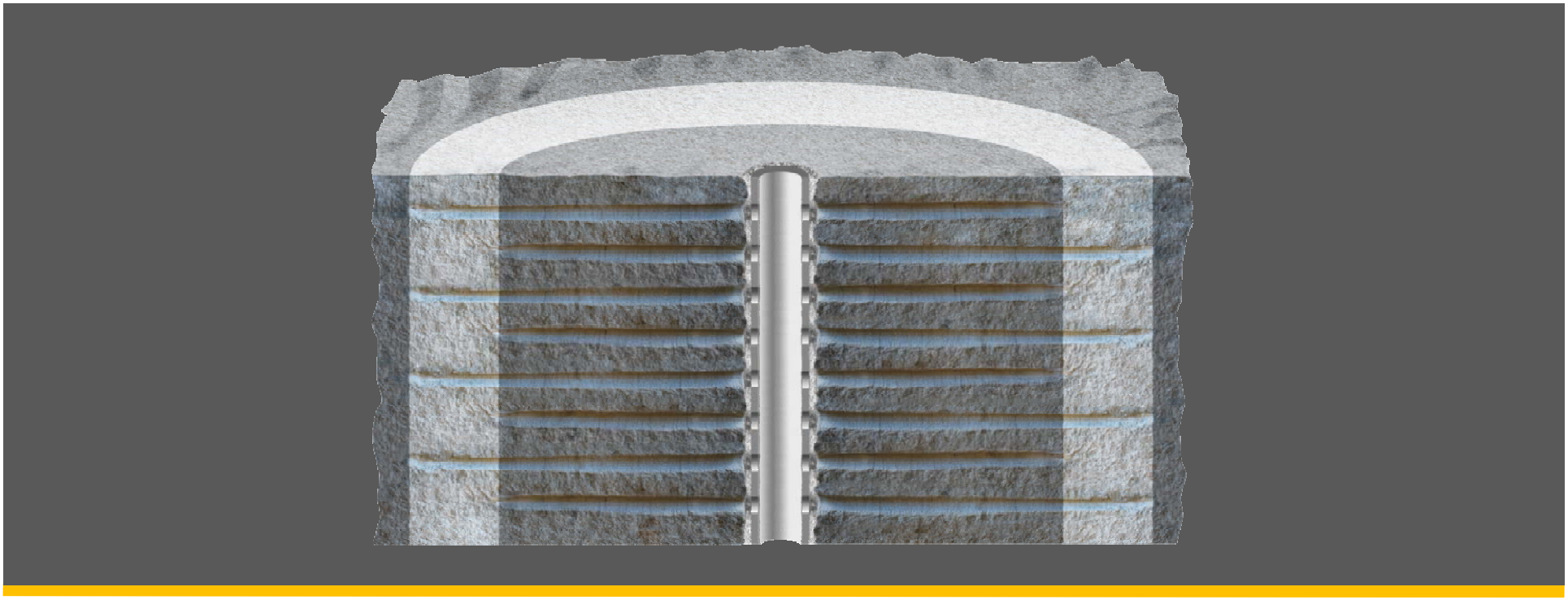


MENAPS-11-12

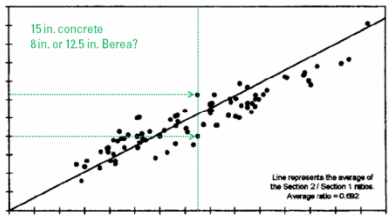
A New Direction for Predicting Perforating Gun Performance

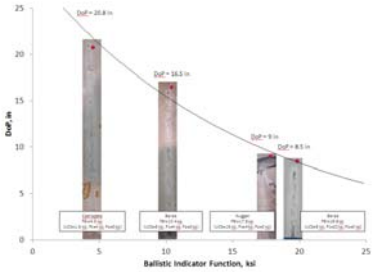
Andy Martin, Brenden Grove, Jeremy Harvey, Lang Zhan,
David Atwood

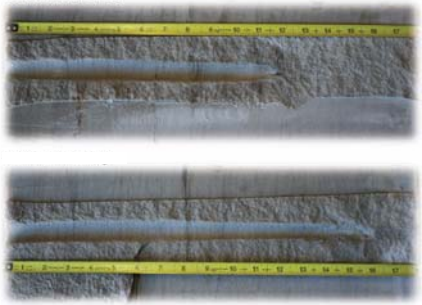
Schlumberger

A New Direction for Predicting Perforating Gun Performance

- Why Perforate?
- Penetration Research
- Penetration Model
- Software





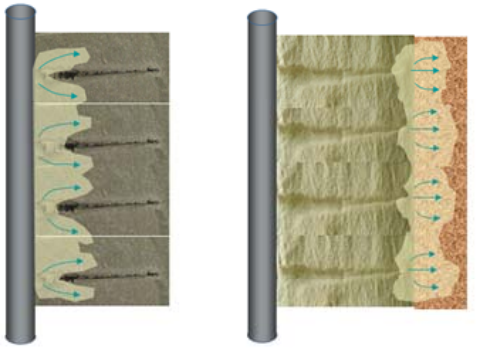


Why Perforate?

- Perforating is a fundamental part of any well completion
- It provides the connection between wellbore and virgin reservoir rock
- It provides the conduit for processes such as hydraulic fracturing or acid stimulation
- The success of a gravel pack completion strongly depends on perforating parameters

Perforating Connects Wellbore to Virgin Reservoir

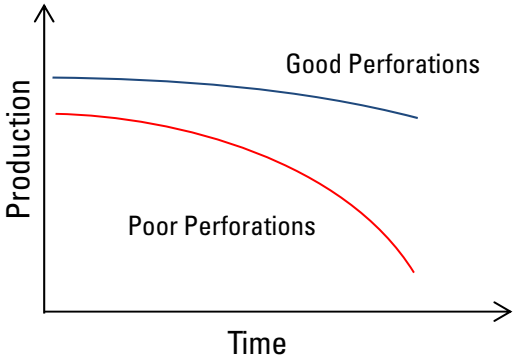
Matrix Acid Treatment



Bad Perforations vs Good Perforations

Additional Benefits of Good Perforating Practices

- Operational efficiency improves such as reduced cleanup periods during a well test or reduced N_2 or completion fluid requirements to fire guns
- Deep, clean perforations prolong the life of a well by reducing near-wellbore pressure drop
- High pressure drop leads to many well problems: scale and aspheltene buildup, fines migration or condensate banking, water coning or production below bubble point

