LOADING MECHANISMS from SHALLOW BURIED EXPLOSIVES

Leslie C. Taylor
William L. Fourney, Ulrich Leiste
Bryan Cheeseman

23 Sept 2008

Acknowledgements

Sponsor

TARDEC

Richard Goetz

David Fox

Team Members

Tim Hennessey	NSWC/IH
Sean Tidwell	NSWC/IH
William Szymczak	NRL
Andrew Wardlaw	ATR Inc.

U of MD Tasks

Using Small-Scale Tests

- Understand interaction between charge and target
- Support development of computational tools
- Explore technology and concepts to mitigate effect of flush & buried charges
- Explore scaling rules
- Measure pressure distribution over face of target as function of time
  - Develop total impulse data
  - Explore effect of target shape on loading
    - Non-deforming targets
      - Vees, pyramids,
      - Others
    - Deforming targets

Loading Mechanisms

Interaction Between Shallow Buried Charge & Target Takes Place in Near Field Of Explosion

- Details Are Important, e.g.:
  - Charge Shape & Detonator Location
  - Charge – Target Geometry
  - Local Soil Properties
    - Including Smoothness of Surface
  - Etc.

Test Charges

PENTOLITE CHARGES (H/D = ~3)

Provided by NSWC/IH

Pressed Pentolite

Explosive Mass: 0.8g 4.4g 8.0g

Detonator – Reynolds RP-87 (0.069g RDX & PETN)

PETN CHARGES (H/D=~3)

DETA Sheet – 63% PETN 37% Binder

Explosive Mass:	0.5g	0.636g	4.4g	8.0g
DETA Mass:	0.68g	0.90g	6.875g	12.59g

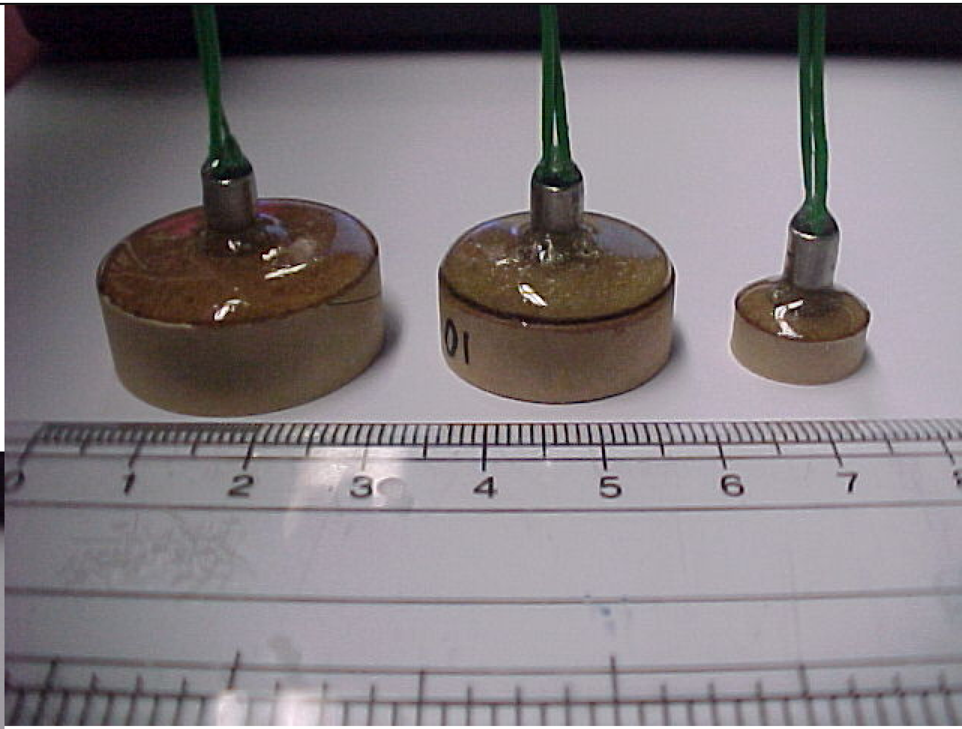
Detonator – Reynolds RP-87 (0.069g RDX & PETN)

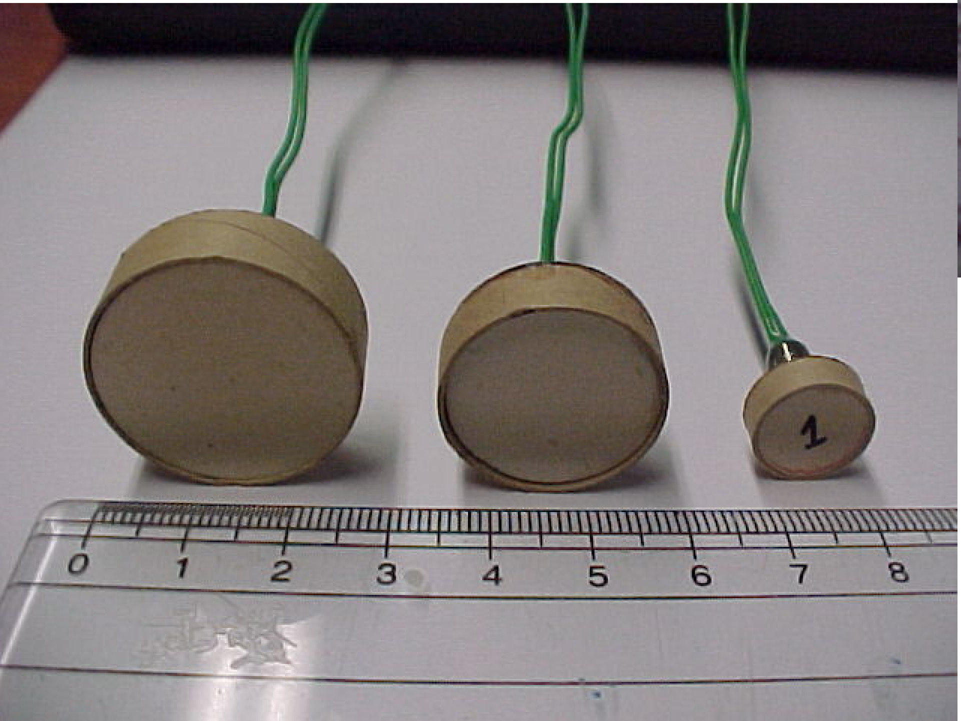
Explosive Mass Always Includes Detonator Explosive

Pentolite Charges

Charge size
(Wt includes RP-87 Det)

Wt.	D(mm)	H(mm)
0.8g	12.0	4.0
4.4g	21.8	7.3
8.0g	26.6	8.9





RP-87 contains .069g explosive

NAVSEA
INDIAN HEAD
Surface Warfare Center Division

DETASHEET Charges

Charge size
(Explosive Weight)
(Wt includes RP-87 Det)

Wt.	D(mm)	H(mm)
0.5g	12.0	2.7
2.5g	21.0	4.6
5.0g	26.0	5.8

Weight given above is weight of PETN plus RP-87 Det (.069g)
DETASHEET is 63% PETN
Total charge wt – about 1.59 times larger

Pressure

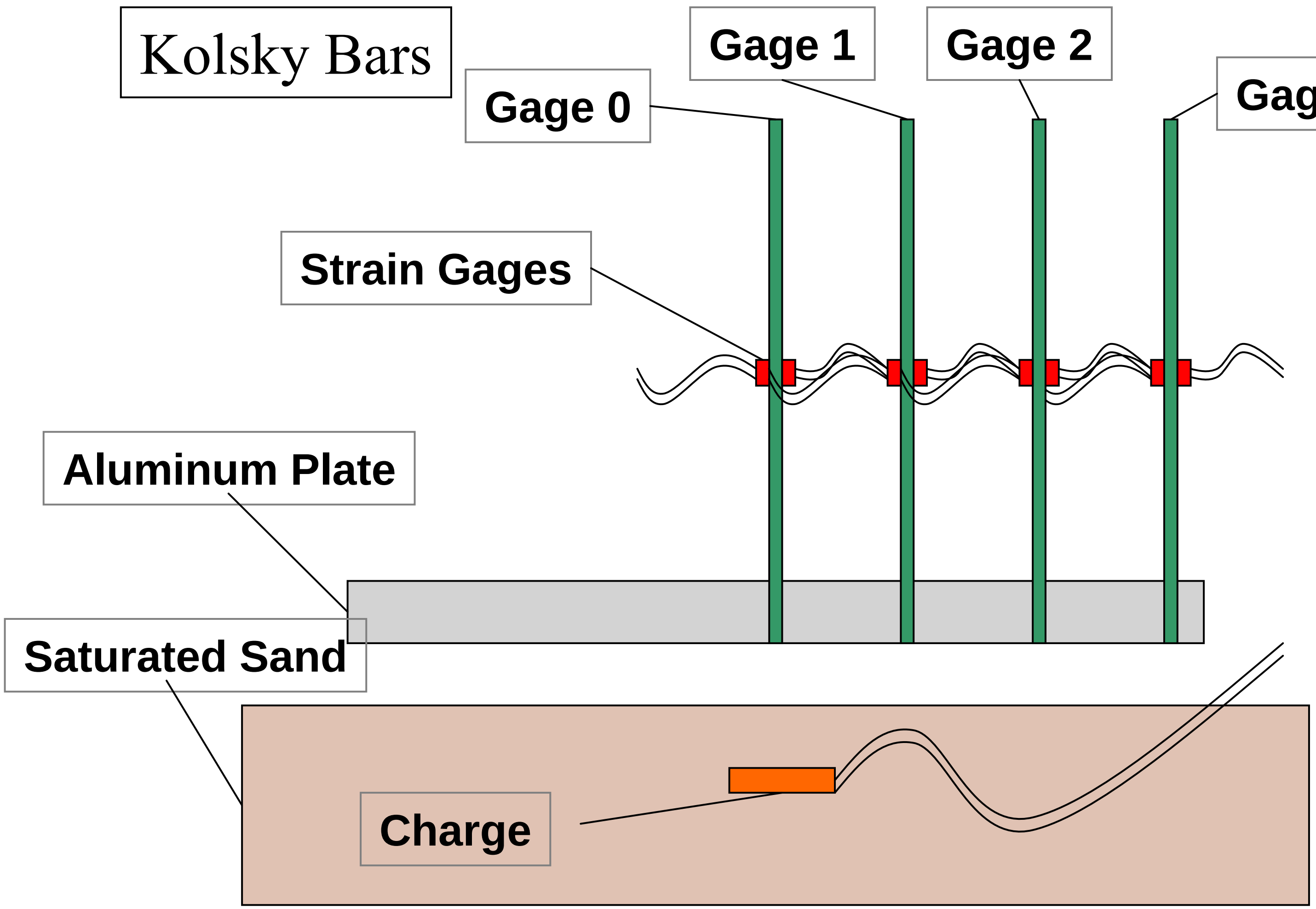
- Pressure at Any Point on Target as Function of Time is Load on Target at That Point

- Pressure Has Proved Very Hard to Measure Accurately

- Substitutes Have Been Used: Integrated Values
  - Impulse Distribution
  - Total Vertical Impulse

