Numerical Modeling of Explosively Loaded Concrete Structures Using a Coupled CFD-CSD Methodology

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Outline

- Methodology
- Background
- Kasun Finite Element Model
- Kasun Finite Element Analysis
  - 1 - 6.9kg Bare Charge
  - 16 - 6.9kg Bare Charges
  - 1 - 155mm Cased Charge
  - 16 - 155mm Cased Charges
- Summary and Conclusions

Flow Solver: FEFLO

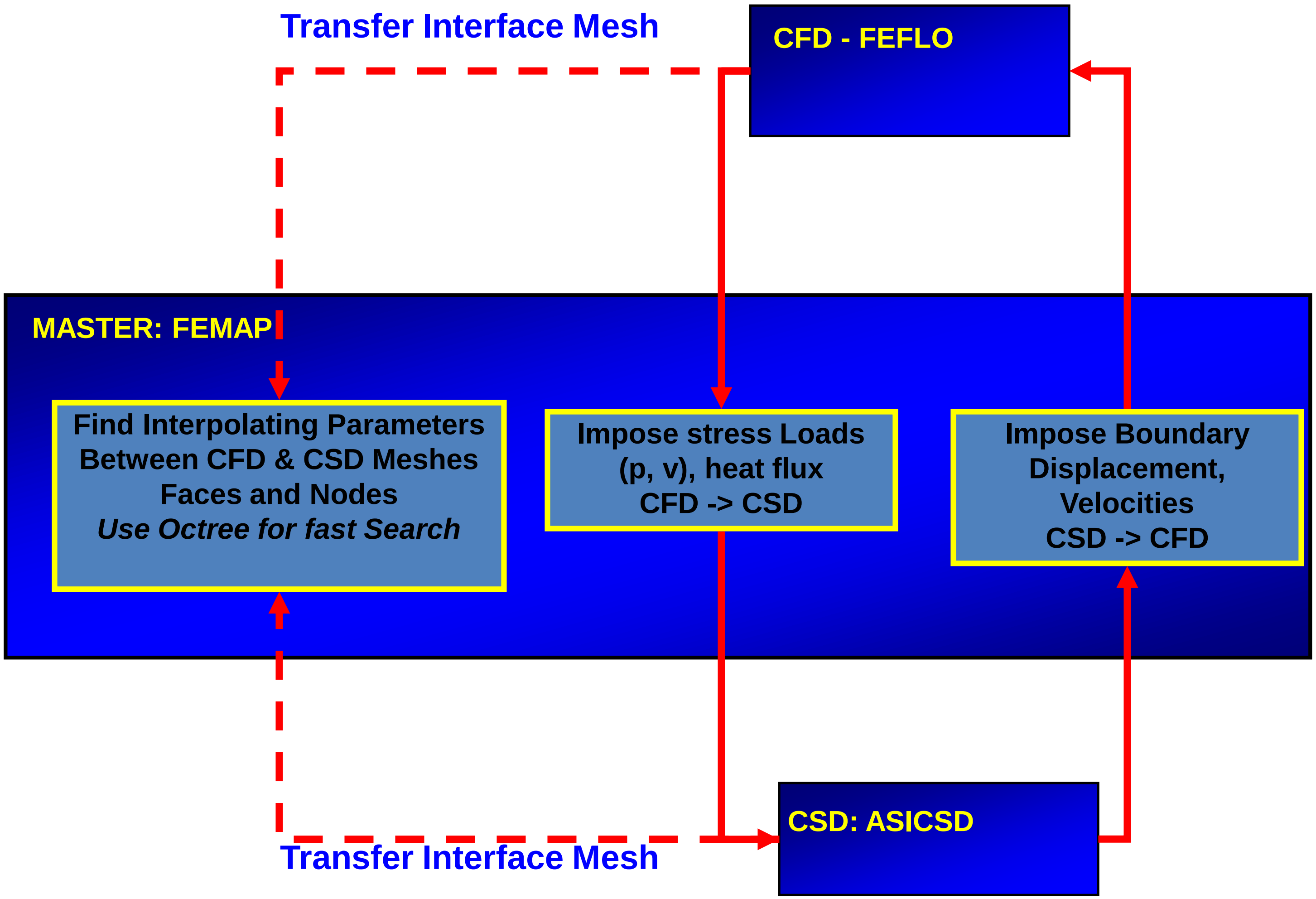
- Adaptive, unstructured grids (triangles/tetrahedra)
- Compressible & incompressible flows
- Inviscid, laminar & turbulent flow
- Several turbulence models (MILES, Smagorisnky, Baldwin-Lomax, Spalart-Allmaras, K-Epsilon)
- Explicit and implicit time stepping
- EOS: Real air, water (Tate), SESAME, polynomials, tables
- State-of-the-art shock capturing numerical schemes (Roe, FCT, HLLC, ENO, WENO, DG…..)
- Body-fitted ALE or embedded for moving bodies/change of topology
- Edge-based FE data structure
- Kinetic combustion modeling
- JWL (HE, non-ideal HE), Miller after-burn models, Cheetah
- *Particles as a dilute phase*
  - Exchange of mass/momentum/energy with flow
- Extensive benchmarking and validation
- International group of users (in many disciplines)

Structural Dynamics Solver: ASICSD

ASICSD:

- CSD solver: specifically for large, plastic deformations
- Beams, shells & solid elements
- Elastic, plastic, viscoelastic materials
- Various concrete models
- Rivets, bolts etc.
- Erosion model, but
- Cracking, rather than erosion for structural break-up
- Mott’s model for weapon case break
- Johnson and Cook model for thermal softening
- Non-reflecting BC

