Penetration of Rigid Projectiles in Sand

presented by

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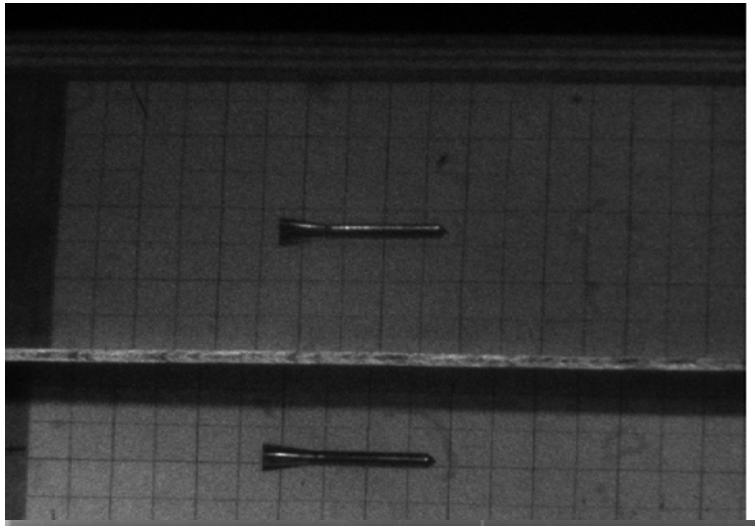
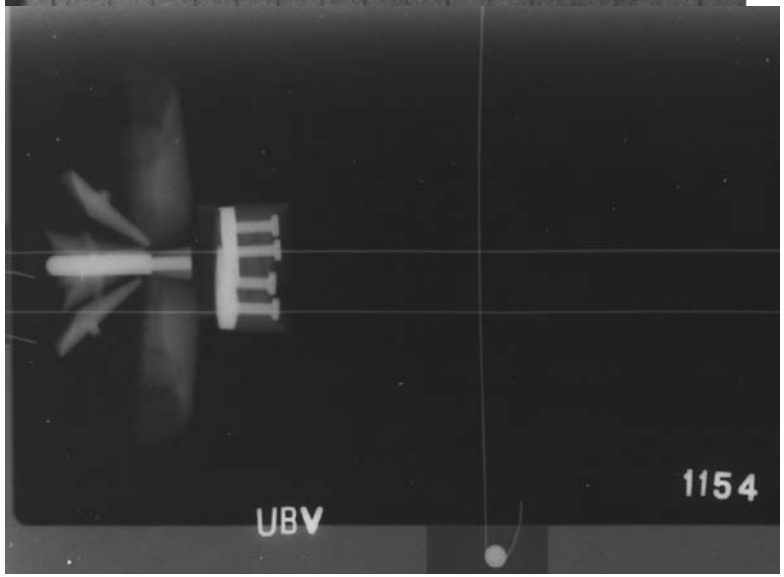
Three shape projectiles and two sands

Investigator	Projectile	Sand	Notes
IAT	Steel and W L/D=10 hemi nose	Ottawa	Stablized Horizontal
OU	Steel L/D=2 flat	Eglin	Vertical
AFRL	Steel L/D=5 hemi	Eglin	Horizontal
IAT	Steel .50 bullet	Ottawa	Horizontal

Sand density was “as poured”.
Projectile diameters: OU-26, AFRL-20, IAT-5 or 7.5 mm