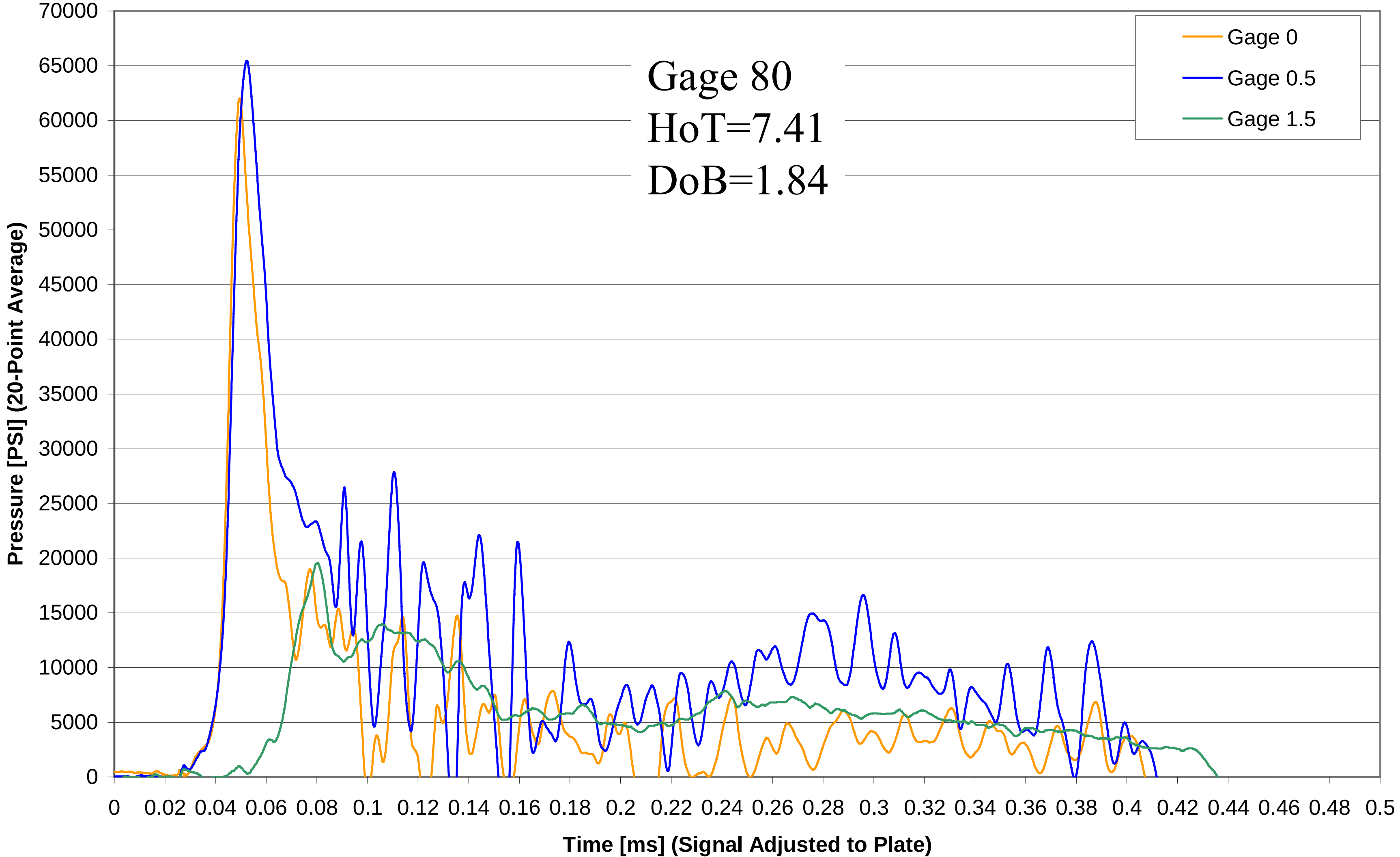
Pressure Test

Fixed Plate Pressure Test

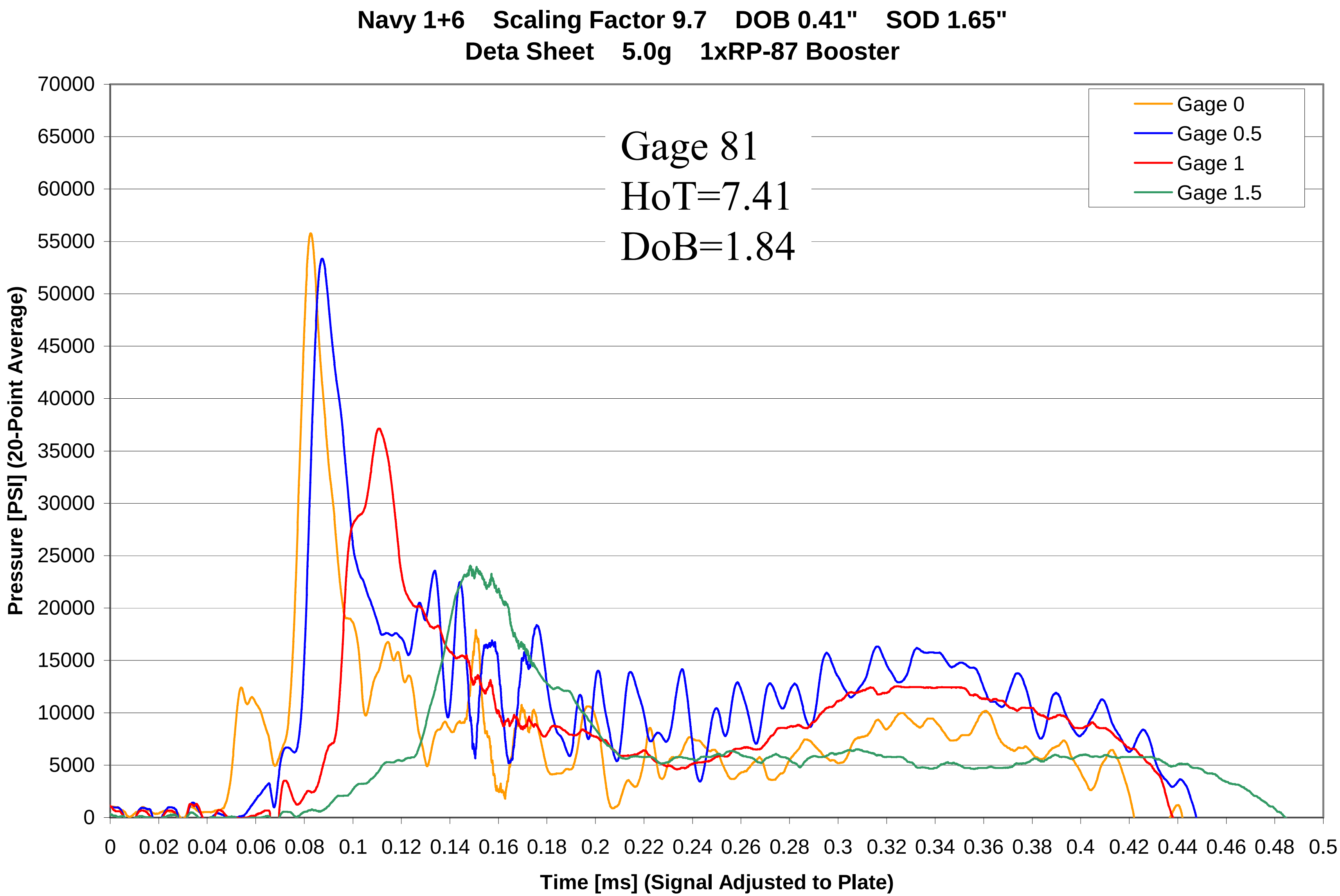


Pressure Test

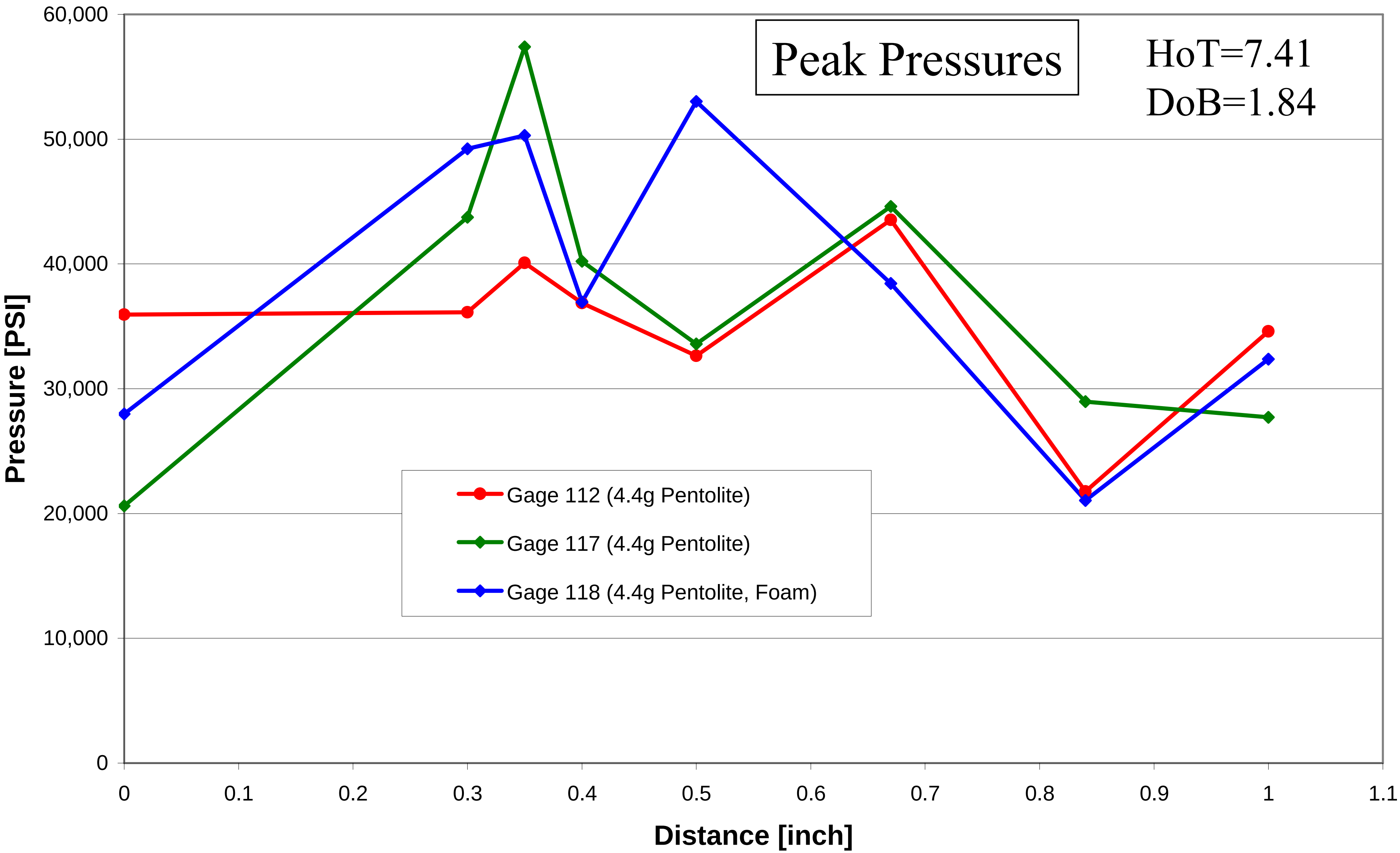
Navy 1+6 Scaling Factor 9.7 DOB 0.41" SOD 1.65"
Deta Sheet 5.0g 1xRP-87 Booster