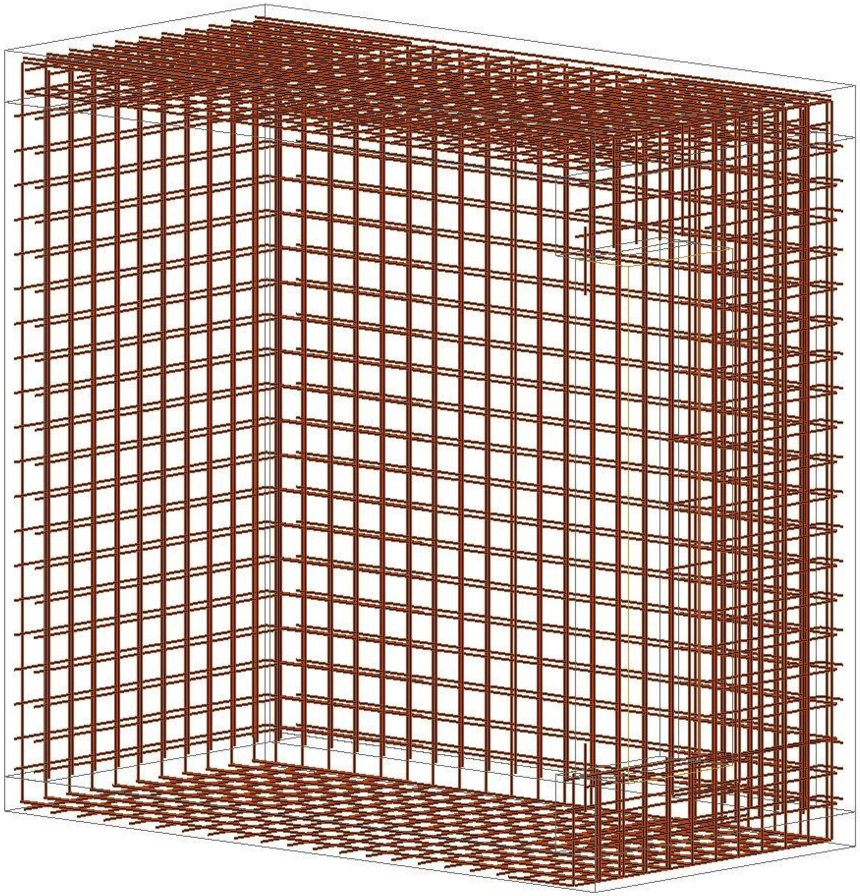
CFD/CSD Loose Coupling Approach

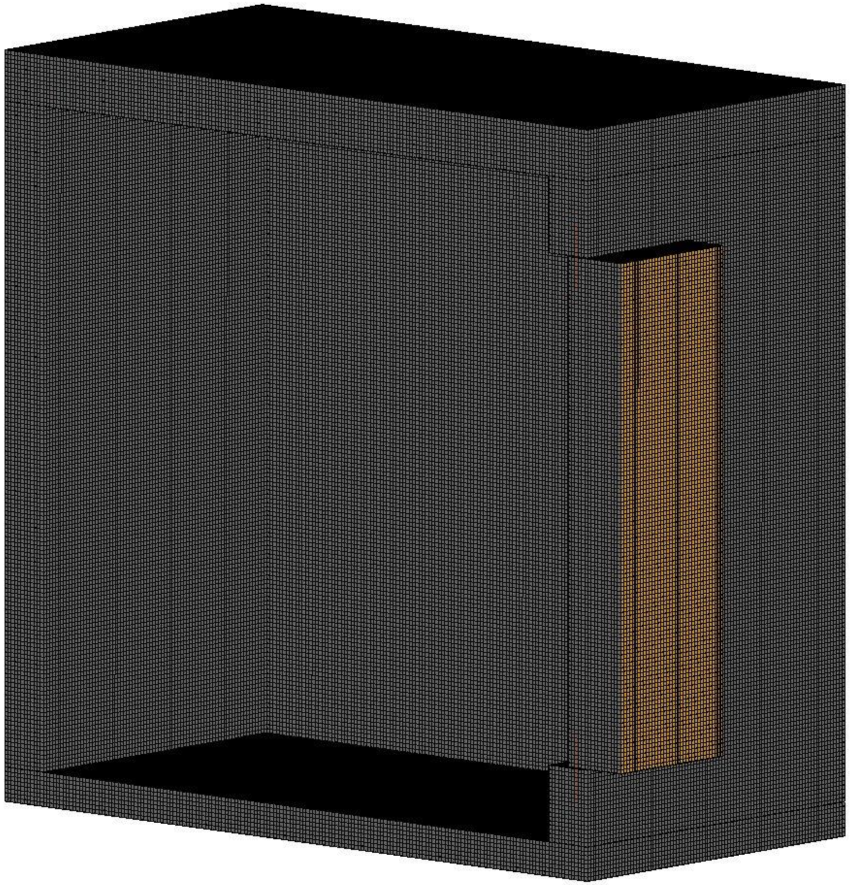


Background

- **Background:**
  - **In 2008, a joint Norwegian and Swedish experimental program was conducted to examined the detonation of explosives within concrete ammunition storage structures**
  - **The program focused on pressure occurring from detonation and the debris thrown caused by the detonation**
  - **The concrete structure known as Kasun III was 2m x 2m x 2m having nominal wall thickness of 150mm**