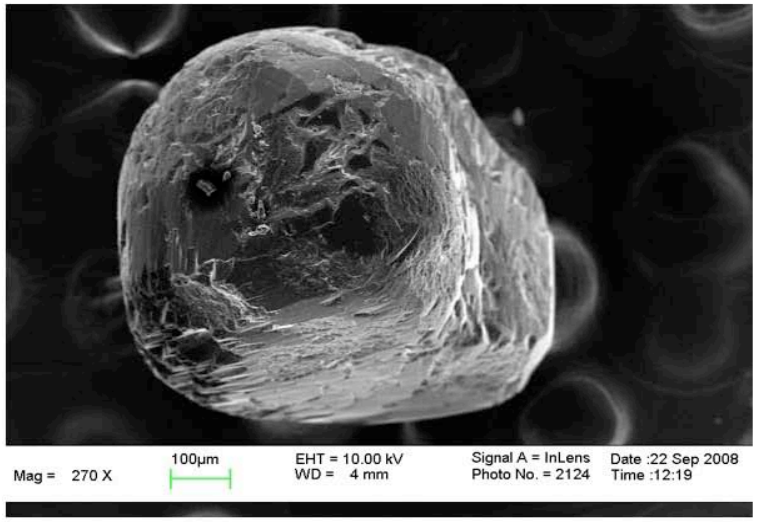
IAT projectiles were stabilized rods

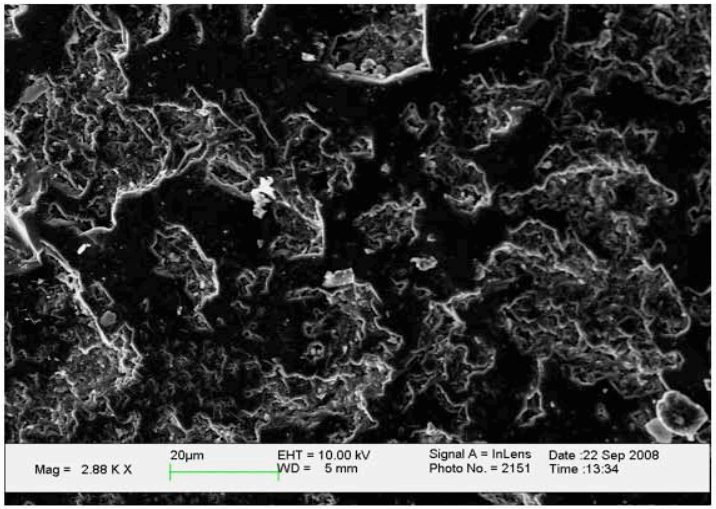




