Agenda

• The Rock Penetration Model
• Model Implementation in the Perforating Software
• Two shaped charges in Oman
• Laboratory test
• Results
Penetration Rock based model (SPE-151846)

\[ DoP = DoP_{ref} e^{\alpha_0(F_{bi,ref} - F_{bi})} \]

Each characterization has DoPref and \( \alpha \).
Penetration Rock based model

\[ \text{DoP} = \text{DoP}_{\text{ref}} e^{\alpha_0 (F_{bi,\text{ref}} - F_{bi})} \]

Each characterization has DoP\(_{\text{ref}}\) and \(\alpha\).
Penetration Rock based model

\[ DoP = DoP_{ref} e^{\alpha_0 (F_{bi,ref} - F_{bi})} \]

\[ DoP_{ref} \] changed and \( \alpha \) fixed
Penetration Rock based model

\[ DoP = DoP_{ref} e^{\alpha_0 (F_{bi,ref} - F_{bi})} \]

Ballistic Indicator Function (function of UCS and effective stress)

\( DoP_{ref} \) fixed and changing \( \alpha \)
Comparing Charges

4.5” Gun 5spf in 7” casing:

- New generation charge
- Previous generation charge

Penetration vs Rock Strength

- Formation Penetration (in)
- Rock Strength UCS (psi)
Rock Model Implementation in the Software
Rock Model Penetration Software Workflow

Modified section 2 rock test
12 shots with various rock/stress combinations (Ballistic Indicator Function, F_{BI})

Characterize charge (Harvey et al)

Perforating Modeling Software
Casing, Fluid Correction (Saucier, Regal butto, etc)

New penetration model (Harvey et al)

Fig. 5. Pressure vessel schematic
Rock Model Implementation in the Software

Other scenarios?

- Carbonates
- Very hard rock
Characterization: Sandstones vs Carbonates (SPE -151846)
Characterization: Very Hard Rock (SPE-151846)
Characterization: Very Hard Rock (SPE-151846)

- Laboratory experiment of very hard rock (SPE-159771 and IPS-12-04)
- New parameter DoPmin implemented
Perforating Software Rock Model Implementation

- Carbonates
- Very hard rock
- Whole range of charges, new and old:
  - Full characterization
  - Approximated characterization

\[ \text{DoP} \]

\[ F_{bi} \]
Two “Approximated” Charges in Oman

Charge-A

Penetration vs Rock Strength

Charge-B

Penetration vs Rock Strength
Verification Test

• Laboratory tests conducted in May-2013
• 9-shot test for each Charge-A and Charge-B:
  – 3 shots with Castlegate sandstone cores (1515 psi)
  – 3 shots with Berea sandstone cores (7852 psi)
  – 3 shots with Crab Orchard sandstone cores (21,830 psi)
  – All above with confinement pressure 5000psi
• Penetration results plotted against $F_{BI}$ and regressions performed to established new $D_{P_{ref}}$ and $\alpha$. These new parameters are now being used in the perforating software.
Charge-A Result
Charge-B Result

![Graph showing the relationship between Dop (inches) and Fbi (psi) with three lines representing New, Old, and Delta.](image-url)
Summary

- Charge-A delta penetration from -0.25 to 0.75 inch
- Charge-B delta penetration from 1.5 to 2.2 inch
- Charge-A and B are now fully characterized delivering additional simulation confidence for both charges.
- Other approximated characterized charges expected not to be far off reality.