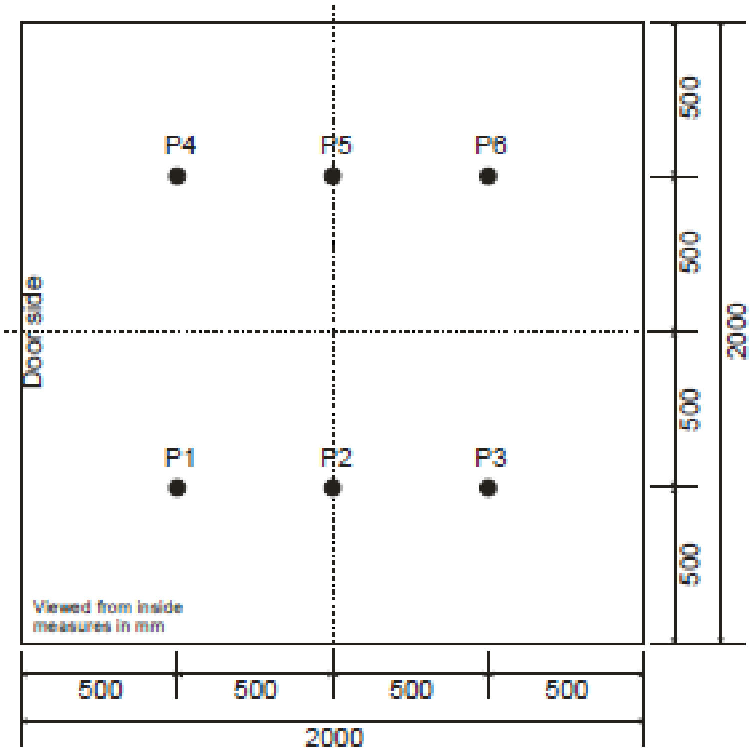
Kasun Finite Element Mesh



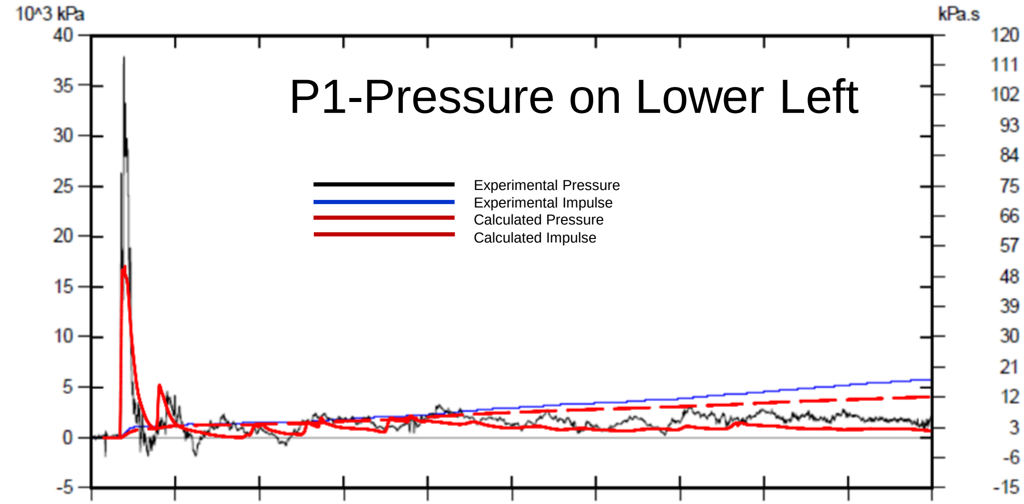


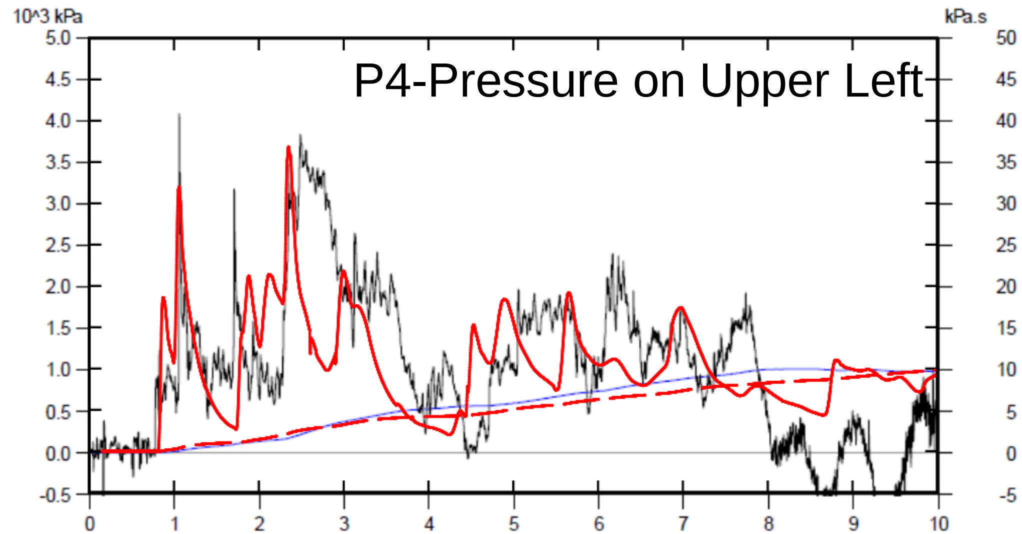
Kasun III Configuration and Charge
1 – 6.9kg Bare Charge

Pressure Comparisons
1 – 6.9kg Bare Charge



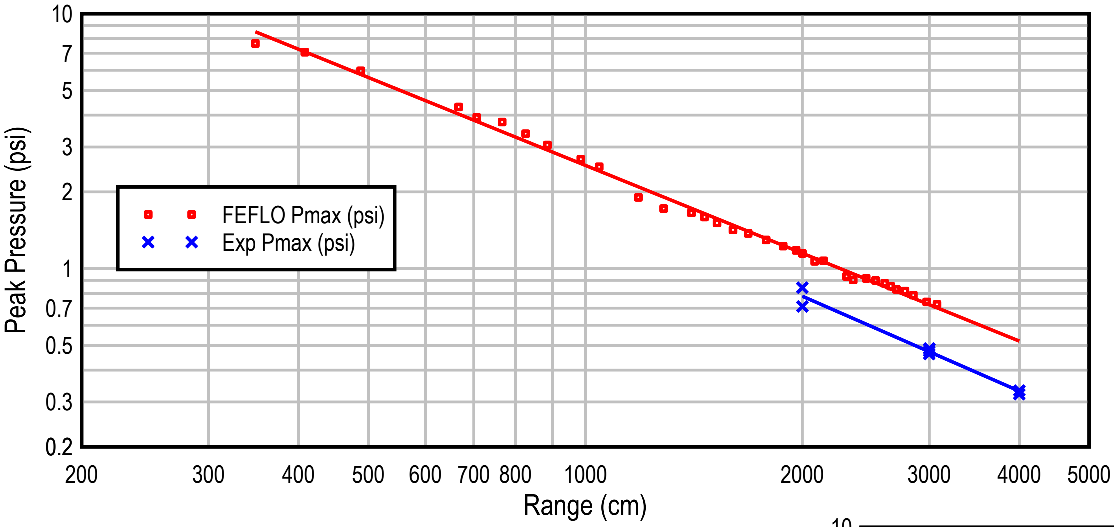
Pressure gauges located on internal wall