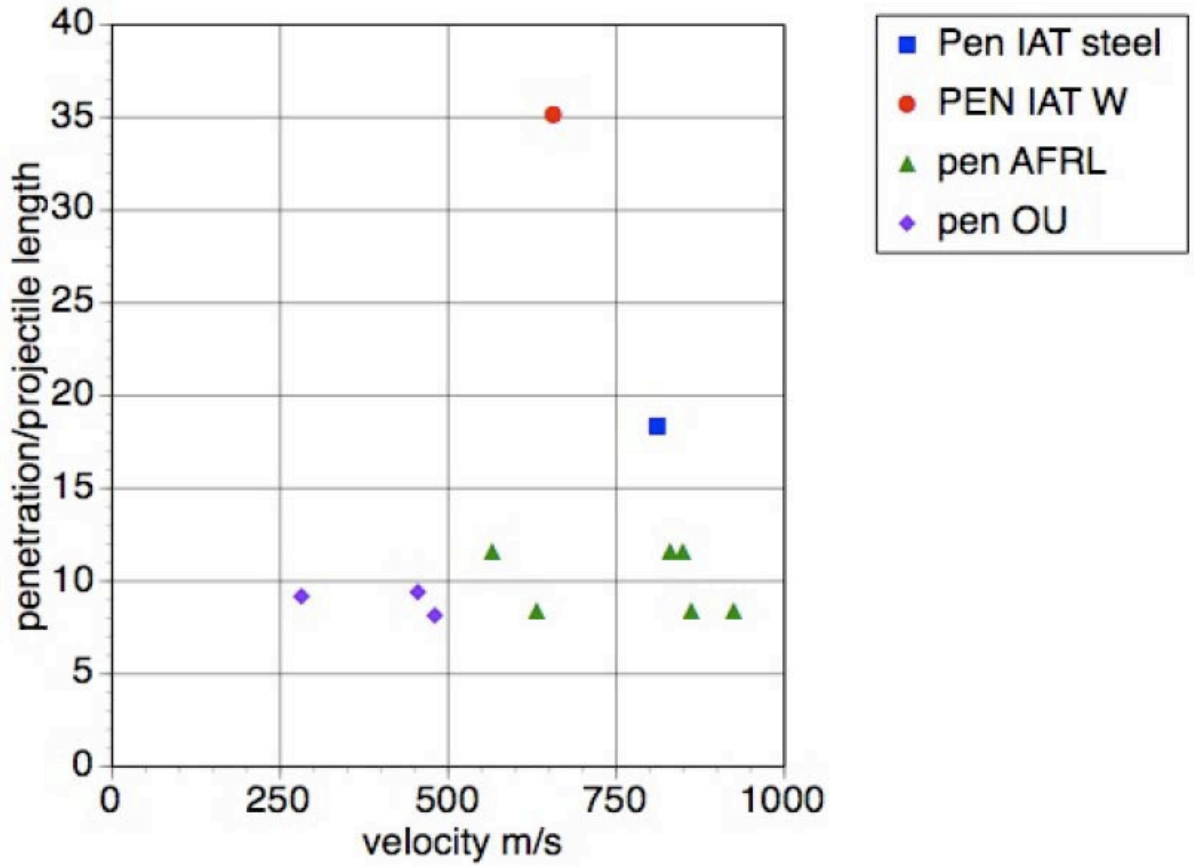
50 mm long, 15 g mass
These projectiles stayed rigid up to about 700 m/s.