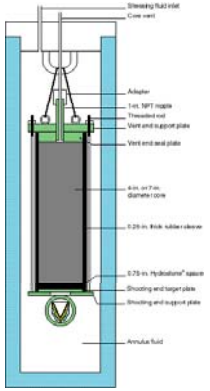


Modeling A Perforated Completion – 4 Stages

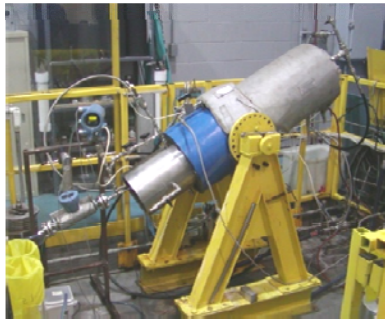
- Stage 1: Gathering Data
- Stage 2: Perforation Tunnel Geometry Estimation
- Stage 3: Perforation Tunnel Condition
- Stage 4: Inflow Performance Estimation

How Do We Choose the Best?

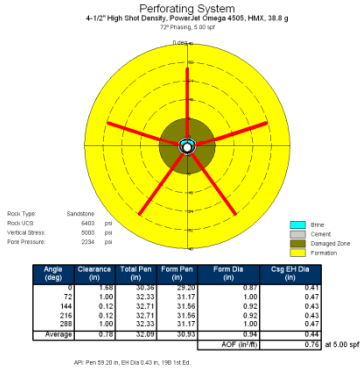
- Section 2 Penetration Tests in Stressed Rock



- Section 4 Flow Efficiency Tests in Stressed Rock



- A Model



Angle (deg)	Clearance (in)	Total Pen (in)	Form Pen (in)	Form Dia (in)	Csg EH Dia (in)
0	1.00	30.95	29.91	0.87	0.41
72	1.00	32.33	31.17	1.00	0.47
144	0.12	32.71	31.56	0.92	0.43
216	0.12	32.71	31.56	0.92	0.43
288	1.00	32.33	31.17	1.00	0.47
Average	0.78	32.09	30.93	0.94	0.44
				AOF (in²/ft)	0.76 at 5.00 spf

API Pen 59.20 in, EH Dia 0.43 in, 19B 1st Ed

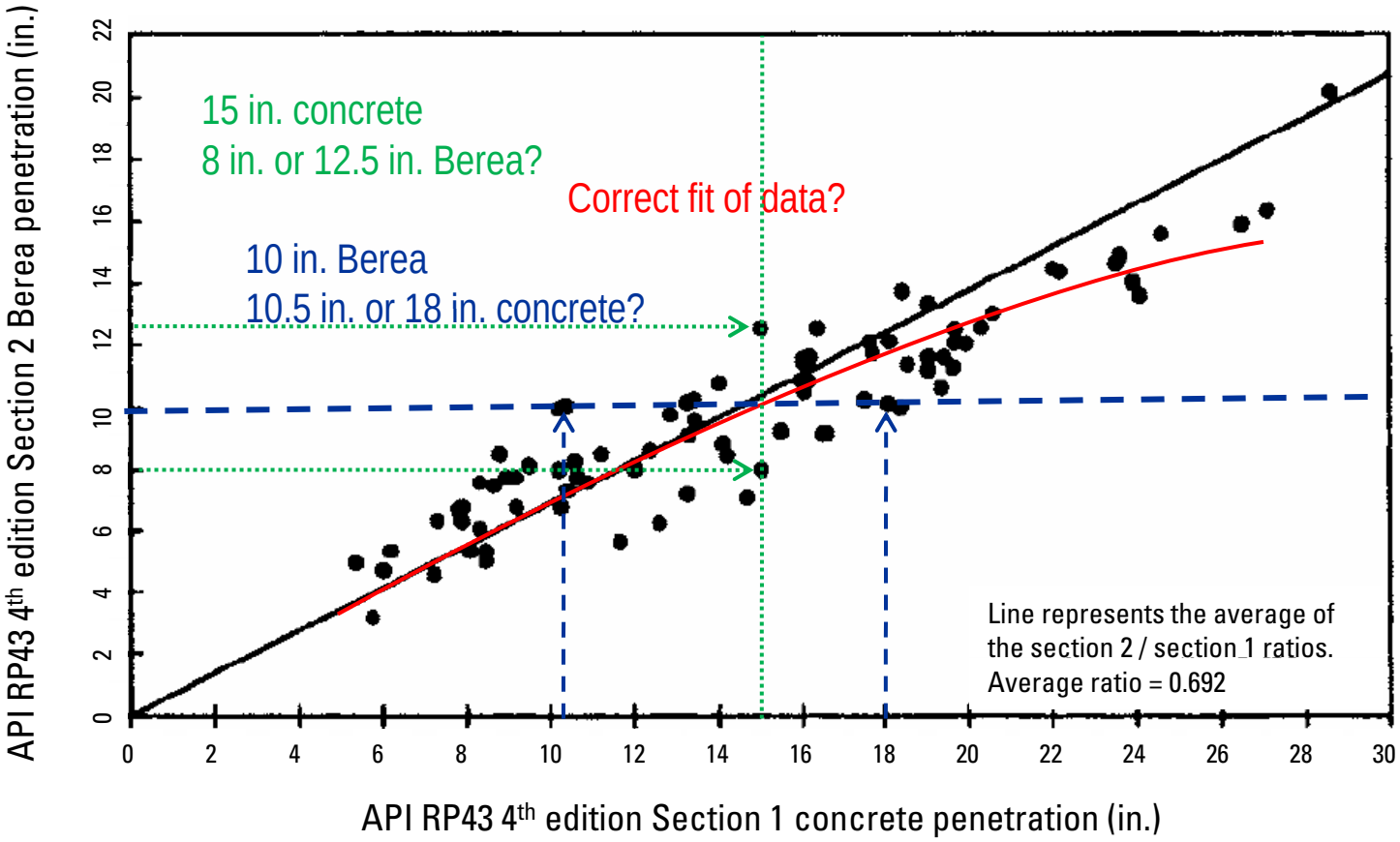
Some History

- Testing shaped charges in stressed rock is not new: it was started in the 1950's