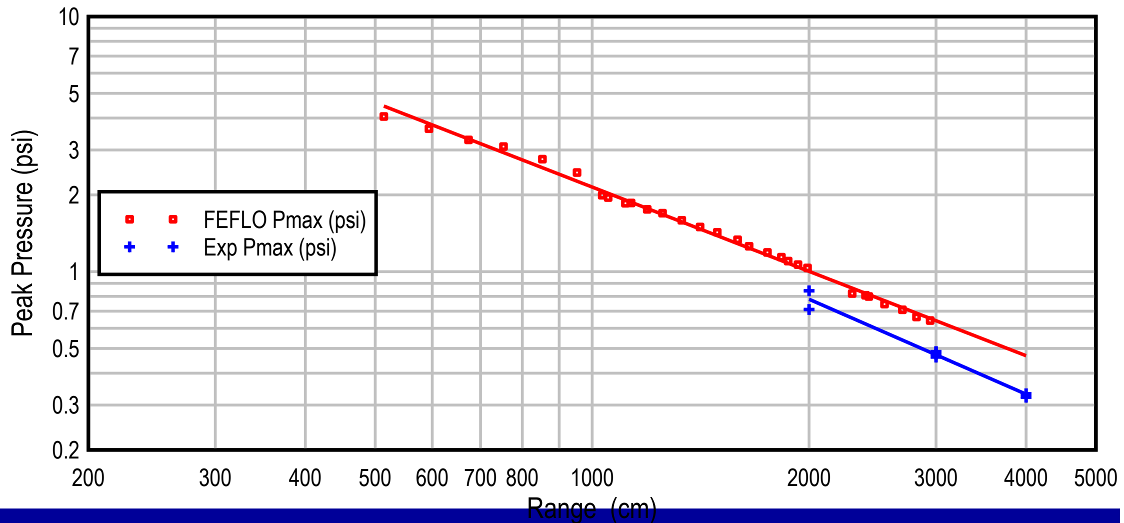


Peak Pressure Versus Range
1 – 6.9kg Bare Charge

Pressure Off The Side

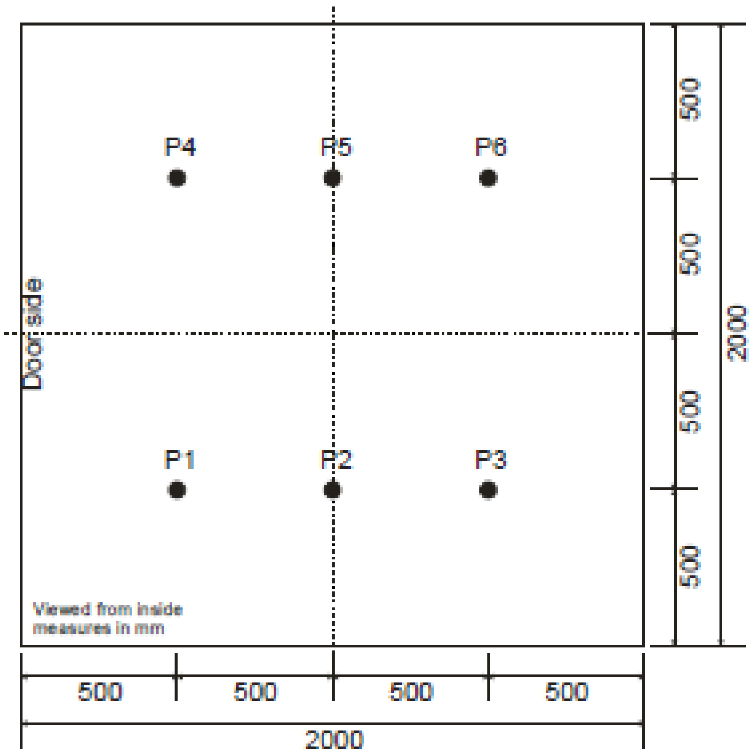


Pressure Off The Back



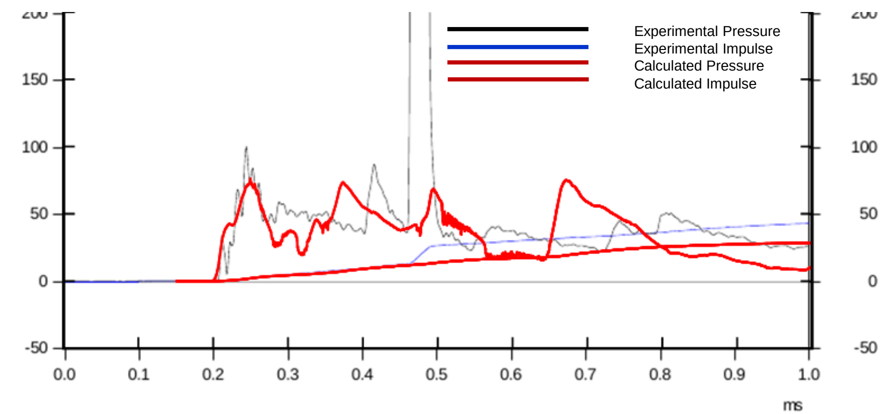
Kasun III Configuration and Charge 16 – 6.9kg Bare Charges

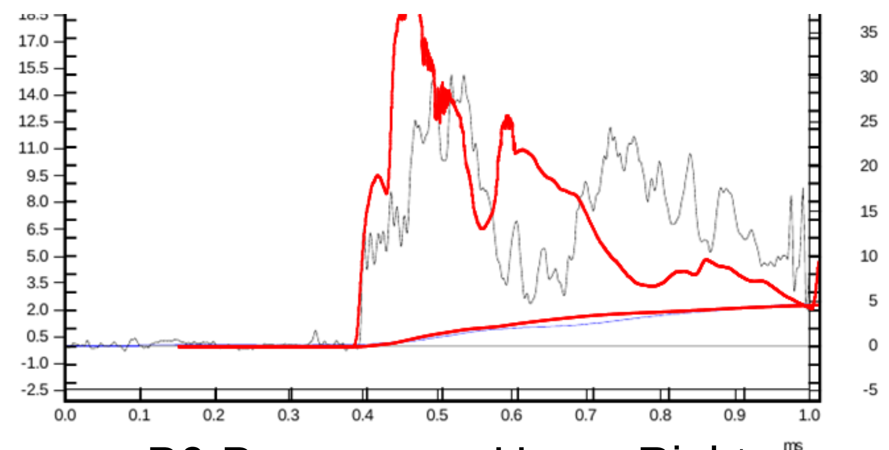
Pressure Comparisons
16 – 6.9kg Bare Charges