Penetration in stand leaves trail of fractured grains



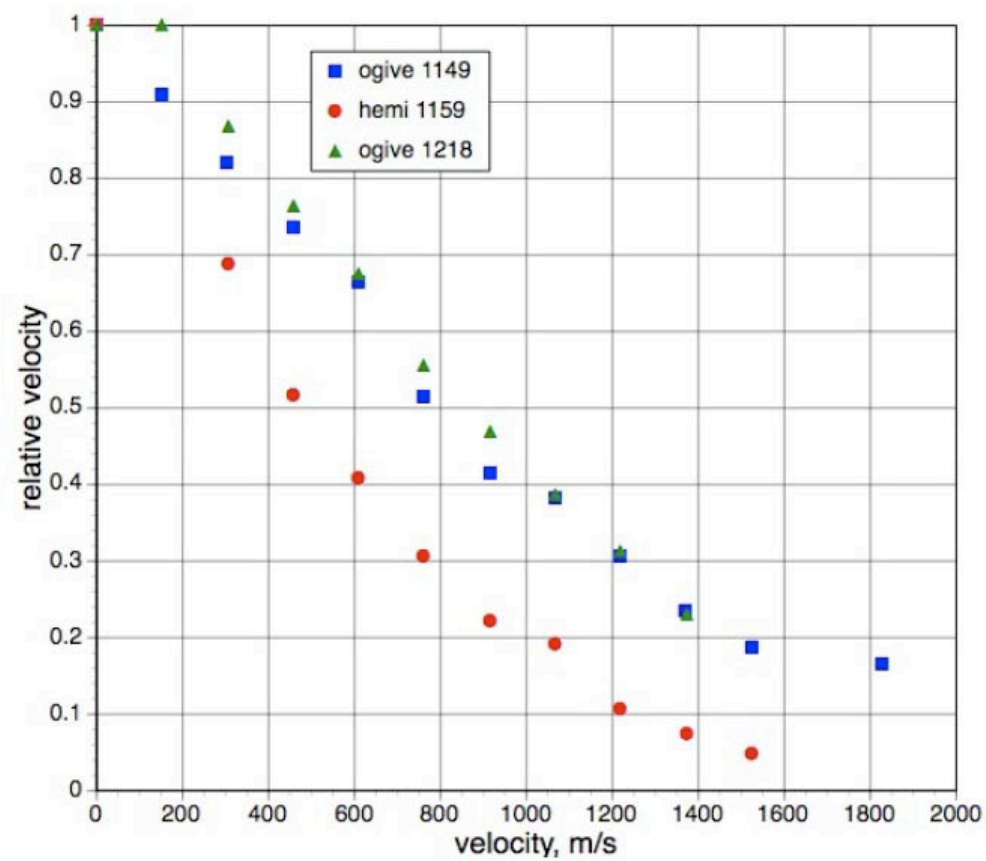


Some trends seen in data



Penetration scales as sectional density.
The angular Eglin sand is harder to penetrate than Ottowa sand.
Penetration is only weakly dependent on velocity.

Final stage of penetration takes place at relatively low velocities.



This implies that there is a lot of penetration at very low speed. Measuring penetration depth is probably not a very good way to characterize projectile performance.

Projectile motion described by Poncelet Equation

$$M\frac{dV}{dt} = -(\rho_s C_p A V^2 + R)$$

Poncelet

$$x = \frac{M}{\rho C A}\left[\ell n\left(1 + \frac{V_0 \rho C_p A}{M}\right)t\right].$$

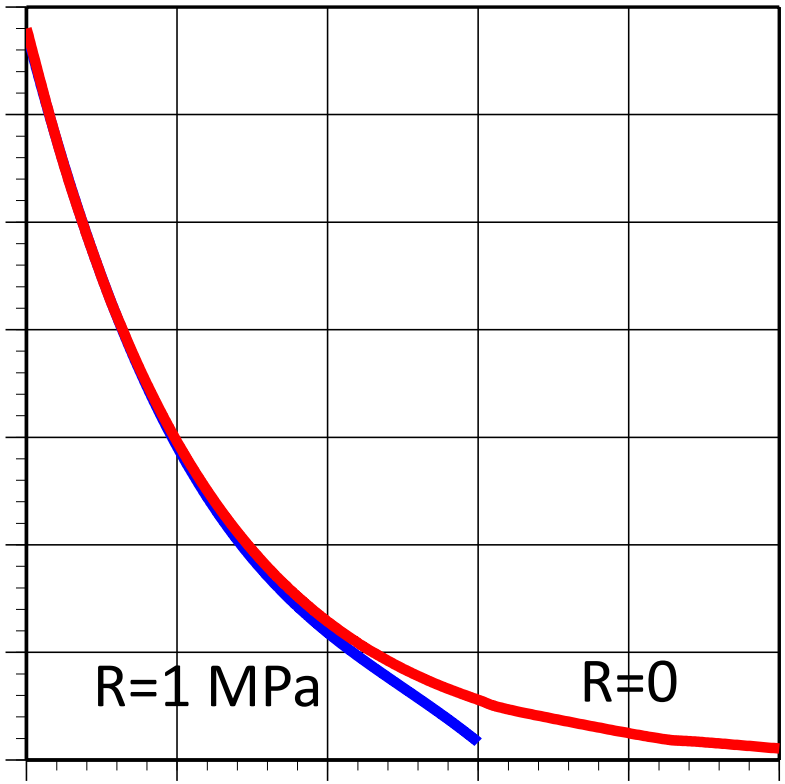
R=0 is purely drag. Then penetration is infinite.

$$x = \frac{1}{k} ln\left[\frac{V_0^2 + \frac{R}{\rho C_p}}{u^2 + \frac{R}{\rho C_p}}\right],$$

