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Title: Abaqus Simulations of Rock Response to Dynamic Loading

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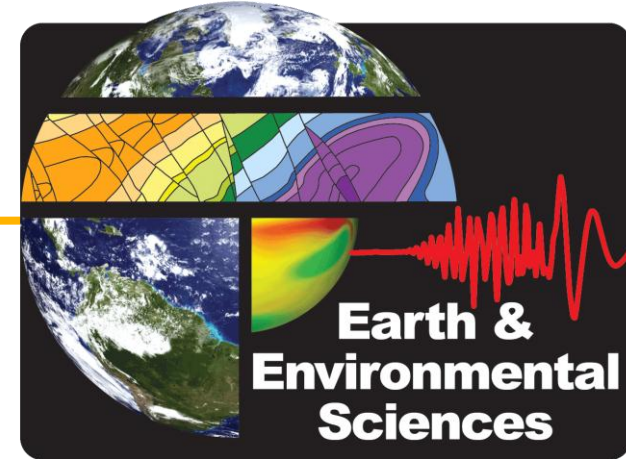
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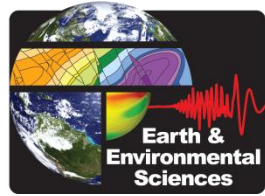
Abaqus Simulations of Rock Response to Dynamic Loading



David Steedman & David Coblentz

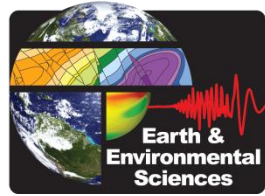
**Los Alamos National
Laboratory/Geodynamics Team
Los Alamos, NM, USA**

Outline

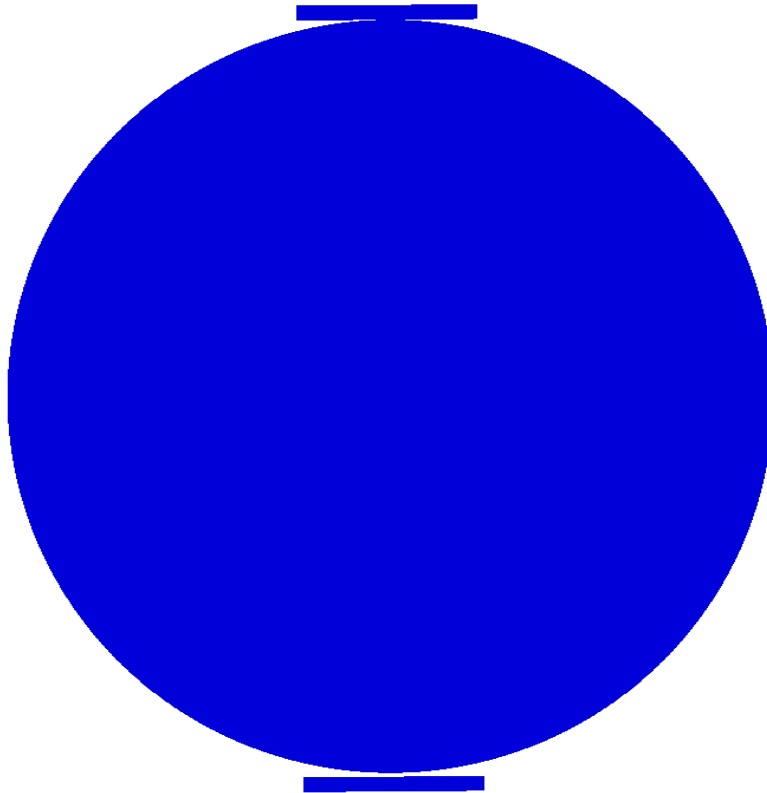
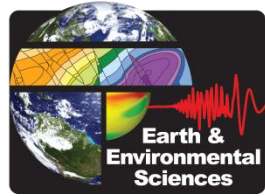


- **Dynamic rock properties**
 - Brittle failure
 - Non-linear EOS and strength
- **Some historic LANL Abaqus simulations**
- **Complex geologic structure**
 - GAMUT to CAE
 - Blocks and faults
 - Recent shock response simulation

Rock Fracture – Dynamic Brazilian Test



Abaqus Rock Fracture Simulation

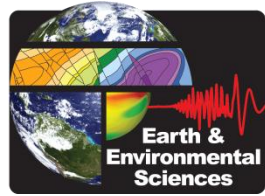


Simulation



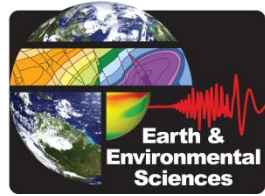
Failed Core

Rock Constitutive Response



- The wide range of loading regime in explosive shock requires specialized material models
- Non-linear P - μ EOS coupled to a 3-invariant yield model in P - Q space
- Properties based on laboratory specimen from formations of interest
- Accessed as an Abaqus user model