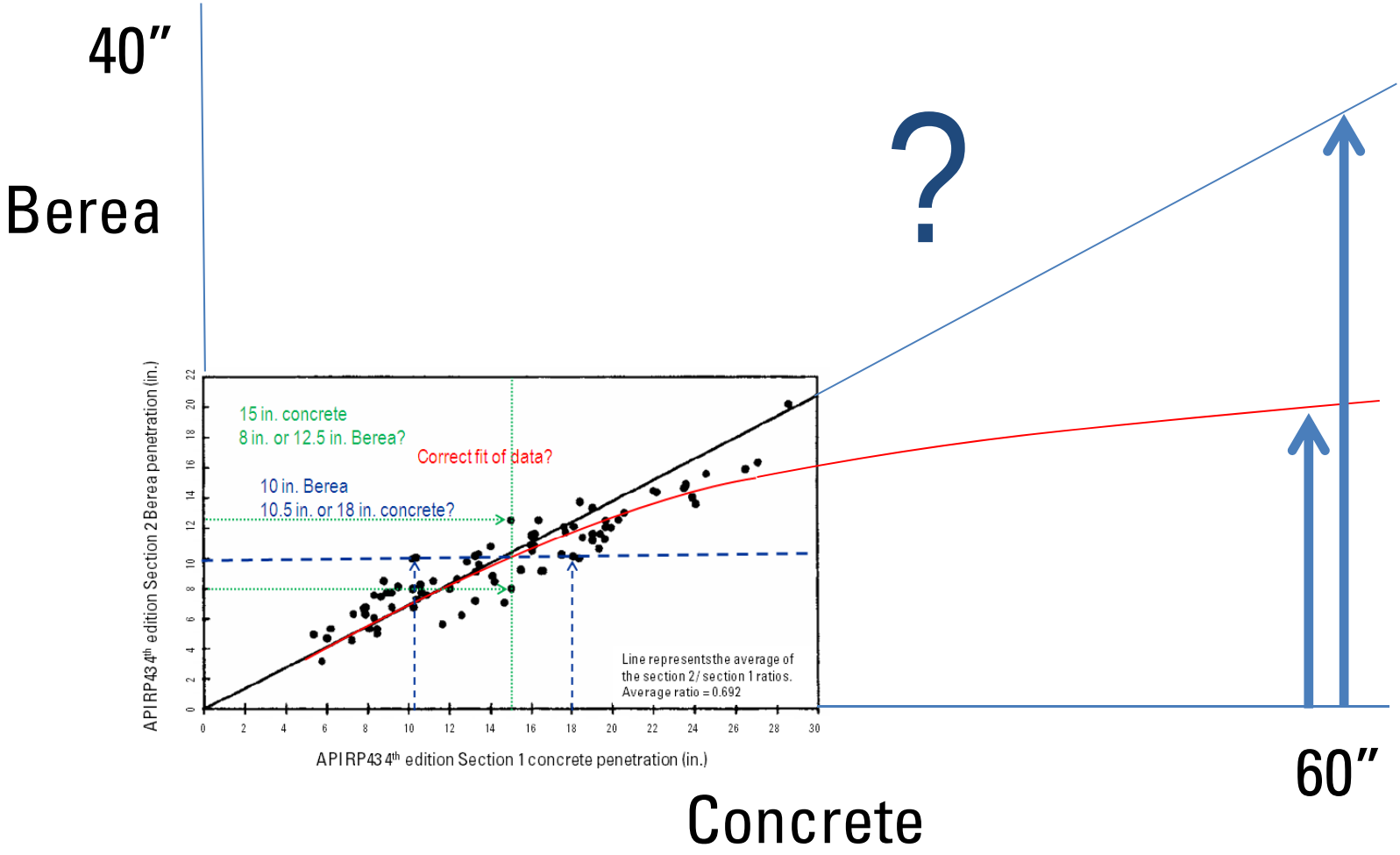
- We need to understand why the industry moved away from systematic testing
- The next few slides will explain

A Move Towards Concrete in 1994 - SPE 27424

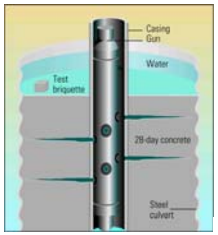
"Simple method predicts downhole shaped charge gun performance"



Modern Shaped Charges Shoot Much Deeper in Concrete

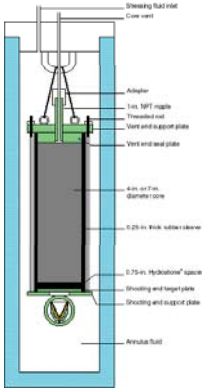


Typical Penetration Work Flow - SPE 125020

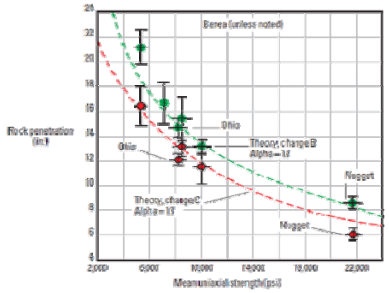


Section 1 concrete

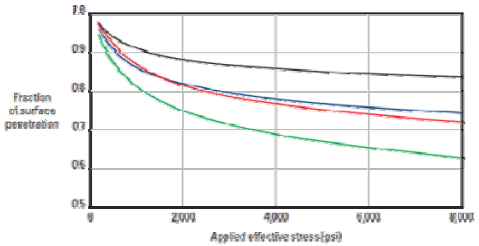
7000 psi Berea



Other rocks
(Thompson, Weeks, etc)