Pressure gauges located on internal wall

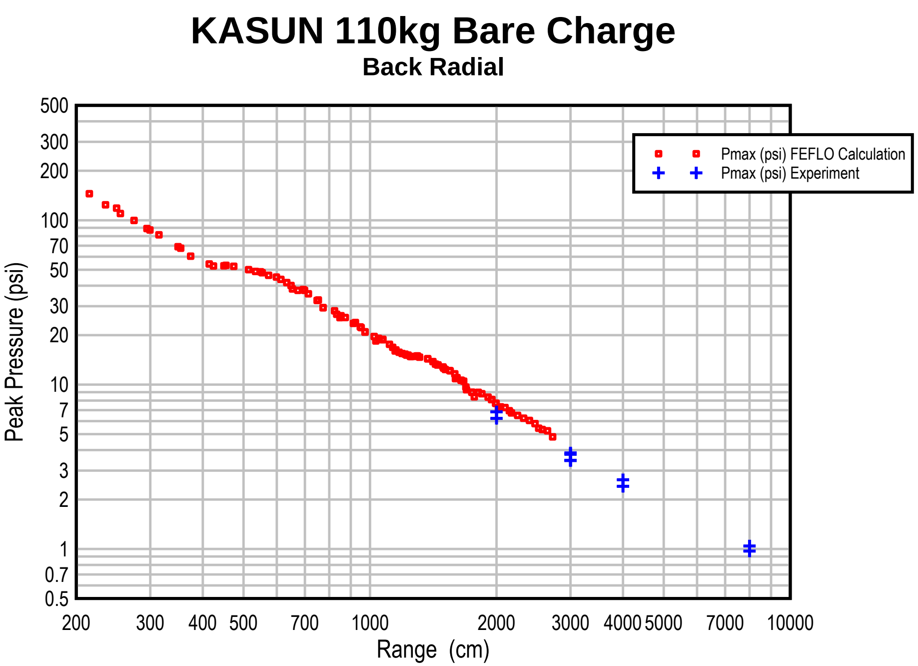
P3-Pressure on Lower Right



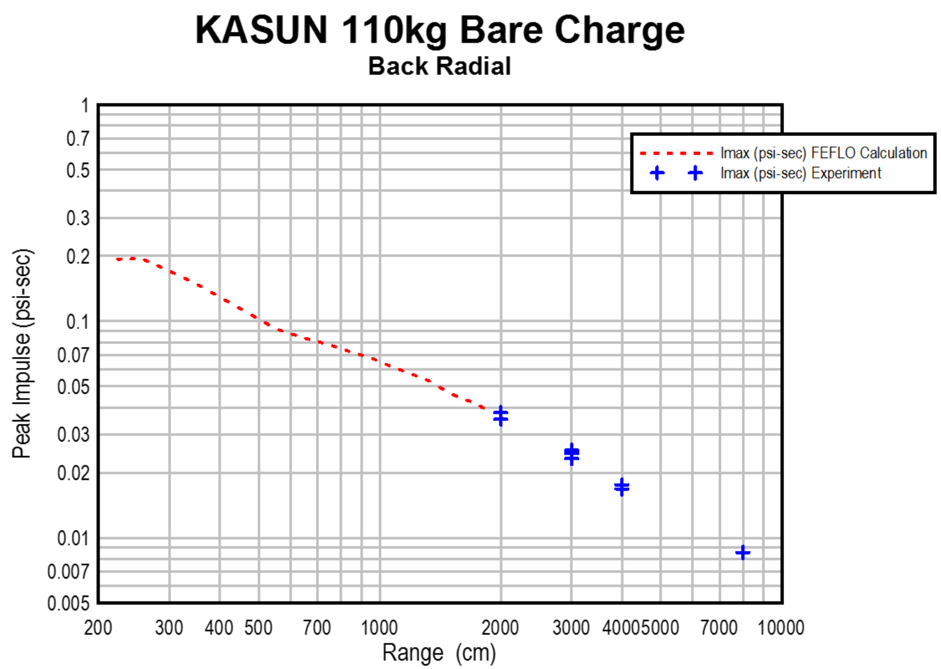


P6-Pressure on Upper Right

Pressure/Impulse Versus Range
16 – 6.9kg Bare Charges

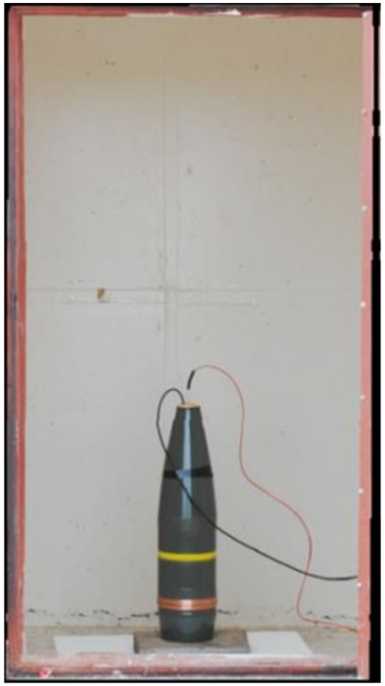


Peak Pressure vs Range



Peak Impulse vs Range

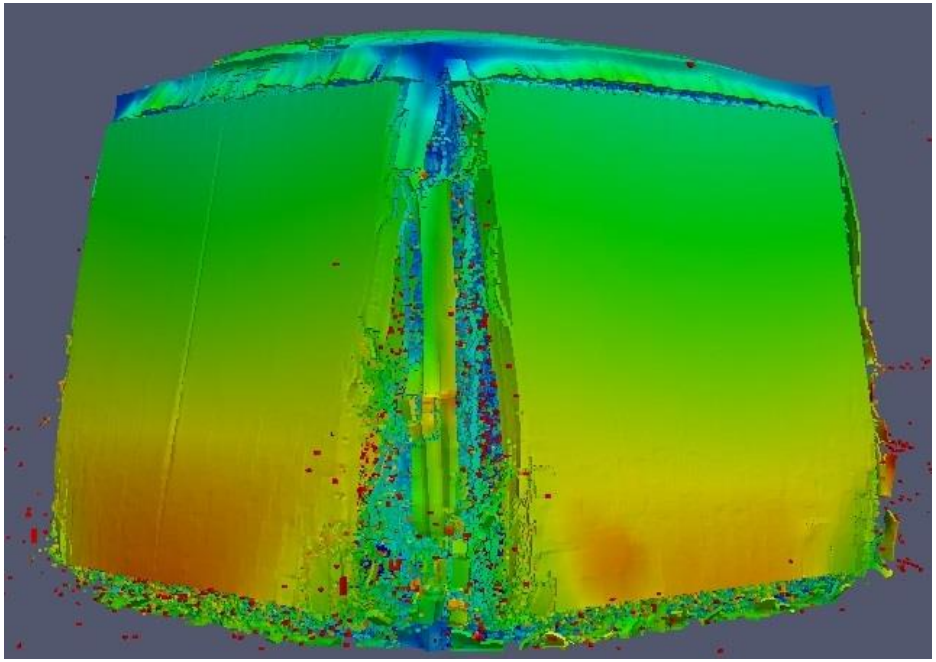
Kasun III Configuration and Charge 1 – 155mm Cased Charge



1 –
155mm Cased Charge

Kasun Structural Response

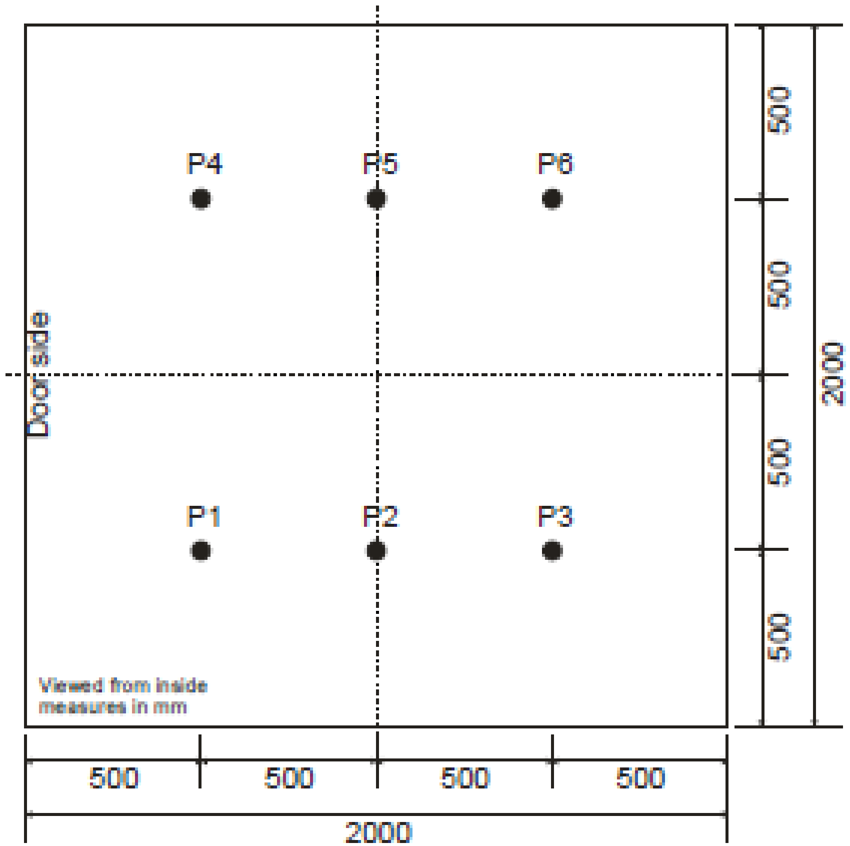
1 – 155mm Cased Charge: 14 ms



Model reproduces:

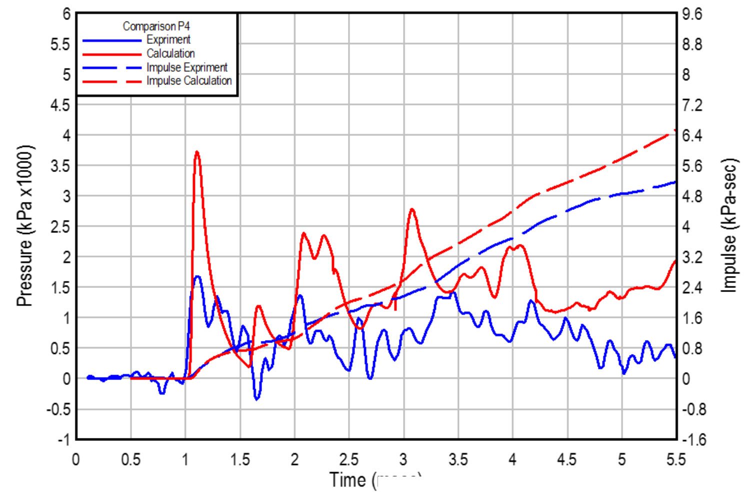
- Bulging in middle bottom of wall
- Separation of walls from floor
- Crack in corner to roof
- Initial separation of roof from walls