Pressure Test



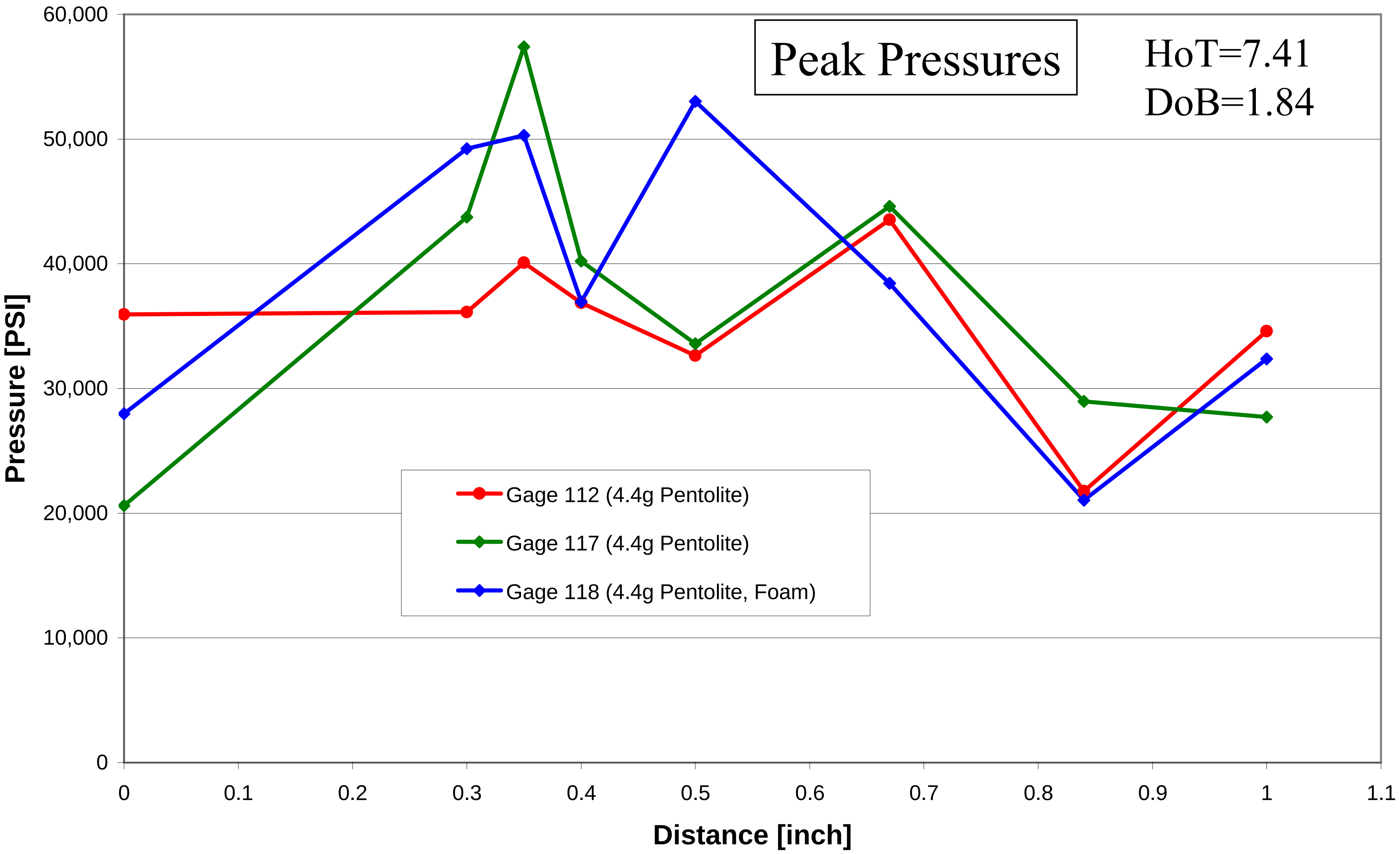
Pressure Test



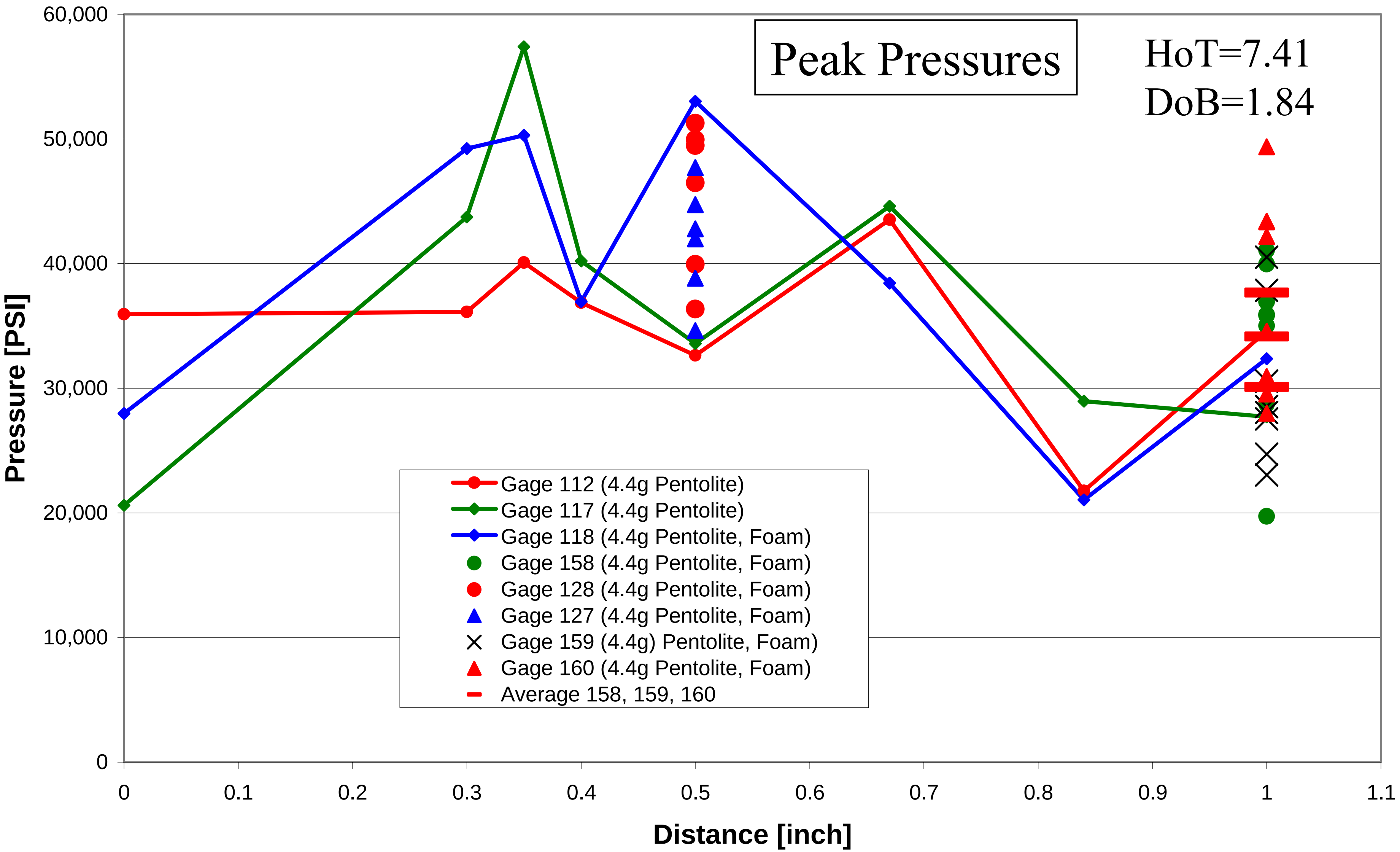
Pressure Test

Eight Kolsky Bars in Circle

Pressure Test



Pressure Test



Loading Mechanisms

- Target Loaded by Soil Driven Against Target by Gas Bubble
- Target Loading Not Truly Impulsive
- Occurs Over Finite Time Appropriate to Bubble Processes
  - Generally Millisec Rather Than Microsec
- Target Loading Depends Upon
  - Charge Size & Shape
  - Charge – Target Geometry,
  - Etc.

Loading Mechanisms

Shallow Buried Explosive

- Shockwave does not play *direct* role in target loading
  - Unless target in contact with surface

- Shockwave plays *indirect* role in target loading

Loading Mechanisms

- Target Loaded by Soil Driven Against Target by Gas Bubble

- Soil Cap Directly Over Charge Major Contributor to Load
  - Properties Of This Material When it Hits Target Important
  - They Are Not *In Situ* Properties
  - Properties & Configuration of Soil Modified by Shockwave

- Shockwave Important for What it Does to Soil Not to Target

Early Time Effects

When Charge Detonates

- Emits Shockwave
  - Essentially Parallel to Top of Charge, Because of Charge Shape

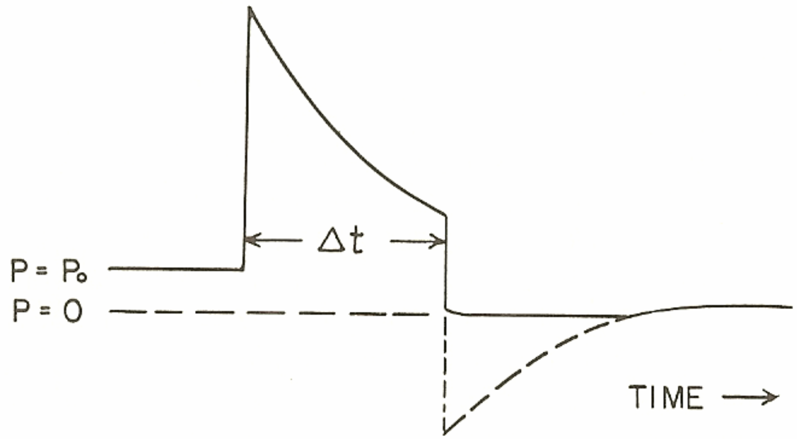


Fig. 7.21 Gauge pressure as a result of surface reflection.

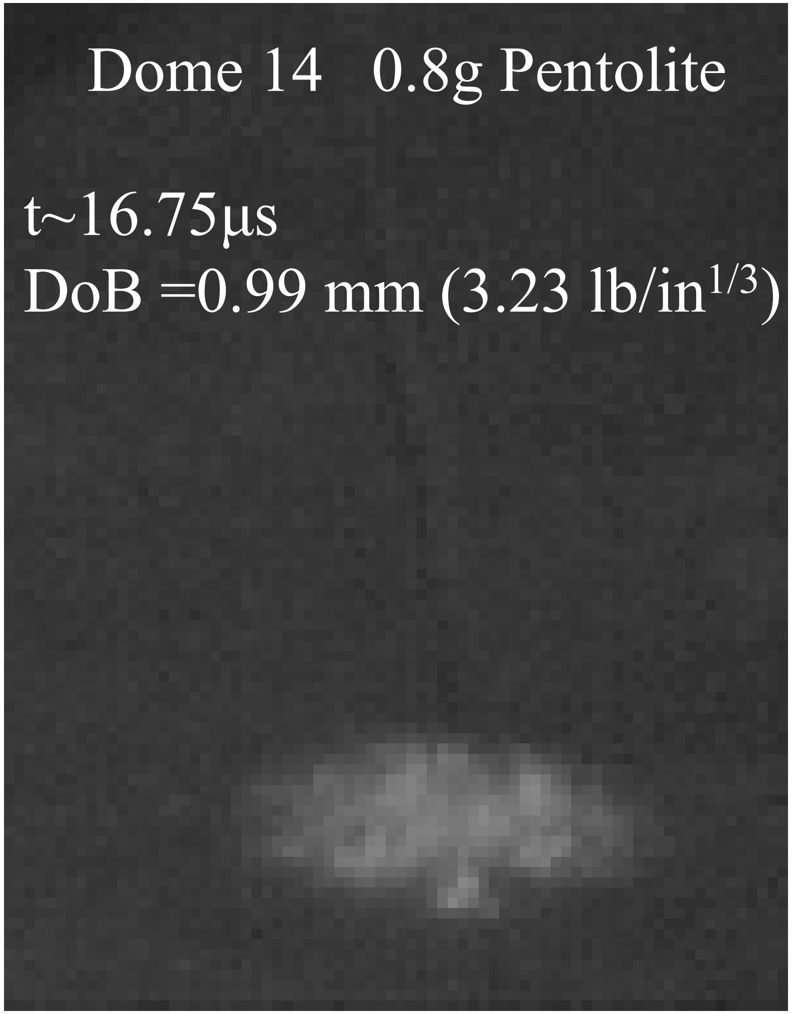
Underwater Explosions, Cole, 1948

- At Surface, Shock Mostly Reflected as Relief Wave in Soil
  - Impedance Mismatch Between Saturated Soil & Air

Early Time Effects

When Charge Detonates

- Not all shock energy reflected
  - Weak shock sent into air
  - Spray thrown up



Early Time Effects

Bulk Cavitation

- Negative Pressure in Relief Wave Interacts With Pressure in Soil Cap
    - Tries To Go Negative

- Water & Saturated Soil Cannot Support Tension – Cavitates

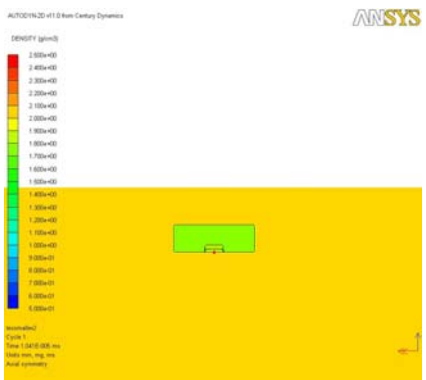
- Bulk Cavitation Creates Three Layers
    - High Density, Low Density, High Density

- If Cavitated Region Present When Soil Cap Hits Target
    - Pressure Rise Interrupted