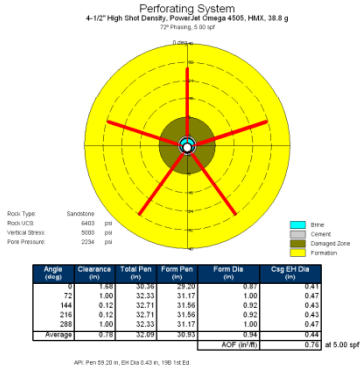


Effective stress
(Saucier, Weeks, Behrmann), etc



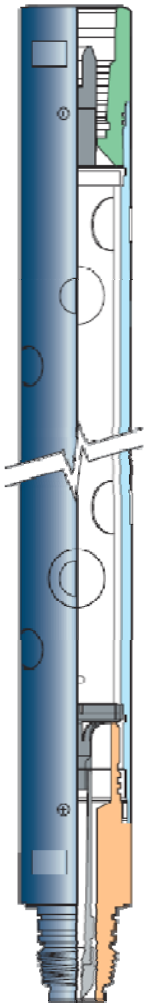
Casing, Fluid
(Saucier, Regalbutto, etc)

Model Output
(Current Industry Models)

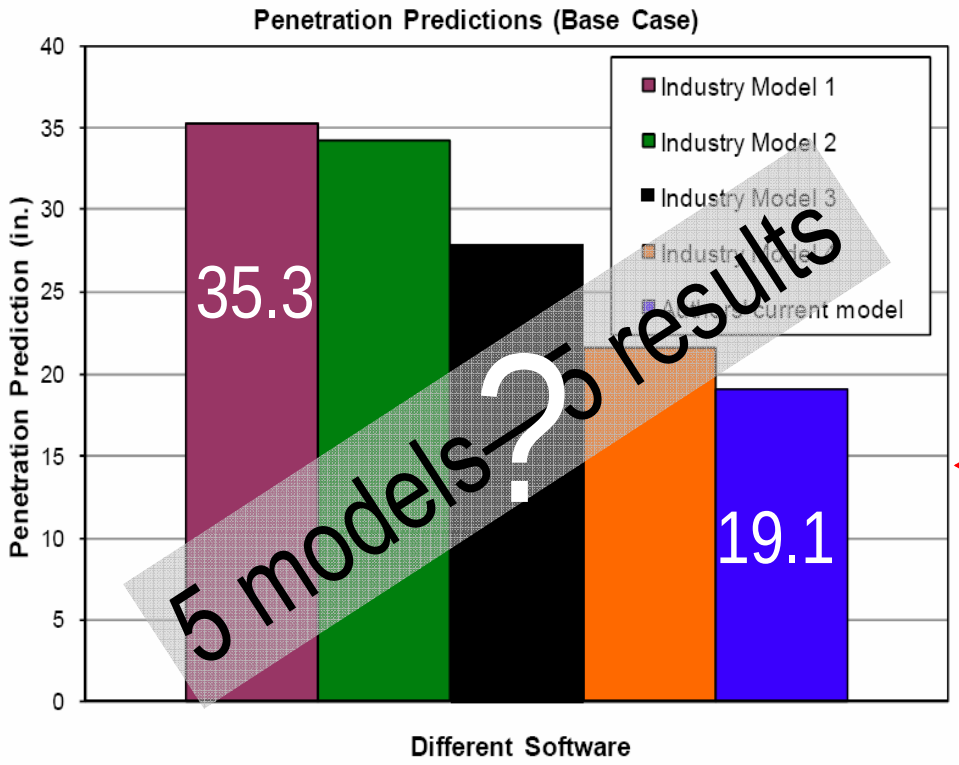


Base case test of models - SPE 125020

- 3 3/8-in. gun
- 41.4 in. API concrete penetration
- Sandstone formation, 6000 psi UCS
- 3500 psi reservoir pressure
- 5000 psi overburden



Penetration Results - SPE 125020



Actually
14.4

Penetration Model - Research

1950's

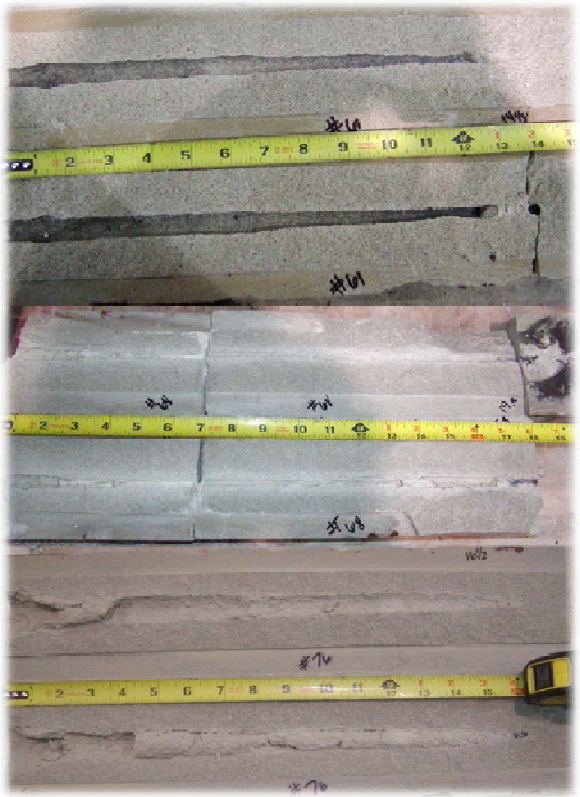
- More than 50 years
- New facility opened 2004
- Accelerated testing started 2007
- Over 1000 tests conducted in stressed rock
- Most comprehensive study ever