$K = 2\rho C_p/\rho_p L$

Penetration prediction

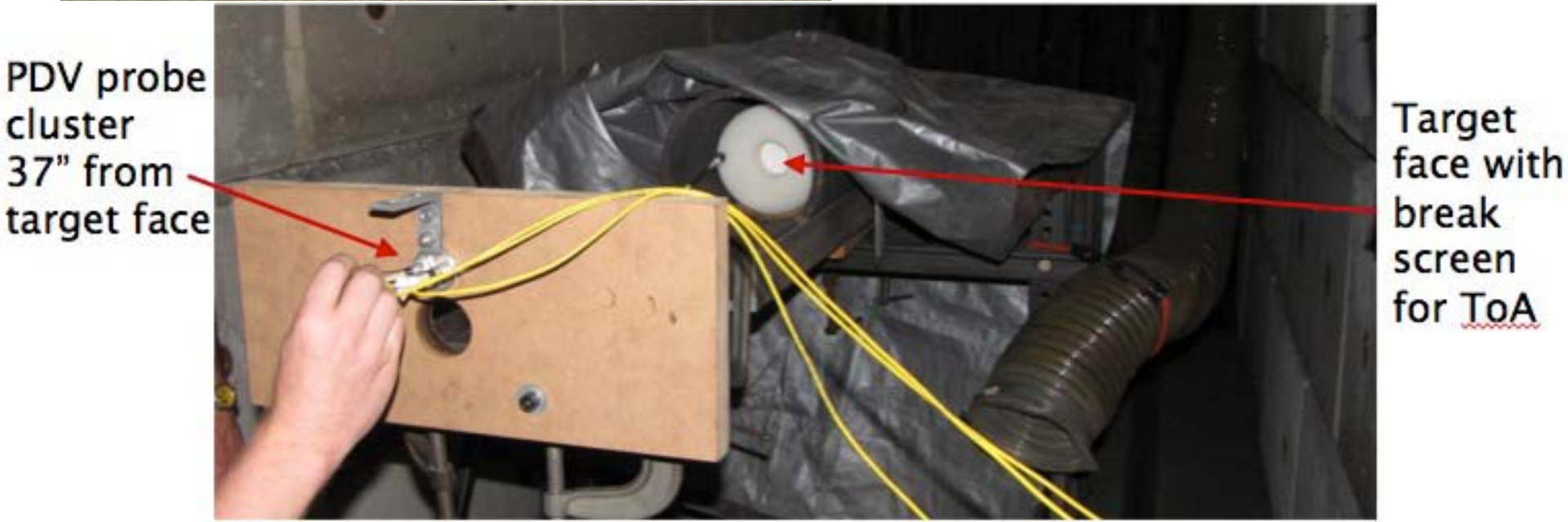
Effect of static strength



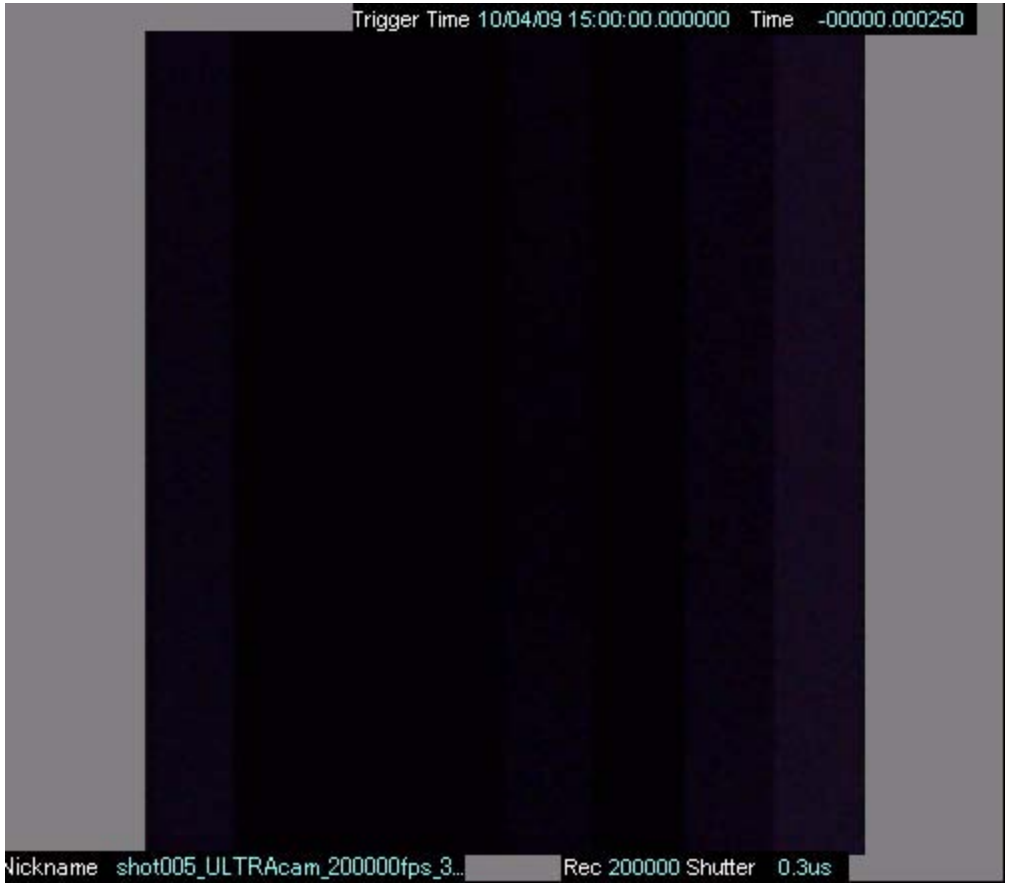
Final depth of penetration very sensitive to ill-defined static strength of sand.

