WOB) and 170–180 rpm, whereas previous wells in the Atwater Valley field had been drilled with about 30,000-lbf (133,447-N) available WOB and 150–160 rpm. Shell and Schlumberger agreed that increasing available weight and rpm was the key to maximizing performance.

A cross-discipline team of Schlumberger and Shell engineers investigated offset performances across the Gulf of Mexico to identify best practices and key BHA design features. With baseline performance determined, the IDEAS® integrated bit design platform was used to model and simulate all combinations of bits and BHAs. The modeling and simulation included dynamic finite-element analysis to help the team determine the optimal drilling system in terms of performance, stability, and directional control.

The results enabled the team to design a customized BHA that included a Smith Bits directional PDC bit (MD/715) for improved stability and enhanced torque response coupled with the PowerV® vertical drilling RSS for automatic well path verticality.
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HPC Infra-structure – Current Status

- **OS & Hardware**
  - Linux Node (computation)
    - In total, 90+ Linux workstations, about 2000+ core
  - Window PC (job management): 10+

- **Simulation Service Statistics**
  - 2015 simulation cases: 1 million
  - Peak daily cases: ~10000
  - Some cases are run with 2 or 4 cores
Performance Improvement

Speed up by software/modeling

Speed up by hardware

Graph showing speedup ratio from 2013 at 20 cores, with dates on the x-axis and speedup ratio on the y-axis.
Challenge

current

Simulation Time vs. Real Time

Hour
0 2 4 6 8 10 12 14

Real 4 8 12 16 24

Number of Cores

future

Simulation Time vs. Real Time

Hour
0 2 4 6 8 10 12 14

Real 4 8 12 16 24

Number of Cores
Thanks!