Today

New Penetration Model - SPE 127920

Properties of Sandstones Used in This Study

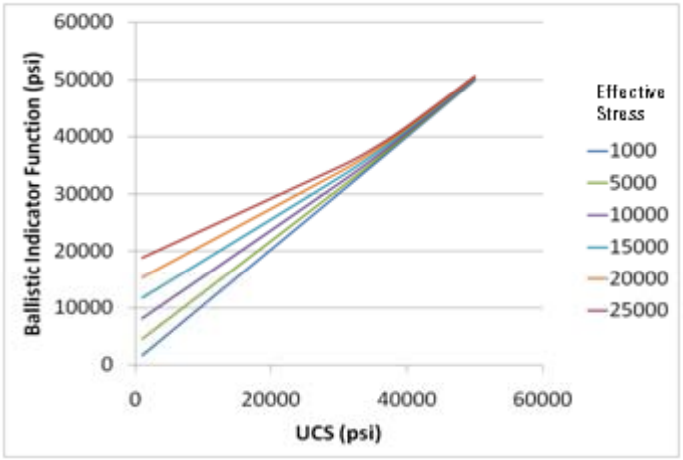
Rock Type	UCS (psi)	Porosity (%)
Castlegate	1,060 to 2,100	27 to 29.2
Berea Buff	3,800	21.6
Berea Gray	5,870 to 9,310	19 to 21
Torrey Buff	5,000 to 11,000	13 to 16
Nugget	16,000 to 18,500	9.4 to 10.6
Crab Orchard	20,000 to 30,000	6.6 to 8.7



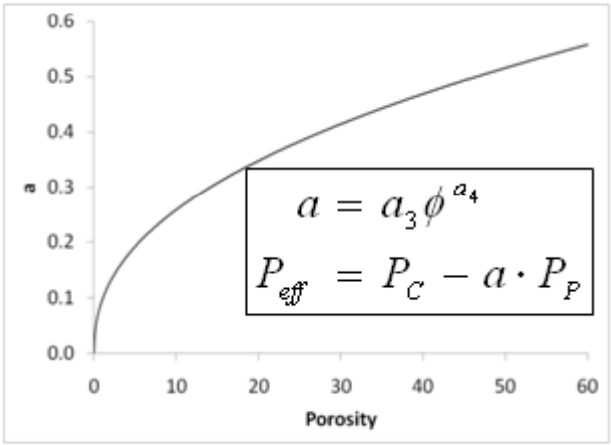
- Weak to strong rocks tested
- Largest ever range of stresses:
  1000 to 20,000 psi (~70 to 1,400 bar)
- Different families of charges used
- First tests of capsule charges
- Range of rock types

Apparent Target Strength: Ballistic Indicator Function

- Rock target can be characterized by a single function
- F_{bi} combines UCS, porosity and stress
- Stress is a function of overburden stress, pore pressure and a ballistic pore pressure coefficient (SPE 111778)
- Pore pressure has less influence in low porosity
- High UCS rocks have less dependence on stress



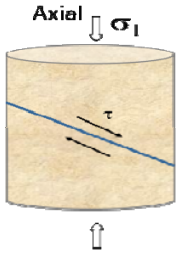
$$F_{BI} = UCS + F_1 P_{eff}$$



$$a = a_3 \phi^{a_4}$$

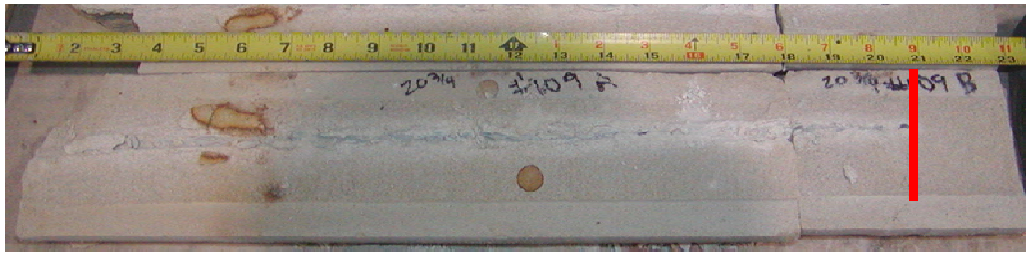
$$P_{eff} = P_C - a \cdot P_P$$

Penetration Trend for Different Strength Rocks



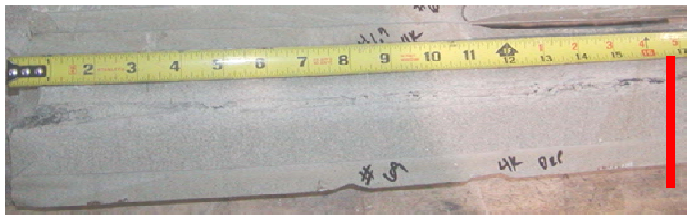
Increased rock UCS → reduced Depth of Penetration

UCS~1,600 psi



20.8 in

UCS~8,000 psi



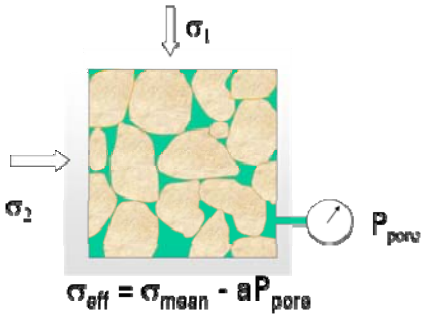
16.5 in

UCS~16,000 psi

9 in

Same effective stress for all shots (4,000psi)

Penetration Trend for Different Stresses



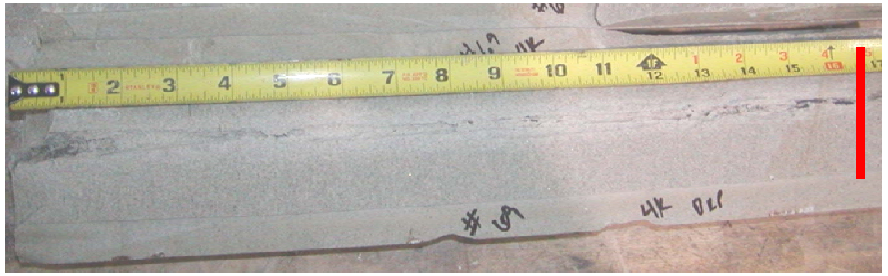
Increased effective stress → reduced Depth of Penetration