More precise measurements of C

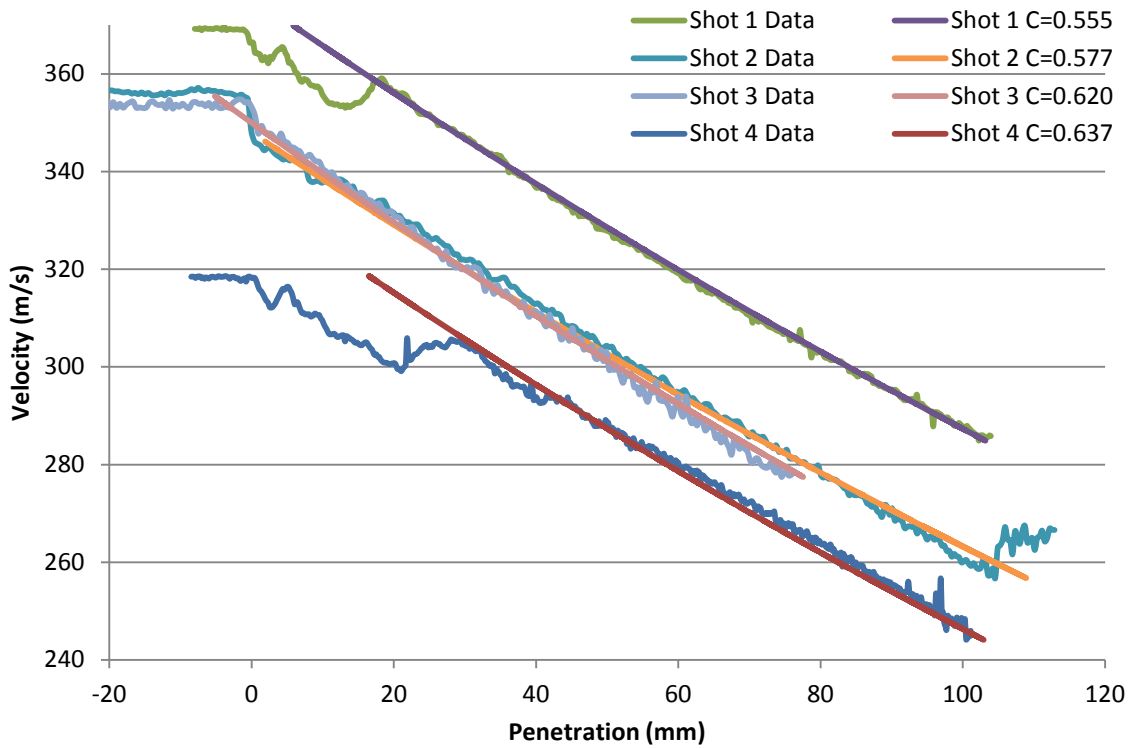
A PDV was used to observe the back of .50 bullets as the embedded into sand targets.