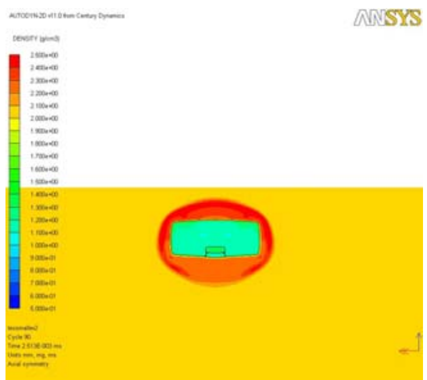
Early Time Effects

Bulk Cavitation

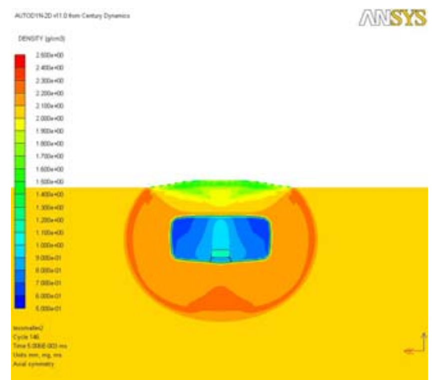
4.4g Pentolite Charge



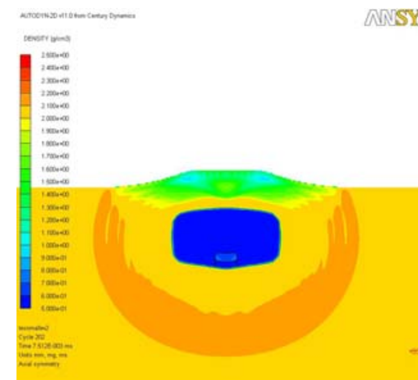
t=0 μs



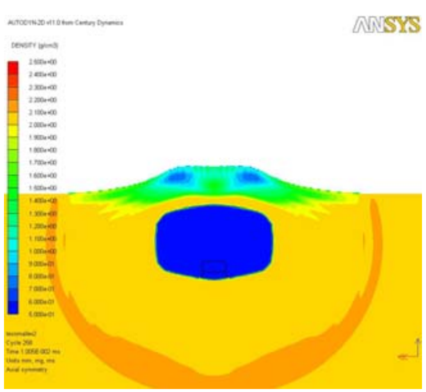
t=2.5 μs



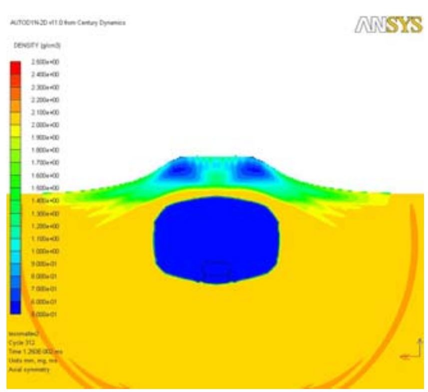
t=5.0 μs



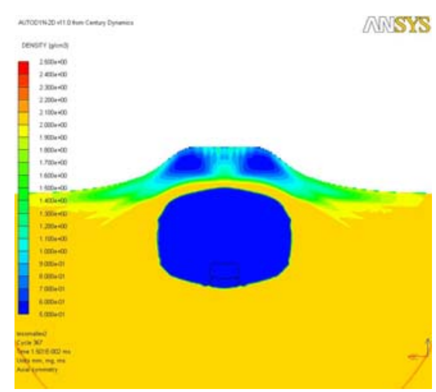
t=7.5 μs



t=10.0 μs



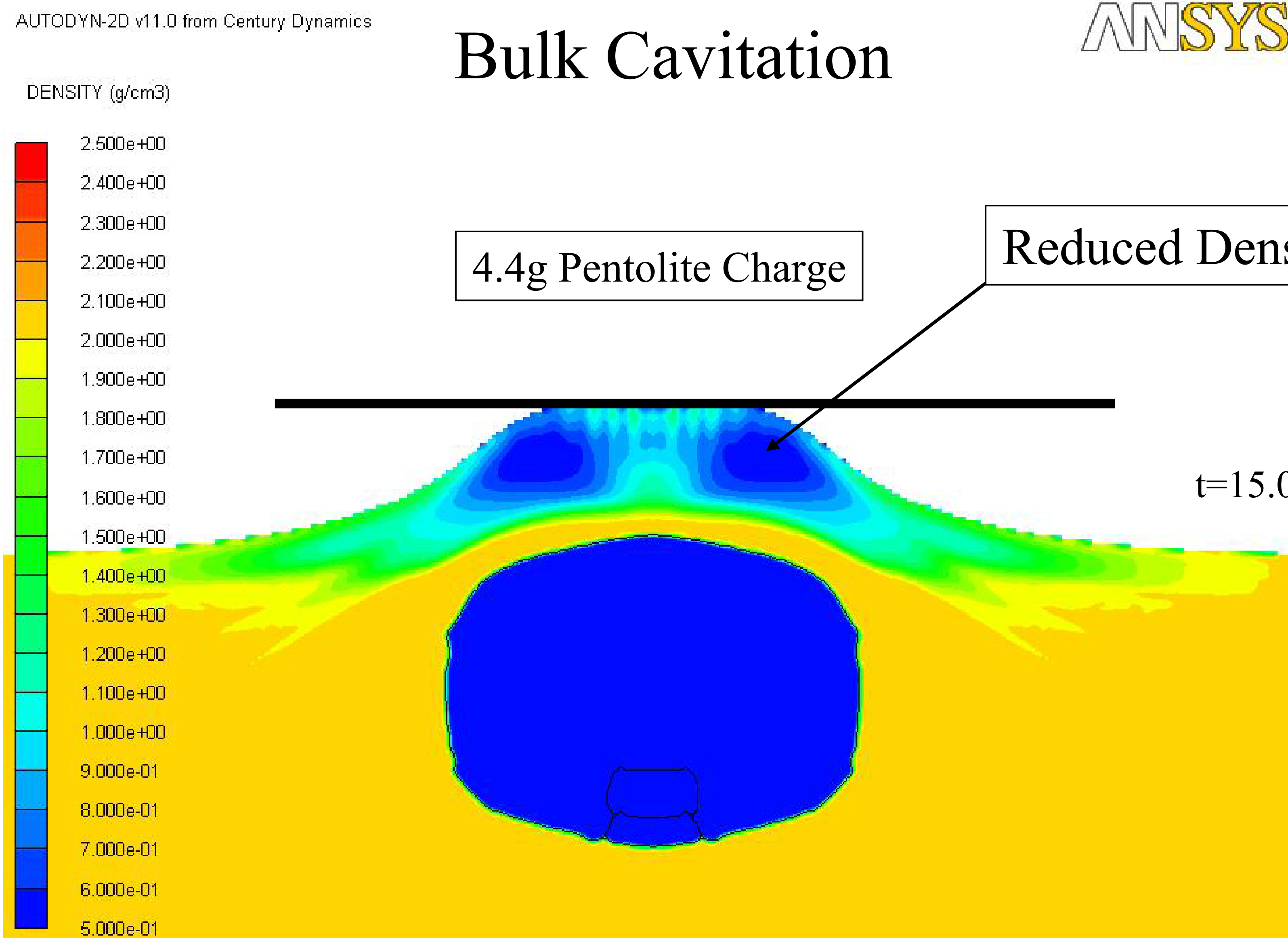
t=12.5 μs



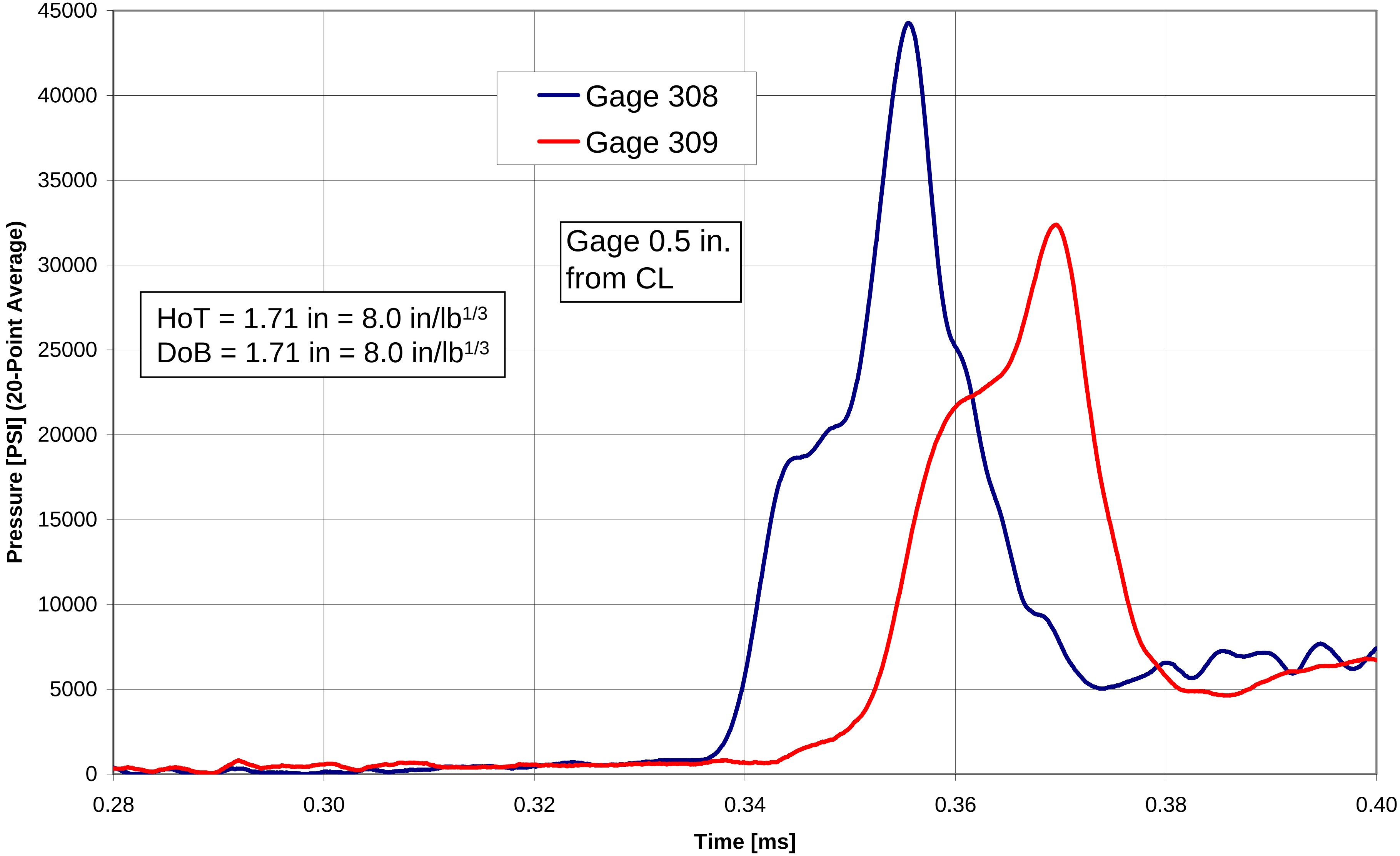
t=15.0 μs

Early Time Effects

Bulk Cavitation



Early Time Effects



Early Time Effects

Richtmyer-Meshkov Instability (RMI)

Occurs when interface between fluids of differing density is impulsively accelerated, e.g. by the passage of shock wave

Development of instability begins with small amplitude perturbations which initially grow linearly with time

Followed by nonlinear regime with spikes appearing in the case of heavy fluid penetrating light fluid

A chaotic regime eventually reached and the two fluids mix

RMI can be considered impulsive-acceleration limit of Rayleigh–Taylor instability.

Early Time Effects

Richtmyer-Meshkov Instability (RMI)

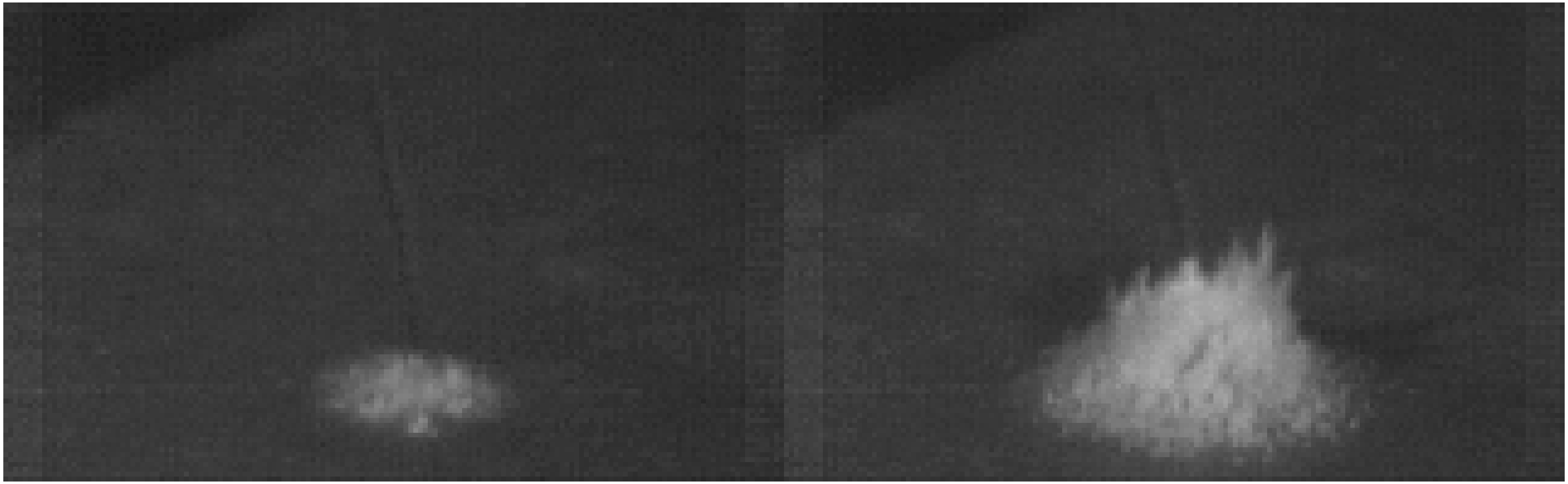
- Our Event Over (Target Hit) Before Chaotic Mixing Phase
- Our Interest – Amplification Of Initial Perturbations
  -Interface Between Soil And Air is Never Smooth
- RMI Origin of Spikes (Fingers) of Material That Move
  Faster Than Bulk of Soil Cap

Early Time Effects

Richtmyer-Meshkov Instability (RMI)

Dome 14 0.8g Pentolite
DoB =0.99 mm (3.23 lb/in$^{1/3}$)

t~16.75μs t=33.5μs later

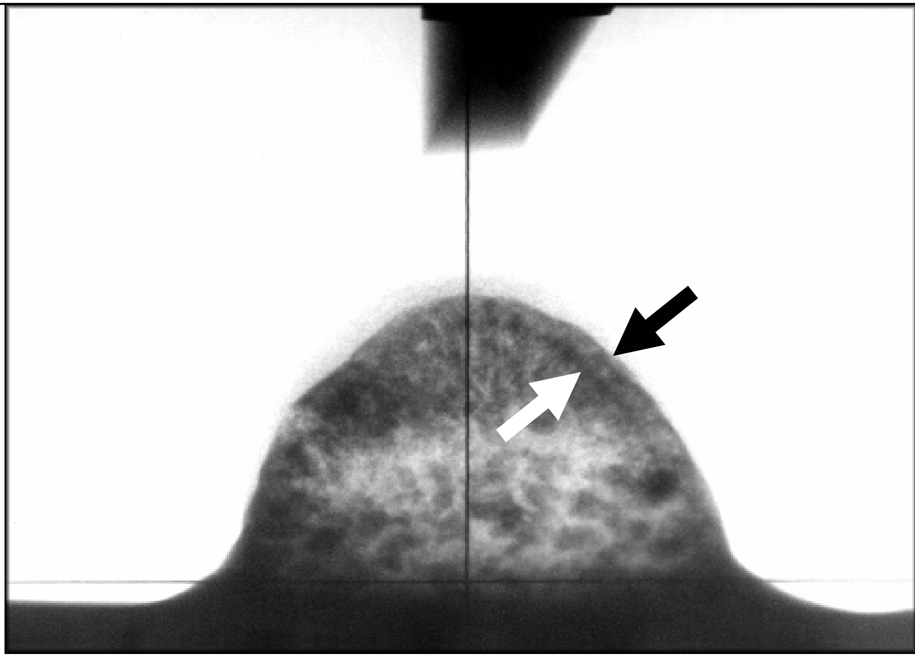


- Since Soil Surface Chaotic, Distribution Of Fingers Chaotic
  - Leads Directly To Difficulty In Measuring Pressure