Effective Stress = 20,000 psi

8.5 in

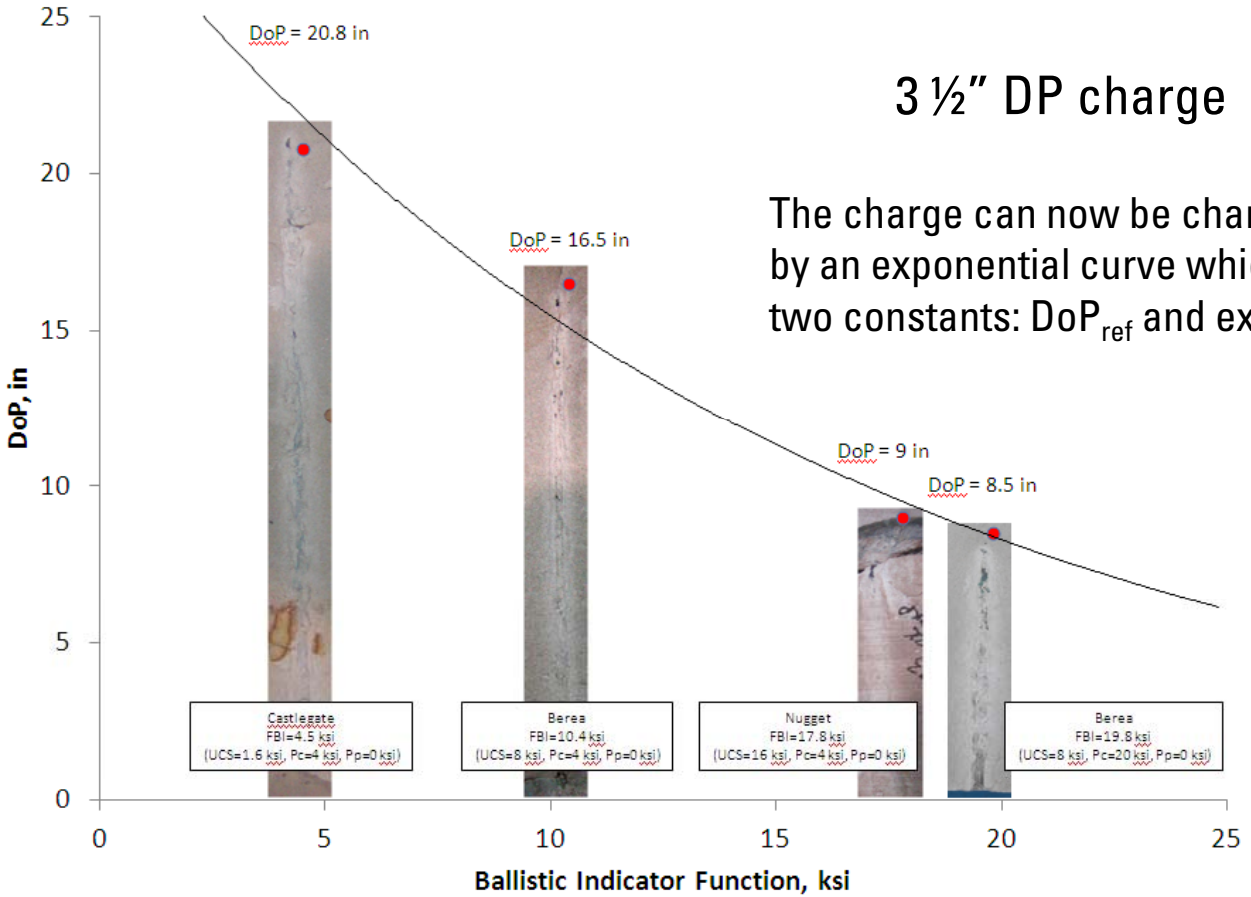
Same <u>UCS</u> for both shots (8,000psi)

Effective Stress = 4,000 psi



16.5 in

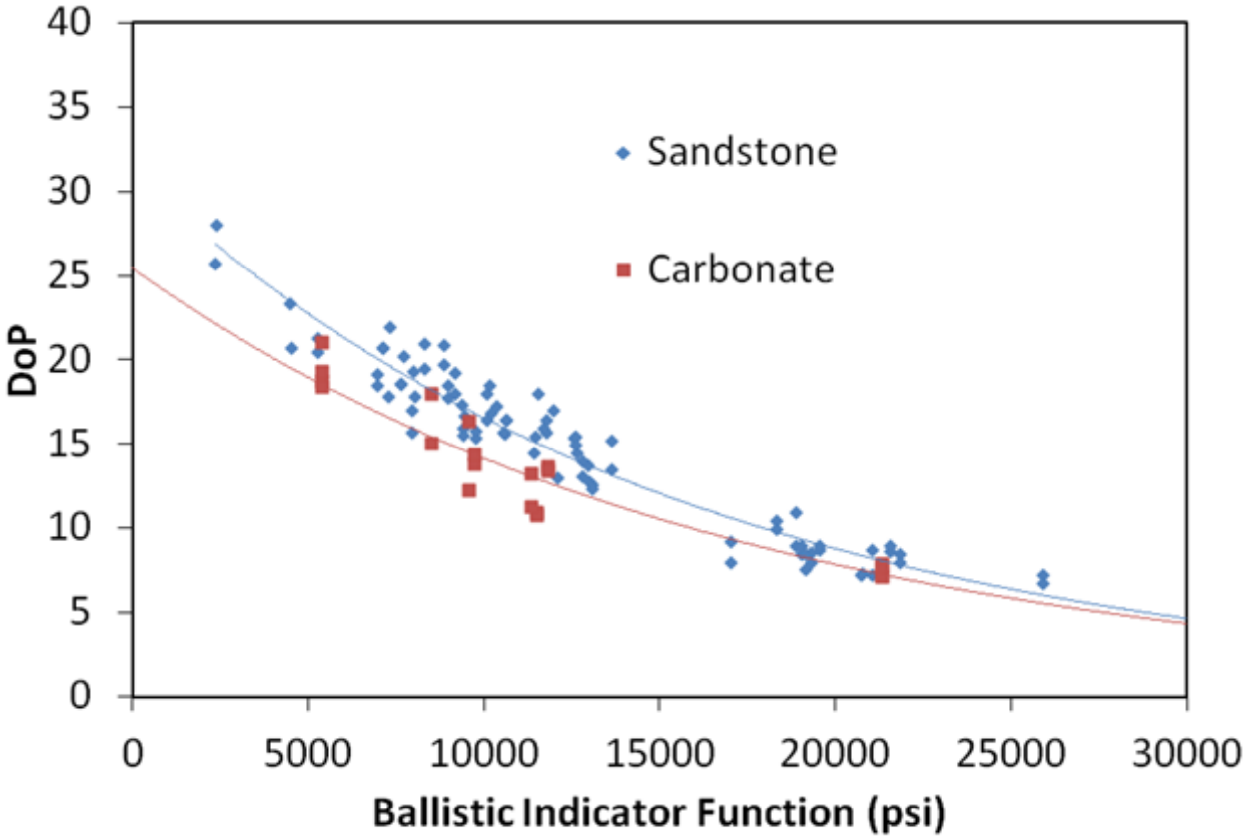
Characteristic Penetration of a Shaped Charge