This was inspired by experiments from OU group.

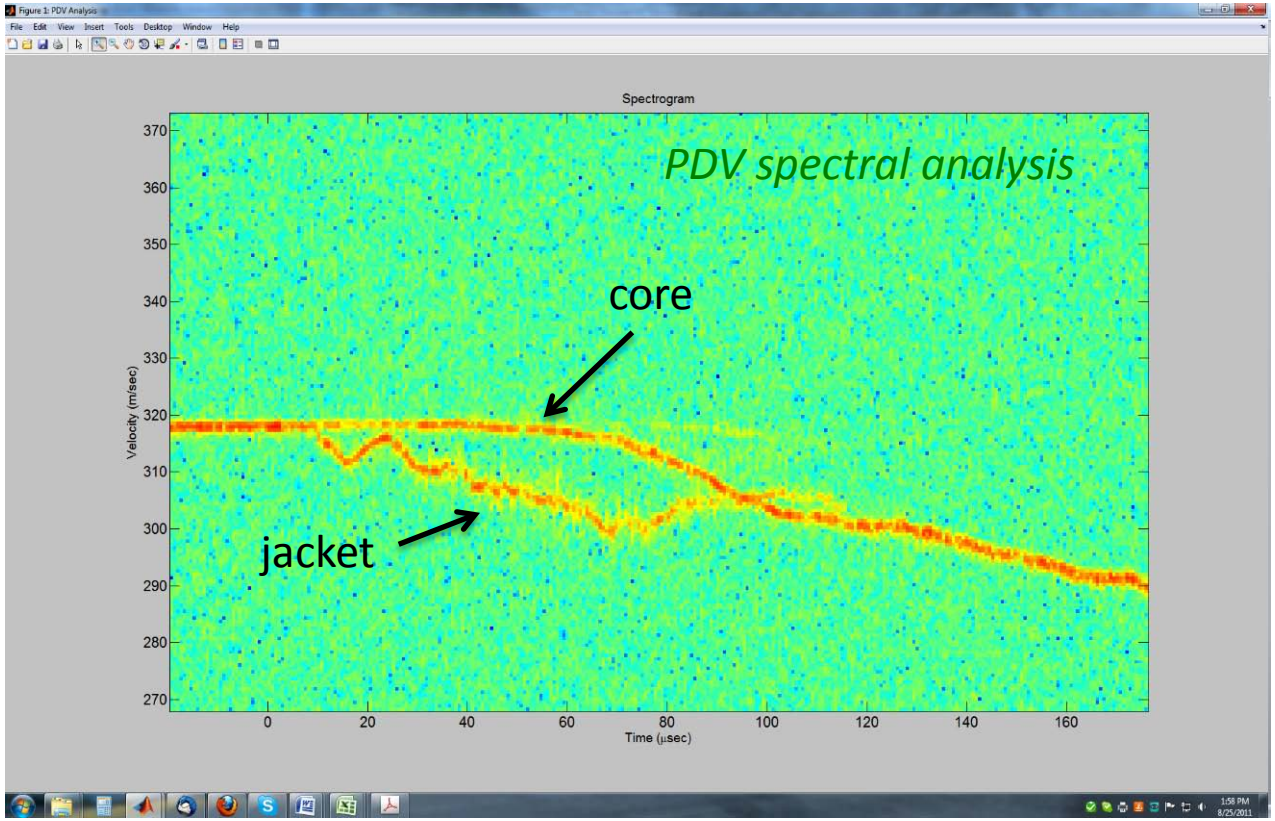


Deceleration of .50 ogive



Four shots. Projectile could be followed for 100mm! Deceleration nearly constant. Data are fit to V^2 force law. This defines the "effective drag", C'. We find C' is about 0.6 and decreases slightly with velocity.