Pressure Comparisons
1 – 155mm Cased Charge

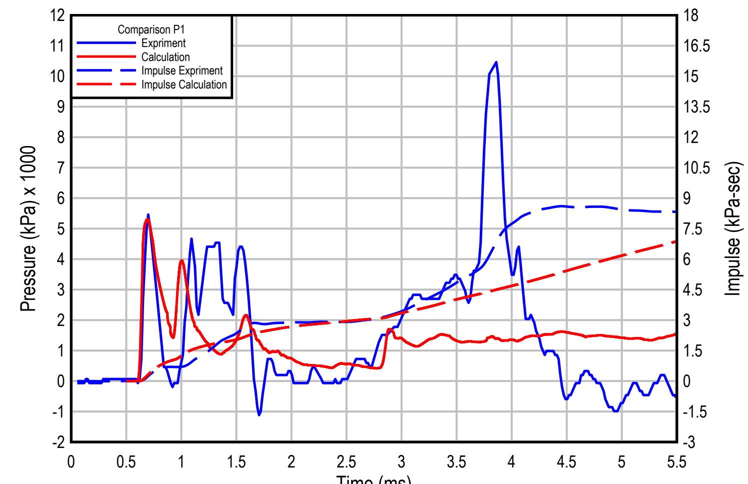


Pressure gauges located on internal wall

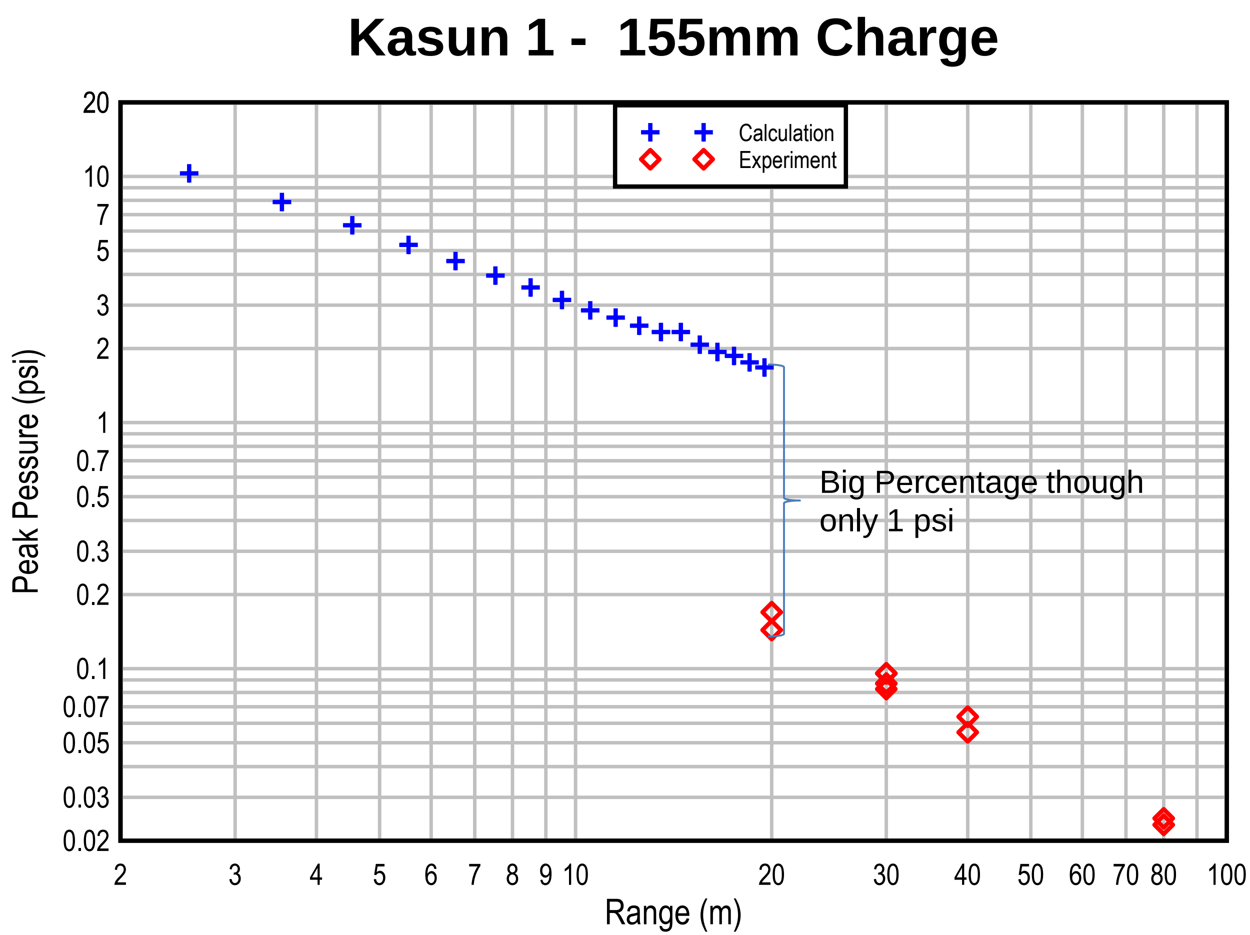
Station 4 - Upper Left



Station 1 - Lower Left

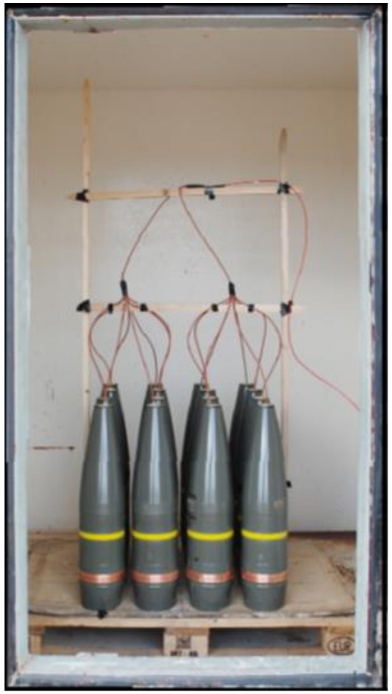


Peak Pressure Versus Range
1 – 155mm Cased Charge



Peak Pressure vs Range

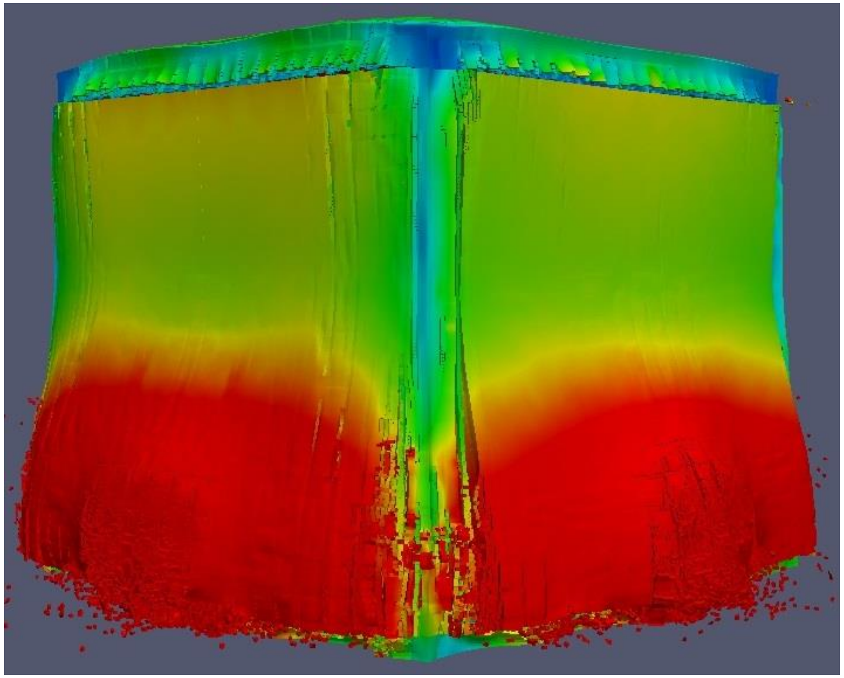
Kasun III Configuration and Charge 16-155mm Cased Charges



16 –
155mm Cased Charge

Kasun Structural Response

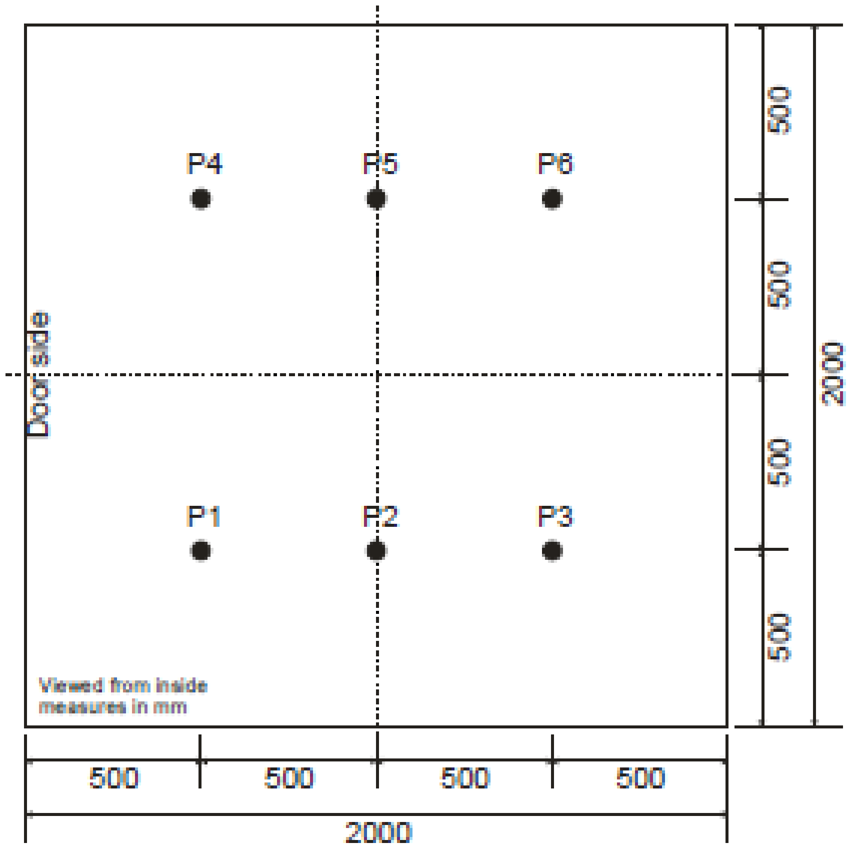
16 – 155mm Cased Charges: 2.8 ms



Model reproduces:

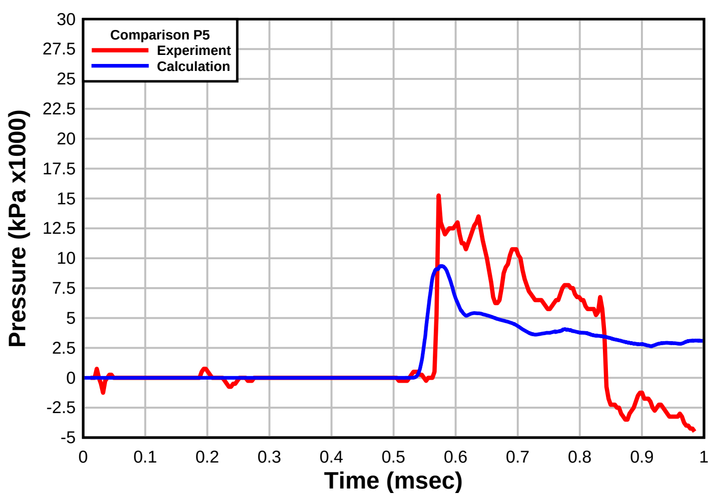
- Bulging in middle bottom of wall
- Separation of walls from floor
- Crack in corner to mid height
- Initial separation of roof from walls

Pressure Comparisons
16 – 155mm Cased Charges

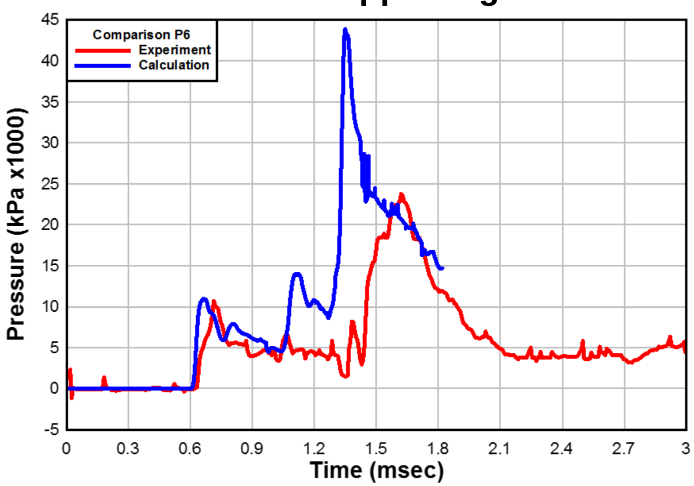


Pressure gauges located on internal wall

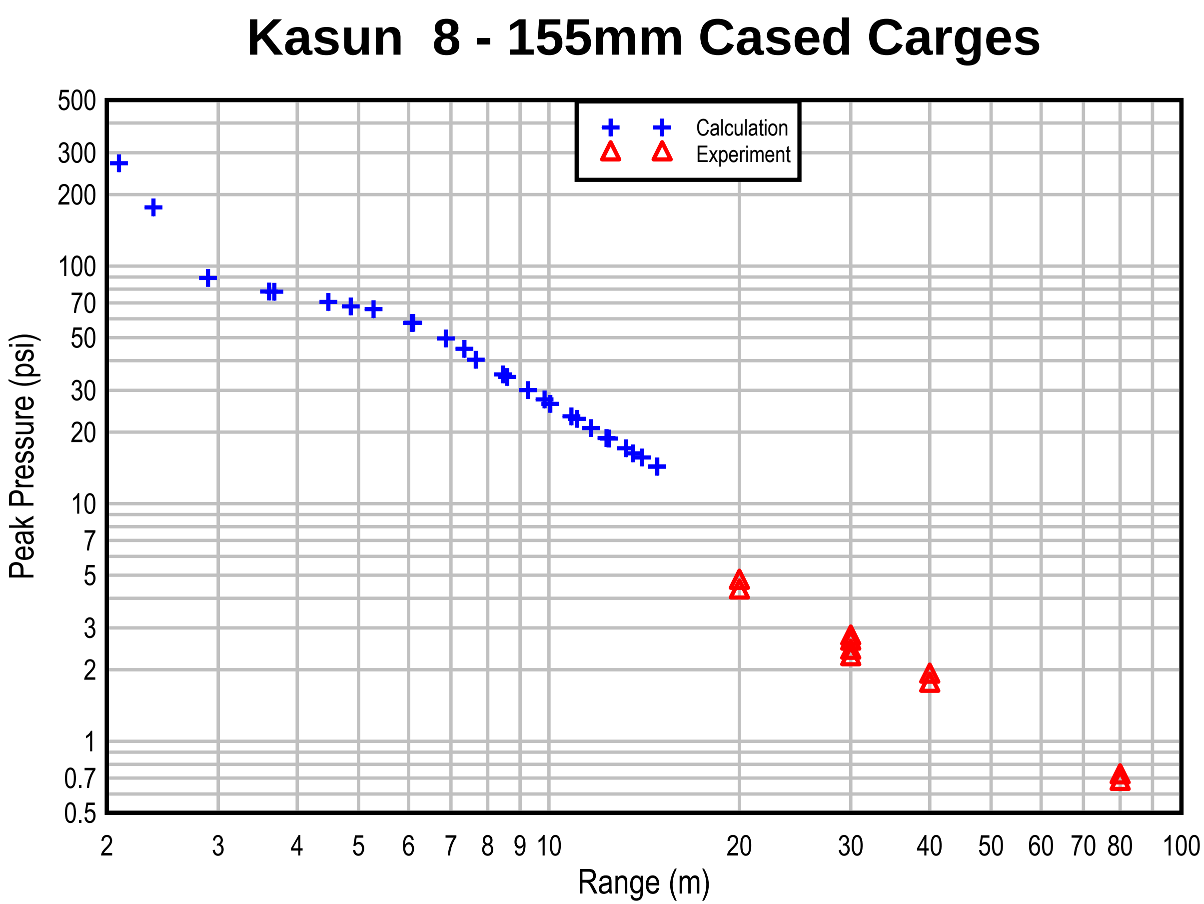
P5 - Upper Middle



P6 Upper Right



Peak Pressure Versus Range 16 – 155mm Cased Charges



Peak Pressure vs Range

Summary of Kasun Analyses

- **Bare Charge Analyses**
  - Calculated internal pressure data represent the TNO experimental data reasonably well though there are differences
  - Computed pressure vs range attenuation is nearly identical to the experimental though the magnitude is slightly greater
- **Cased charge analyses**
  - Calculated internal pressure data represent the TNO experimental data reasonably well though there are differences
  - Computed pressure vs range attenuation has the correct trend compared to the experimental though the magnitude is greater
  - Fragments do considerably more damage to the lower structure than the bare charge

Conclusions/Recommendation for Kasun Analyses

Conclusions

- Bare Charge Analyses
  - The results of the calculation generally reproduce the experimental results following trends and amplitudes within about 20% or a few psi at far field.
- Cased charge analyses
  - The results of the calculation generally reproduce the experimental results following trends and amplitudes within about 30% or a few psi at far field.

Recommendation

- Though pressures and debris launch velocity are useful, the primary metric for these test is the observed debris field.
  - The ability to automatically load the coupled-code fragment data into an accepted trajectory code would be helpful.

Applied Simulations, Inc.

Questions?