3 ½" DP charge

The charge can now be characterized by an exponential curve which uses two constants: DoP_{ref} and exponent α

Sandstone vs Carbonates



- Austin Chalk: 3000 psi, UCS
- Indiana Limestone: 7600 psi, UCS
- Carthage Marble: 20,000 psi, UCS

- Similar function with different coefficients

New penetration work flow - SPE 127920

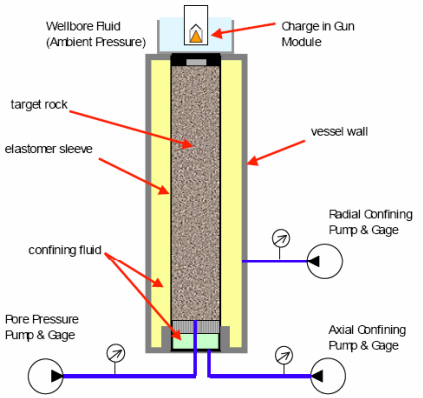
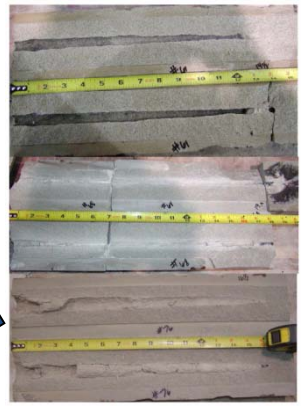


Fig. 9. Pressure vessel schematic

New section 2 rock test

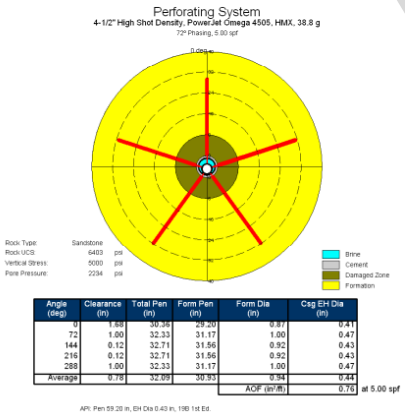
3 rock/stress ns
(Ballistic , F_{RI})

Direct link to rock



Characterize charge
(Harvey et al)

New Model



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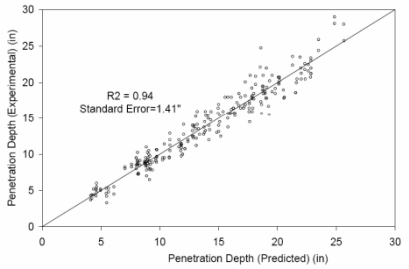
288	1.00	32.33	31.17	1.00	0.47
Average	0.76	32.59	30.93	0.94	0.44
				AOF (in²/ft)	0.76

at 5.00 spf

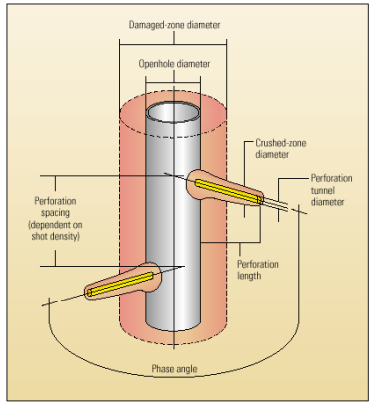
API: Pen 59.26 in, EH Dia 0.43 in, 19B 1st Ed.

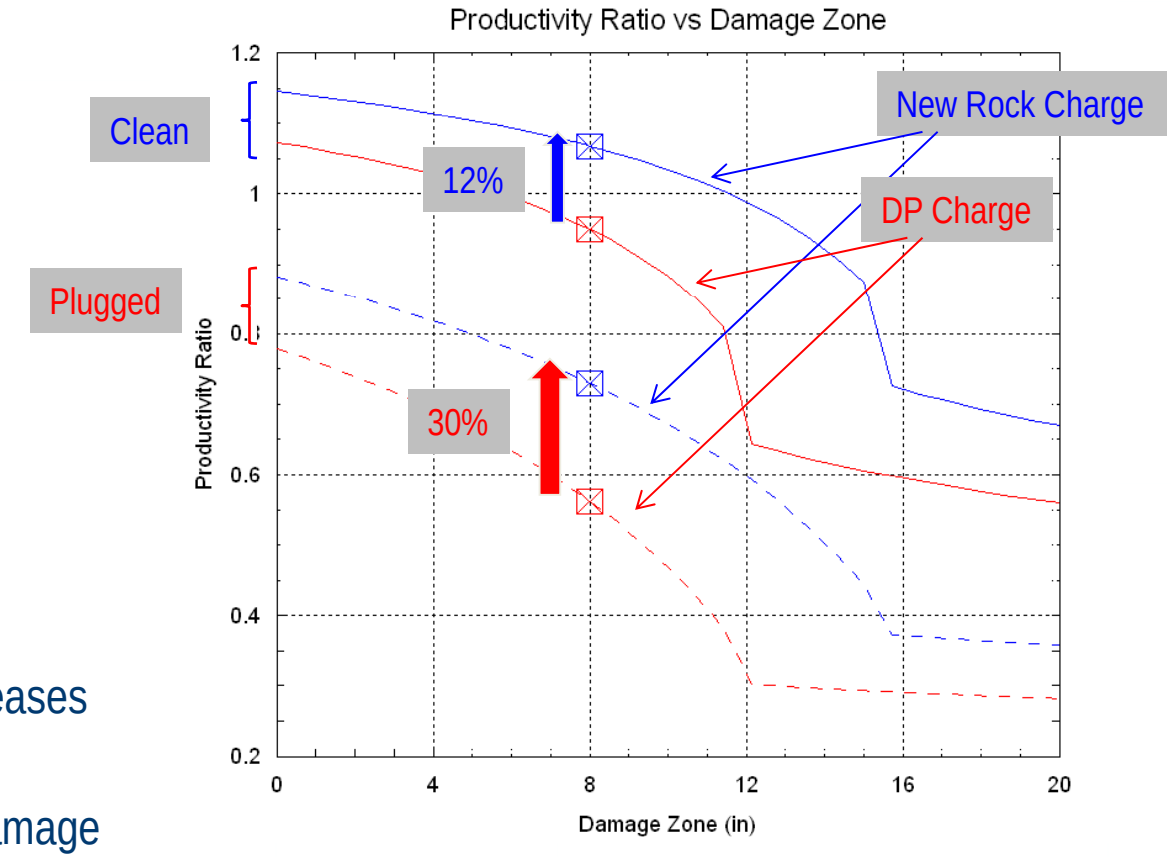
Casing, Fluid
(Saucier, Regalbutto, etc)