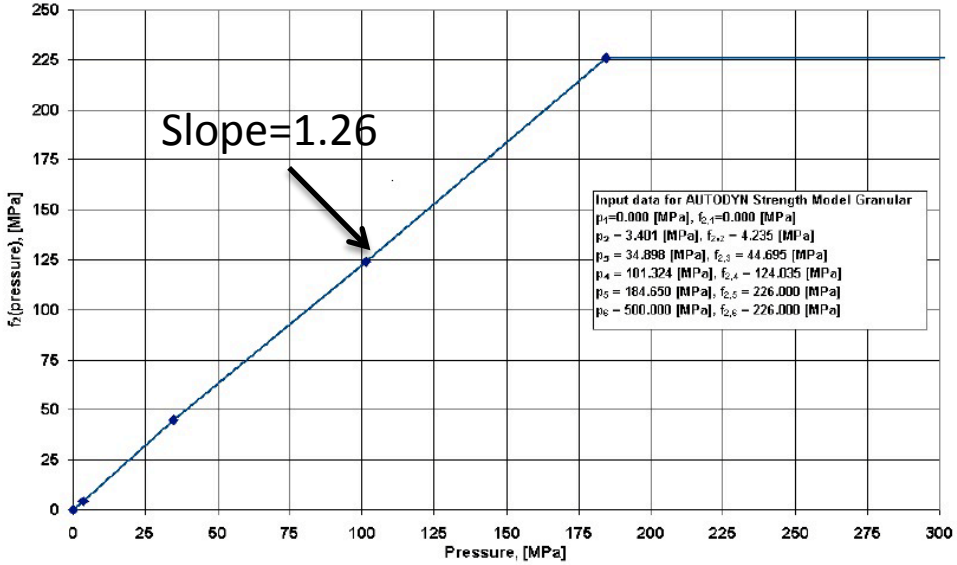
The initial transient is due to jacket setback



The PDV separately tracks distinct velocities. This slippage integrates to exactly the observed value of about 1 mm. (The data processing algorithm picks the brighter branch.)

Role of strength of sand

- Sand is usually modeled with strength proportional to pressure. E.g. Laine and Sandvik:



- If we take $R \approx Y = \alpha P$, and $P = \frac{1}{2}\rho_s V^{2,}$ then the effective value of C, C', is given by

$$C' = C_P + \alpha/2$$

since the peak stress at our velocity is below the 177 MPa cap.

Effective drag C' has two sources

- C_p is assumed due soley to KE delivered to sand. Our projectile is similar to a 1:3 cone. If V = velocity of projectile, the sand moves laterally with velocity u = V/3.

- In time Δt, the loss of energy of the projectile is $\rho_p LV(dV/dt)\Delta t$. The gain of energy of the sand is $\frac{1}{2}\rho_s V\Delta t u^2 = (1/18)\rho_s V^3\Delta t$. This implies

$$dV/dt = -(1/18)(\rho_s/\rho_p)V^2/L$$

The Poncelet solution (for R=0) is $dV/dt =- C_p(\rho_s/\rho_p)V^2/L$

Hence C_p=1/18 for a 1:3 nose.

Caveats in the analysis on this and previous slide:

We do not know the "wetted area"

We do not know alpha for dynamic compression of Ottawa sand

The impacts are transonic in thesdand.

Importance of strength

- From Laine and Sandvick, $\alpha = 1.26$.
- Thus, the dynamic strength alone gives $C' = 0.63$.
- Combined C' should be about 0.68.
- Indeed this is very close to the observed value.
- The implication is that most of the penetration resistance of sand is due to Mohr-Coulomb strength, e.g. friction.

Conclusions

- Penetration depends on sand type, sand density, and projectile density.
- The more angular Eglin sand is harder to penetrate.
- The penetration resistance of sand is to a good approximation proportion to velocity squared.
- Most of the resistance of sand is due to friction.
- For a given type of sand, total penetration depends little on velocity.

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