Early Time Effects

Spherical Spreading

- Soil Cap Quickly Assumes Shape of Rough Hollow Dome
- Soil Cap Thins as Material Above Charge Spreads Over Surface of Dome
- Thinning Shortens Peak Loading Duration



Flash X-Ray
Shot 17-1. 125.9 µs Fairly Dry Sand
Bergeron, Walker & Coffey, DRES-SR-668, April 1998

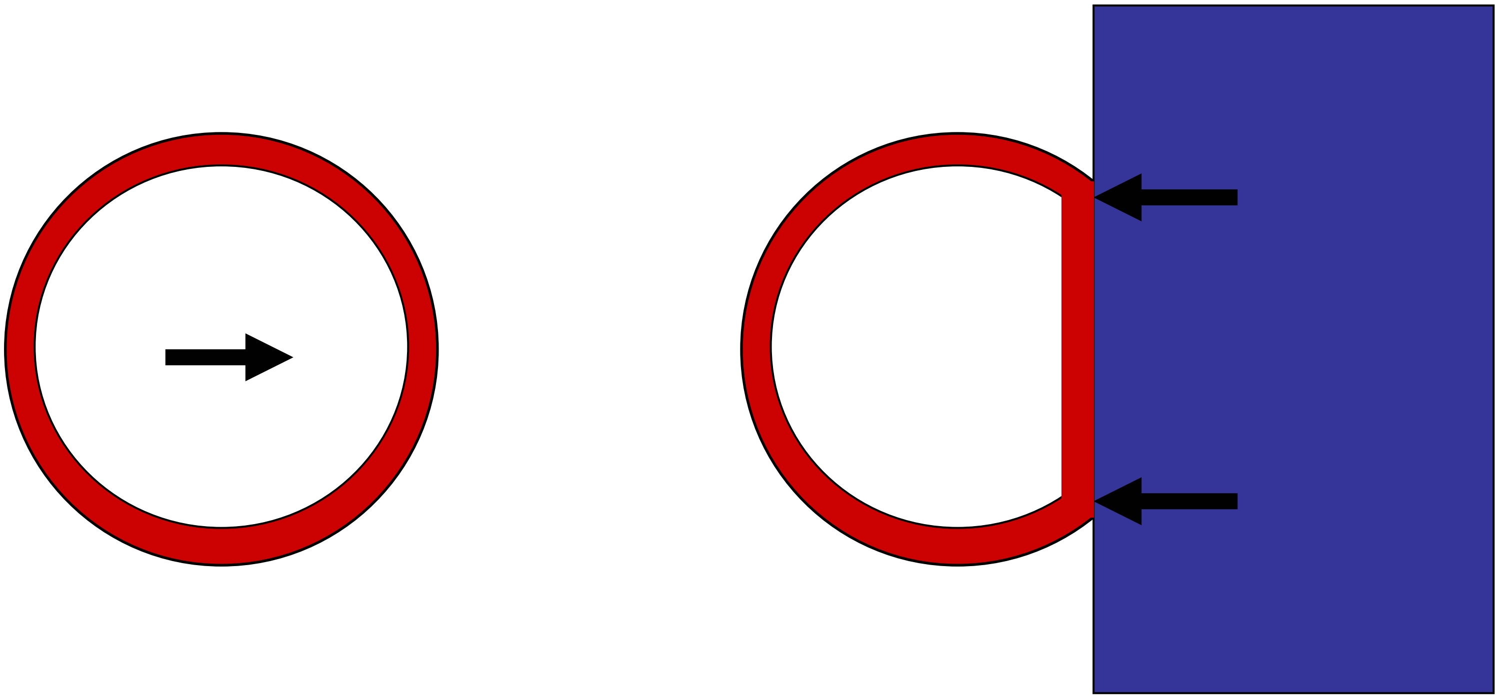
Wt = 106 g
DoB = 30 mm
D = 62mm
T = 22mm
t = 0.1259 ms

If W = 4.4 g
DoB = 10.4 mm
t = 0.0436 ms

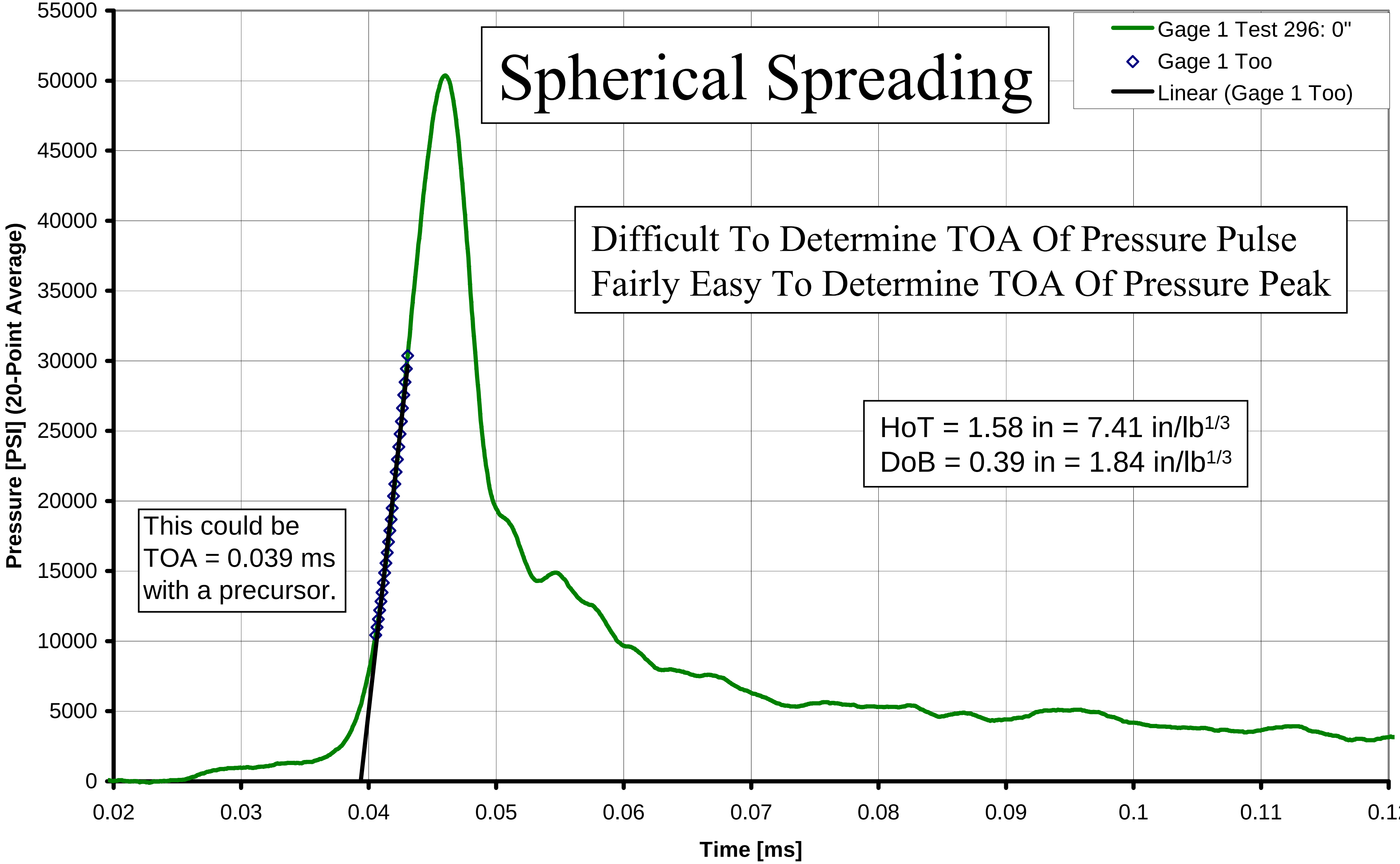
Early Time Effects

Spherical Spreading

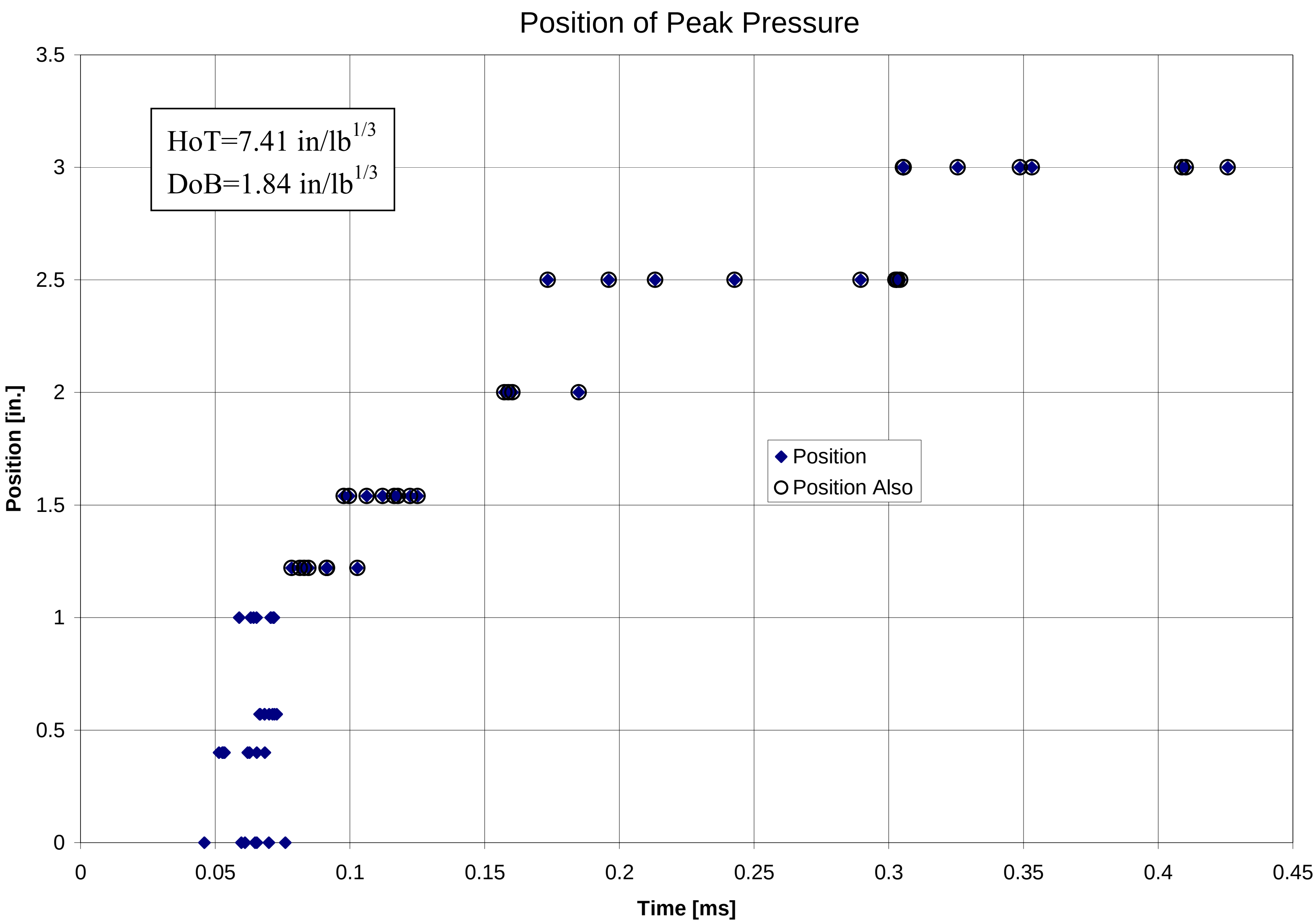
Consider Dome as Hollow Ball Hitting a Plane Target