New penetration model
(Harvey et al)

Productivity from New Perforation Model





- Karakas & Tariq model
- Kc/K = 0.8, 0.1
- 8 in. of damage
- Additional penetration increases effective wellbore radius
- More important for deep damage
- More important for dirty perforations
- Perfect combination is deepest penetration and clean tunnels

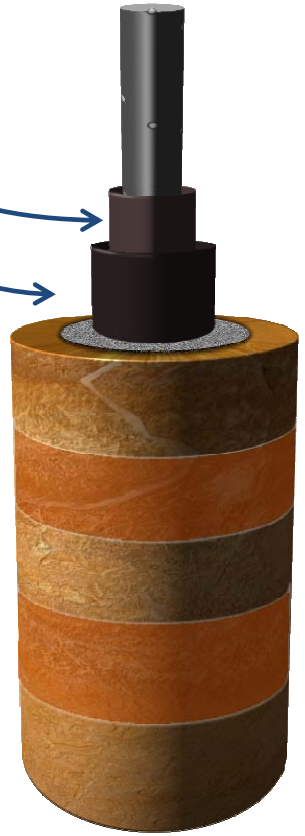
Productivity from New Software

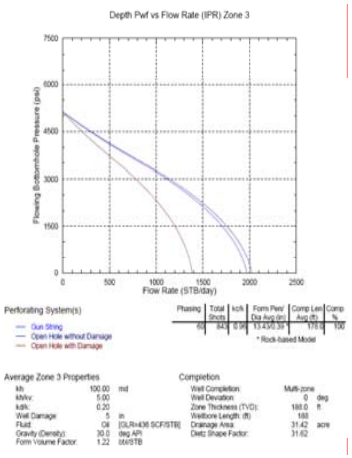
Multiple Gun Strings

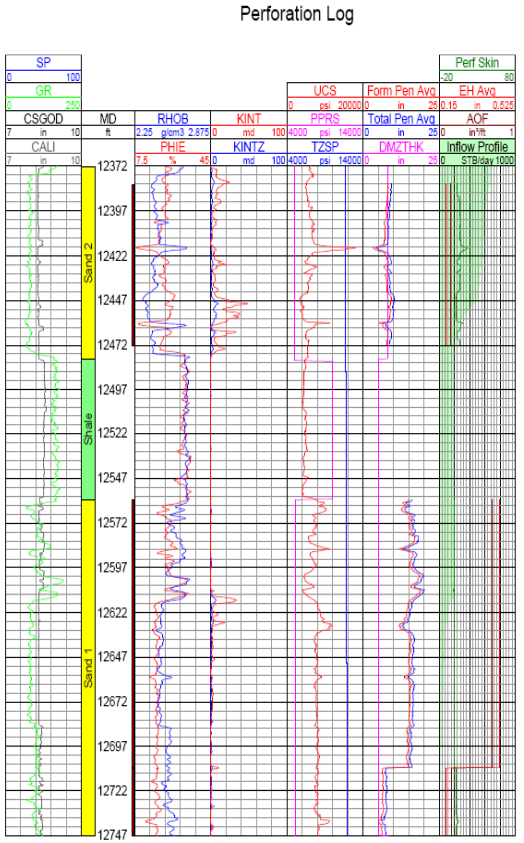
$$DoP = DoP_{ref} e^{\alpha_0 (F_{bi,ref} - F_{bi})}$$

Multiple Casing Analysis

Multiple Zone Analysis



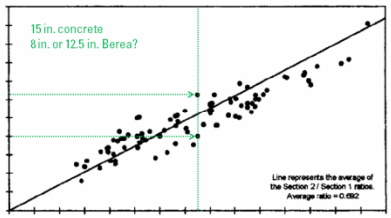
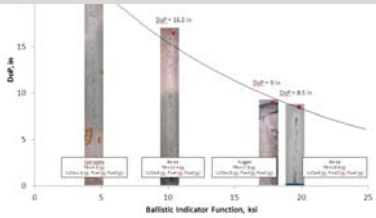
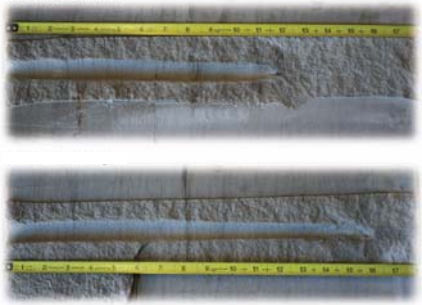




Summary

- Concrete penetration should not be used to predict perforation tunnel geometry (penetration) in stressed rocks
- Shaped charges should be characterised in stressed rock
- We propose a new section 2 test program
- Our current perforation analysis software includes our rock model

A New Direction for Predicting Perforating Gun Performance

- Why Perforate?
- Penetration Research
- Penetration Model
- Software

Questions ?