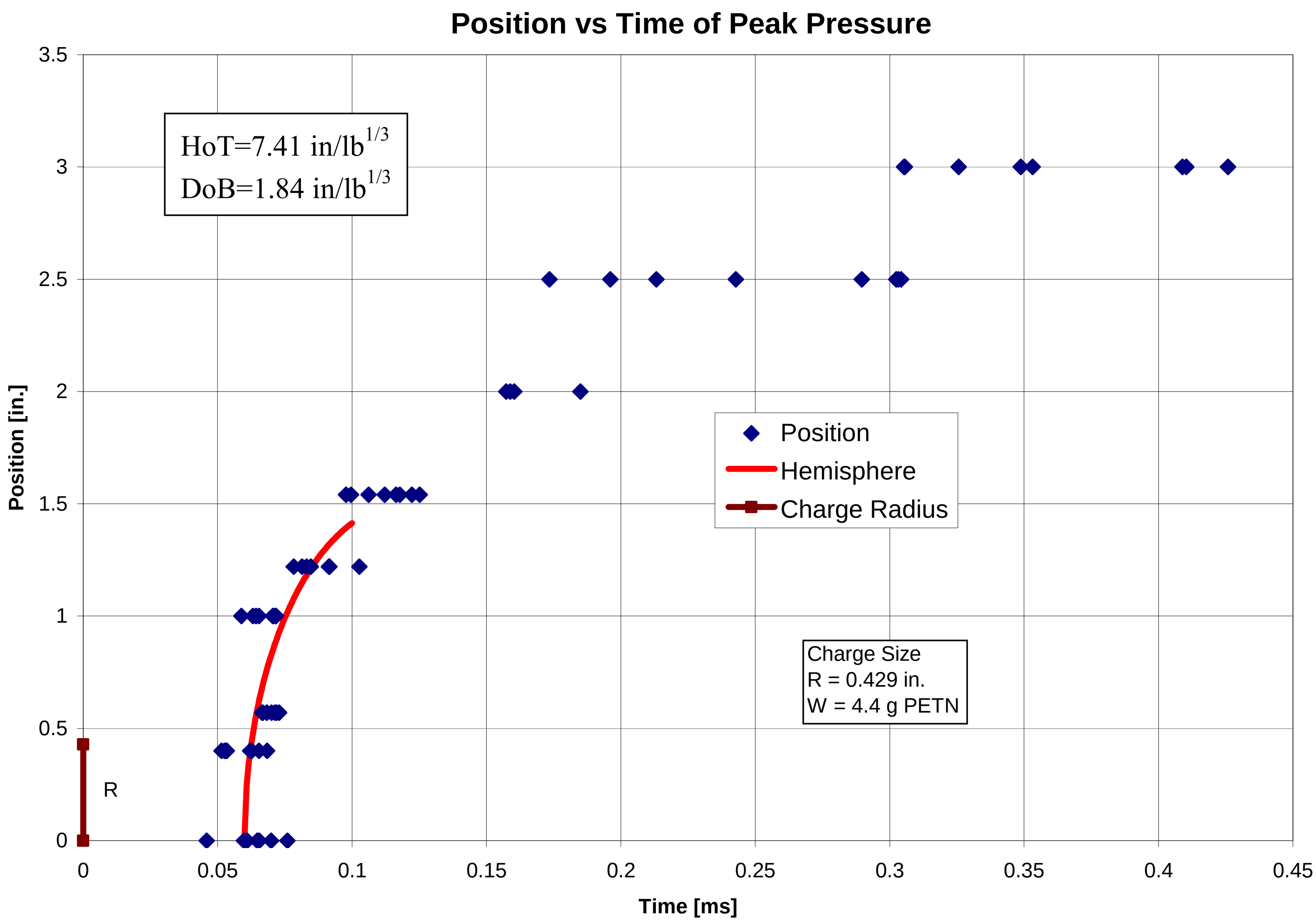
Early Time Effects



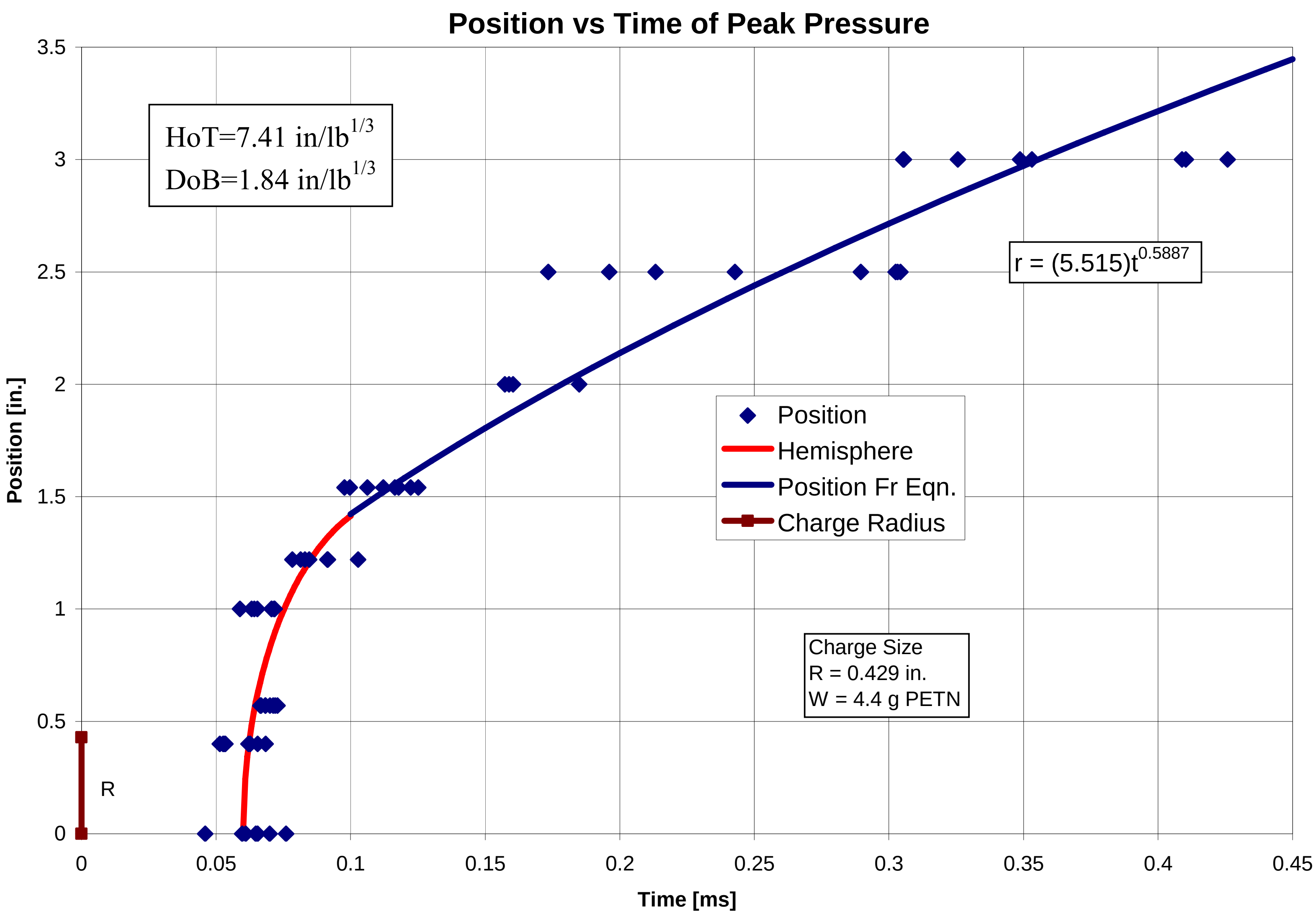
Spherical Spreading



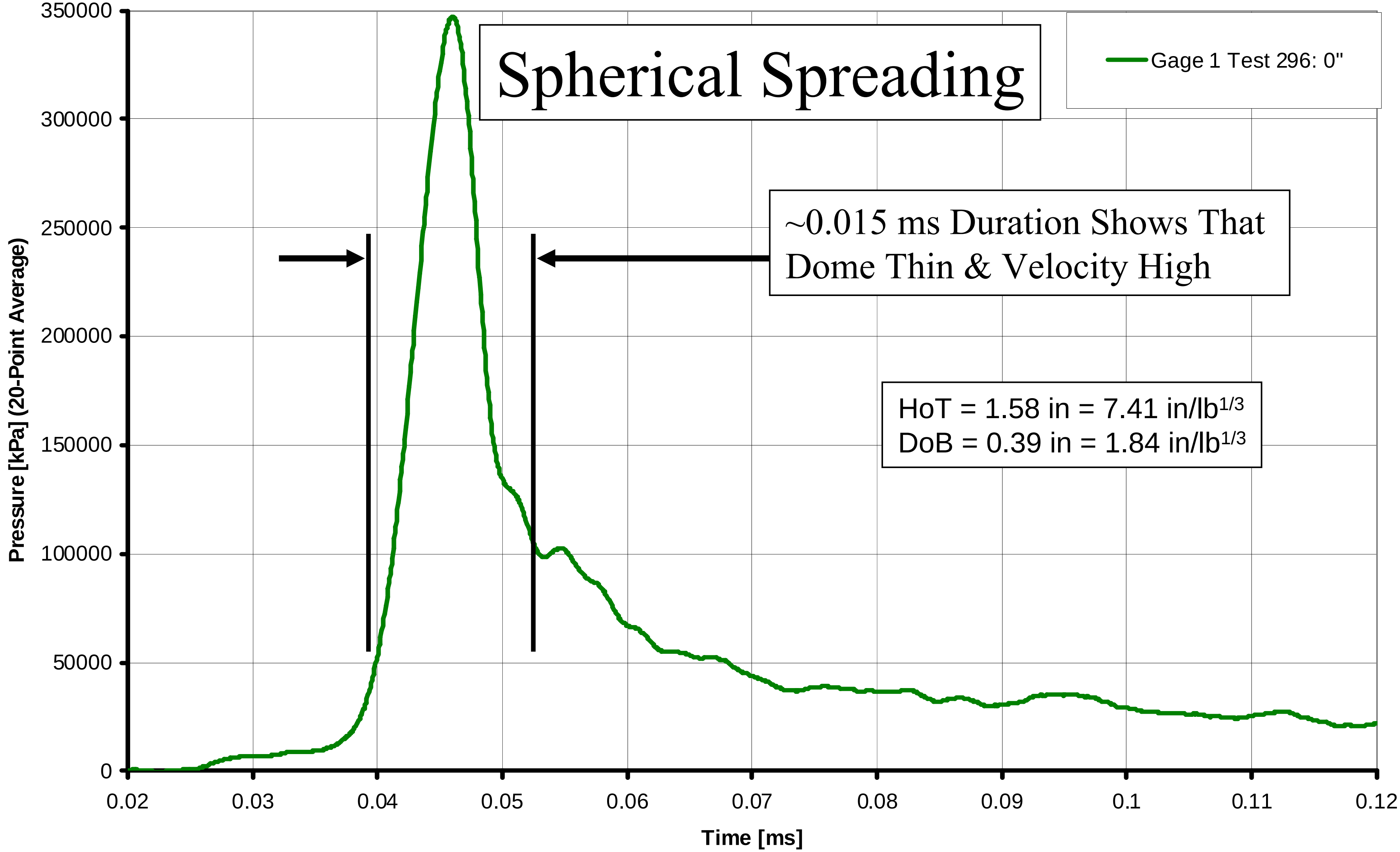
Spherical Spreading



Spherical Spreading



Early Time Effects



Early Time Effects

- Residual Shock in Air & Spray Hitting Target
  - Pressure Precursors
- Cavitation in Soil Cap
  - Variability in Pressure Rise Rate
- Richtmyer-Meshkov Instability
  - Variability in Value & Time of Peak Pressure
- Spherical Spreading & Dome Hitting Target
  - Rapid Initial Pressure Rise & Fall
- All Happens In Very Short Time - e.g. at 4.4 g Scale
  - First 0.1 ms After t = 0
    (Scales to 1ms for 10 lb (4.5 kg) Charge)
- Effect Confined to ~ 3.5 Times Charge Radius

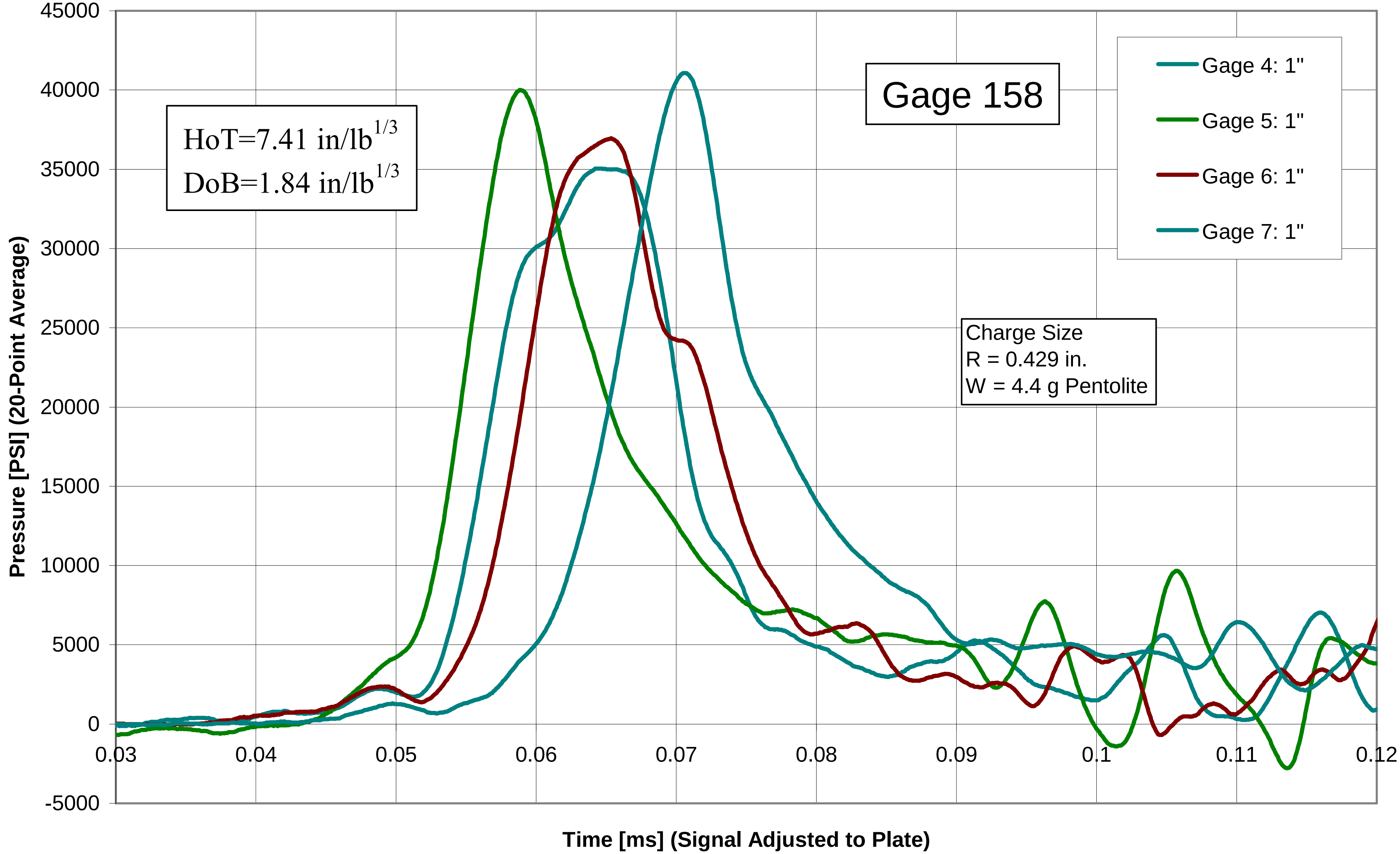
- Not The Whole Story

Late Time Effects

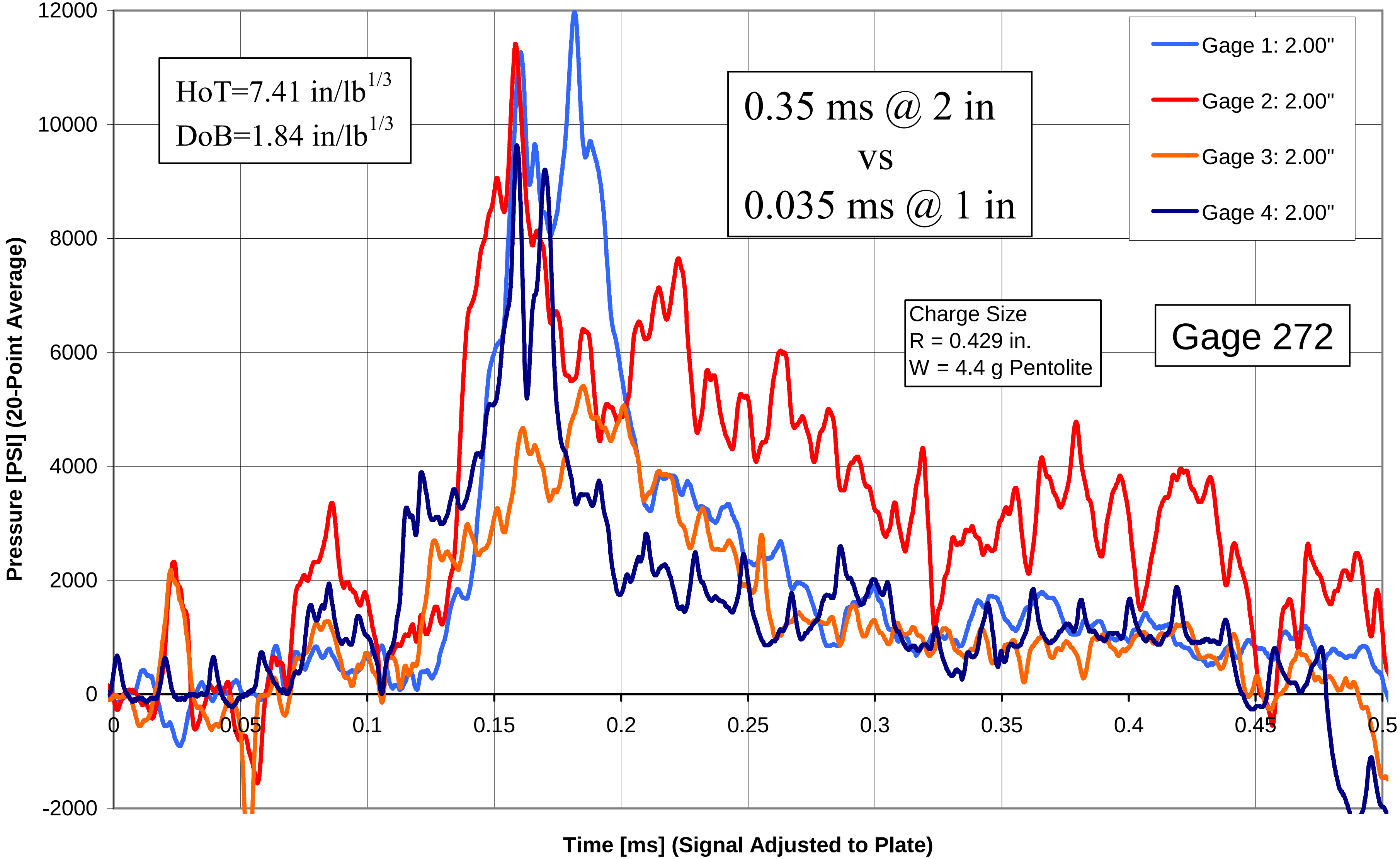
Two Additional Processes

- Material Outside Soil Cap Scooped Out of Crater by Explosive Gas
- Gas Pressure on Bottom of Target Trapped by Material Coming Out of Crater
- Pressures Much Lower
  - Act Over Much Longer Time
  - Act Over Much Greater Area

Late Time Effects



Late Time Effects



Late Time Effects

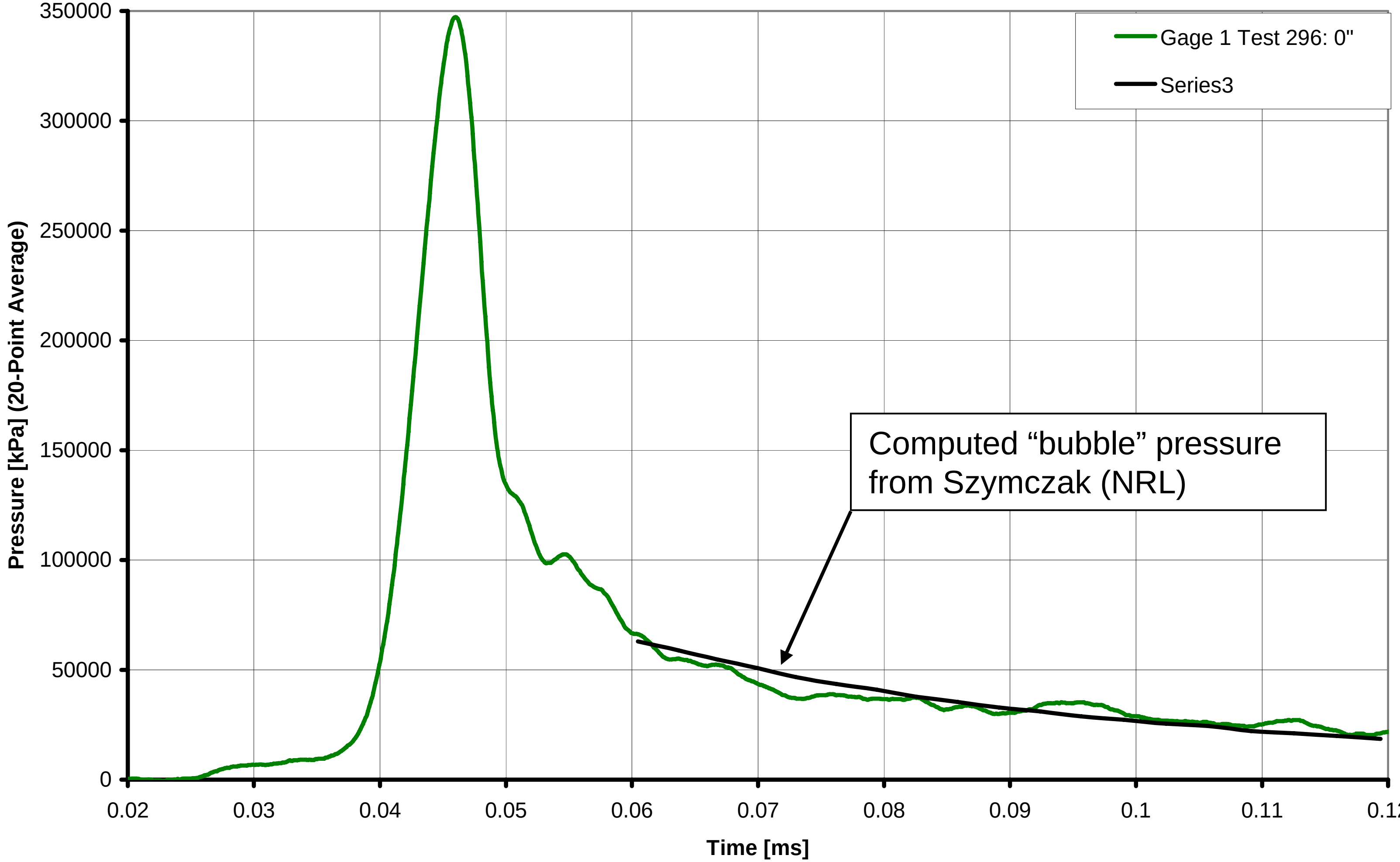
- Material Streaming Out Of Crater & Hitting Target
  - Travels Parallel To Wall Of Crater
  - Ring-shaped Stagnation Region on Target
  - Thickness Of Region Increases Rapidly
  - Vertical & Radial Velocities Comparable

- Lower Pressures & Longer Duration

  t = 0.35 ms @ 50.8 mm vs 0.035 ms @ 25.4mm

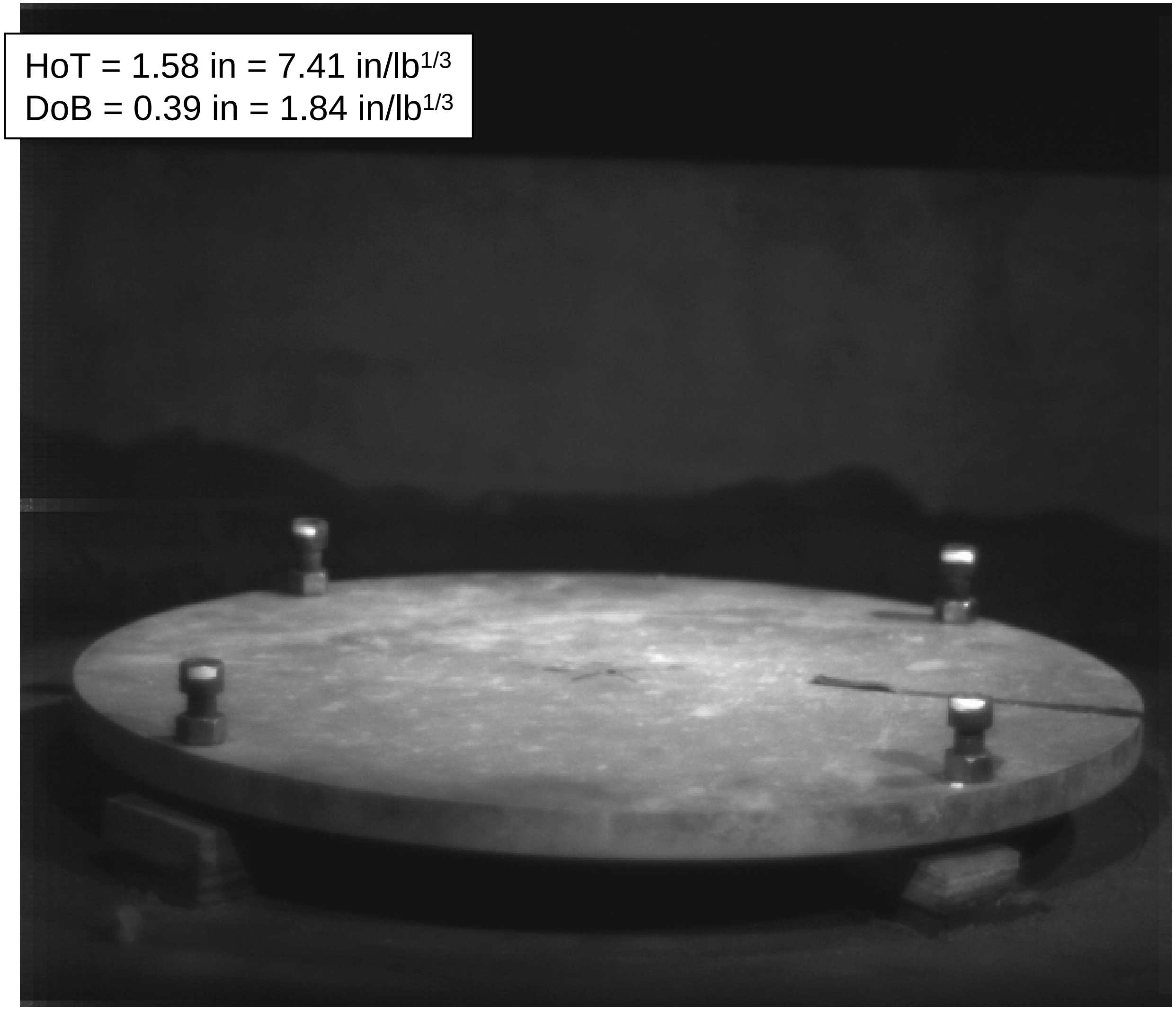
  p_{max}=12,000 psi @ 50.8 mm vs 40,000 psi @ 25.4 mm

Late Time Effects

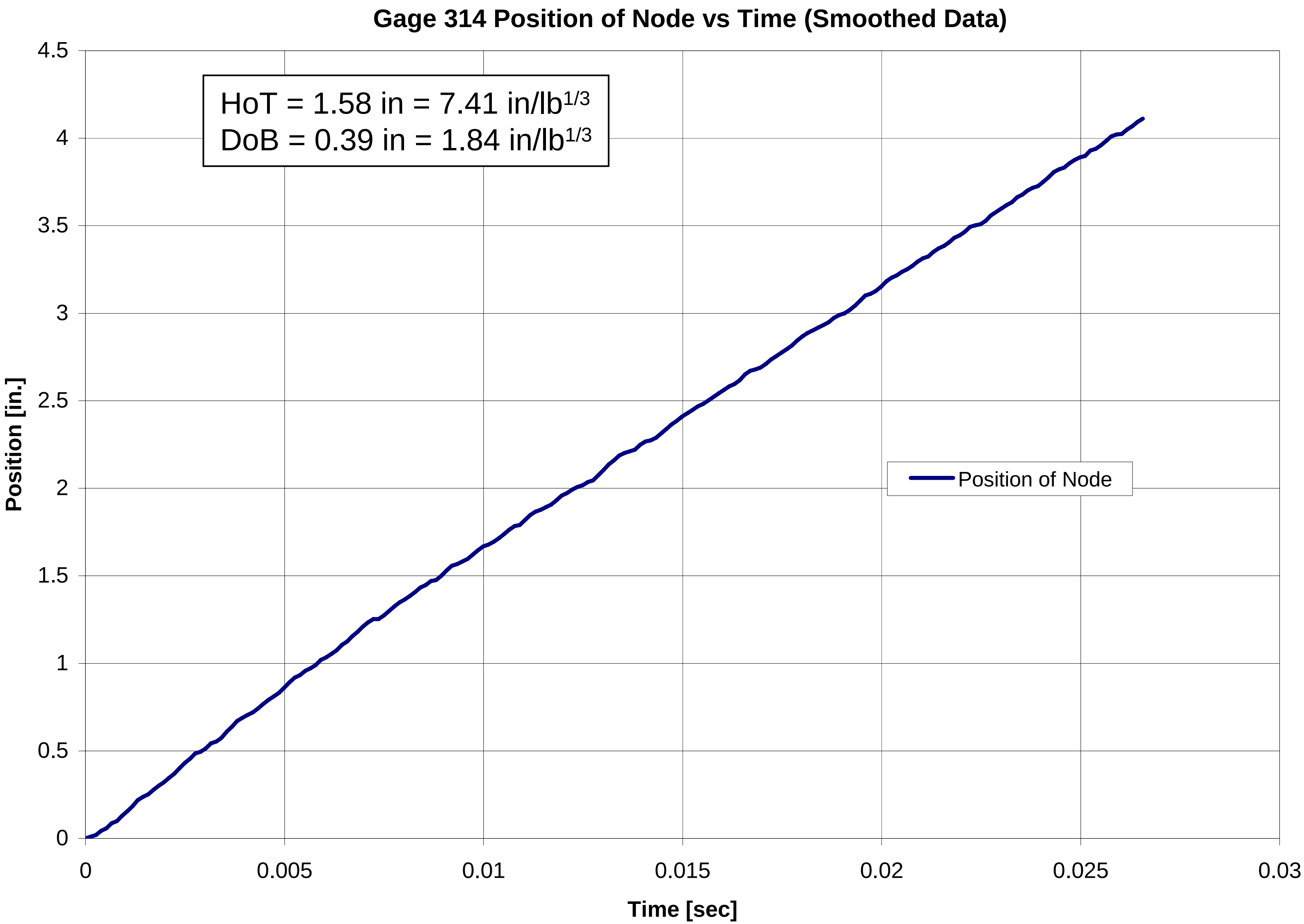


- Annular Jet of Saturated Soil Provides Confinement for Explosive Gas Pressure in “Tail” of Pressure – Time Curve

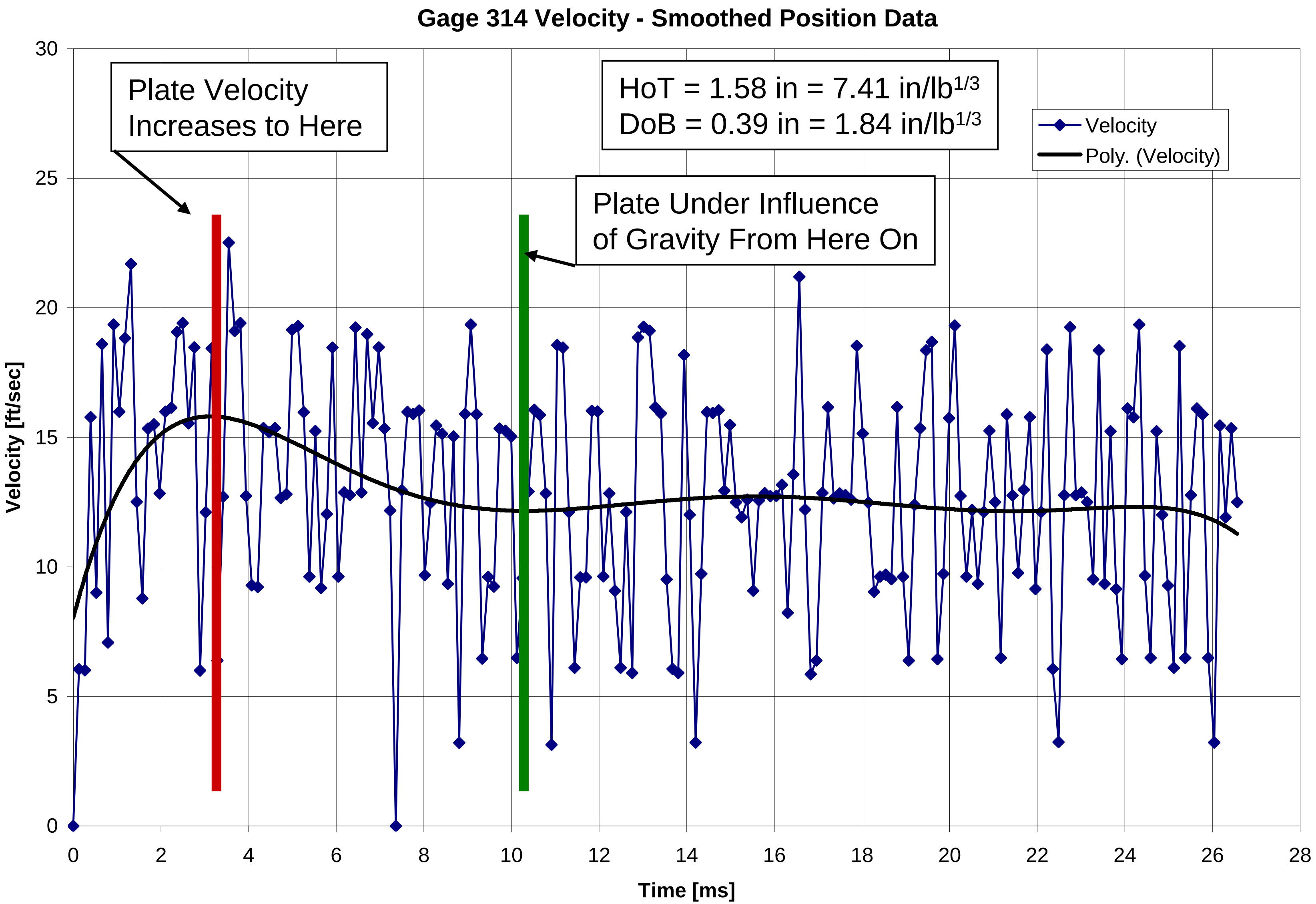
Late Time Effects



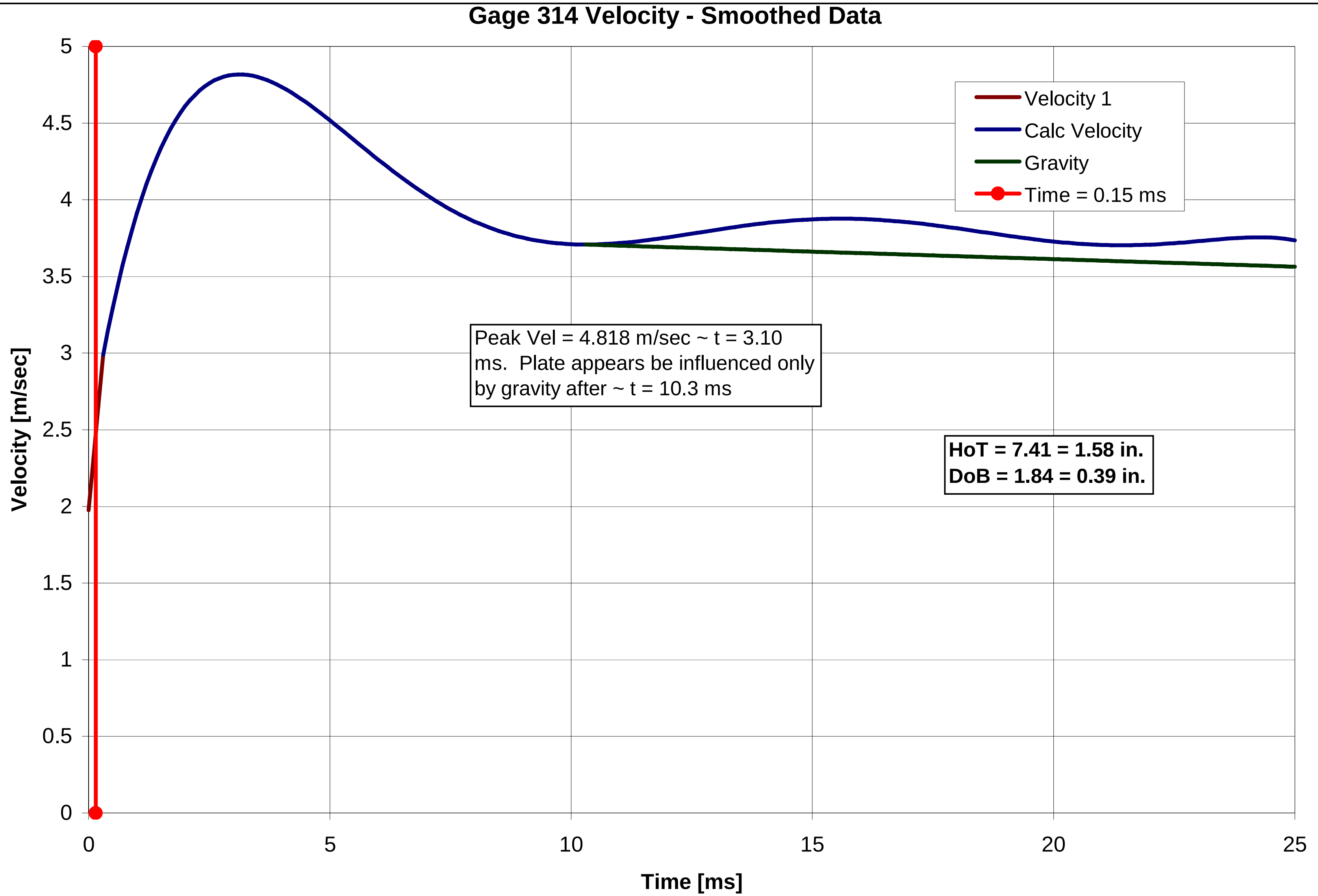
Late Time Effects



Late Time Effects



Late Time Effects



Late Time Effects

- In Spite of Lower Pressures Resulting From
  - Impact of Material From Crater
  - Pressure of Trapped Gas
- Late Time Processes Make Major Contribution to Impulse

- Target Plate Gained Velocity for ~ 3 ms
- Increase After ~ 0.15 ms Due to Late Time Processes

- Also Notice:
  - Plate Slows at Greater Than 1g Until t~10 ms
  - Gas Bubble Can Over-Expand & Slow Plate

Summary

- Primary Loading Mechanism
    - Soil Driven Into Target by Expanding Gas Bubble
- First Phase
    - Complex, Modulated by Shockwave
    - Very Brief
    - Acts on Small Portion of Target
    - Provides About Half Total Vertical Impulse
- Second Phase
    - Dominated By Crater Excavation Processes
    - Pressures Lower
    - Order of Magnitude Greater Duration
    - Much Larger Area of Application
    - Provides About Half Total Vertical Impulse

Leslie C. Taylor
Ph: 301/405-5339
University of Maryland
Paper: ISB 277-2008