Generic Rock Response Model

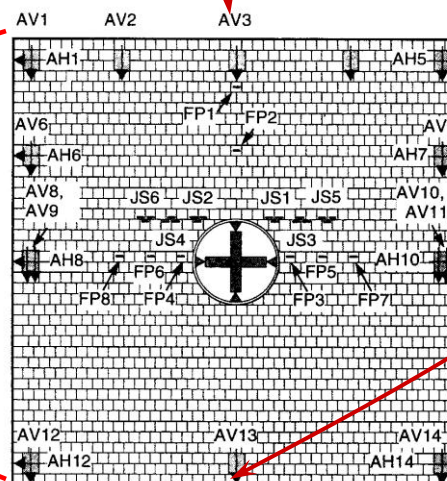
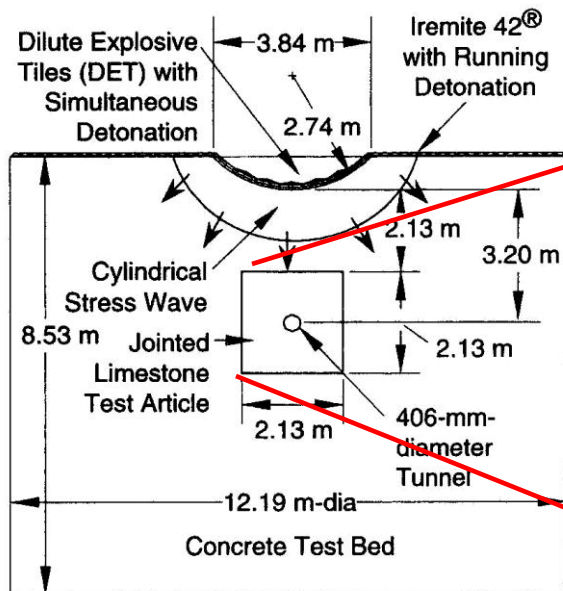
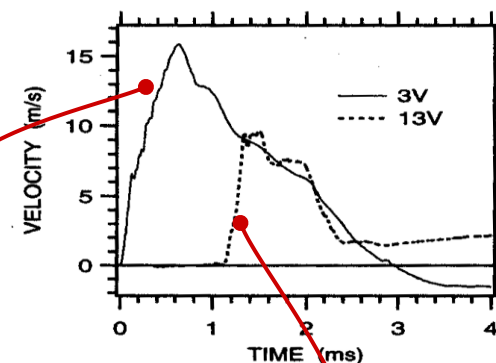


- The wide range of loading regime in explosive shock requires specialized material models

“2-D” Dynamic Lab-Scale Test

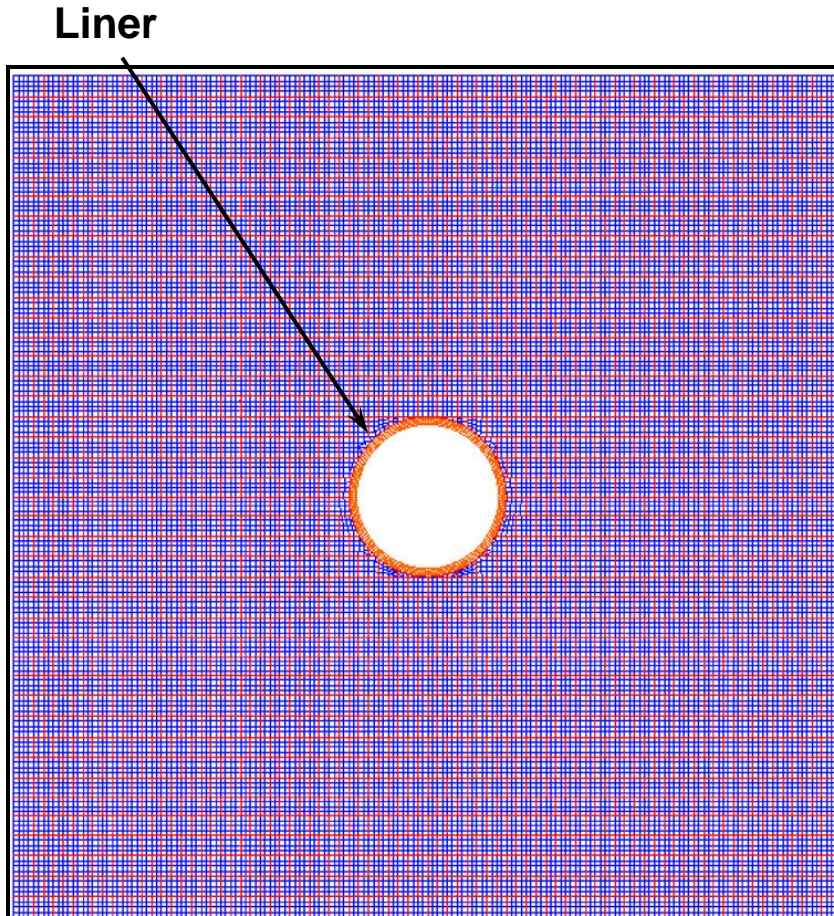
- 5-cm square milled limestone bars
- Stacked around a 0.406-m ϕ aluminum tube
- Embedded in a concrete test bed
- Loaded by shaped cylindrical charge

Measured Velocities used as BCs



Ref: J. K. Gran, et. al.,
“Dynamic Response
of An Opening in
Jointed Rock,”
*Int. J. Rock. Mech.
Min. Sci.*, 35,
1021-1035, 1998.

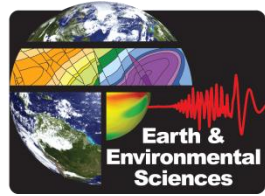
2-D Plane Strain Abaqus Model



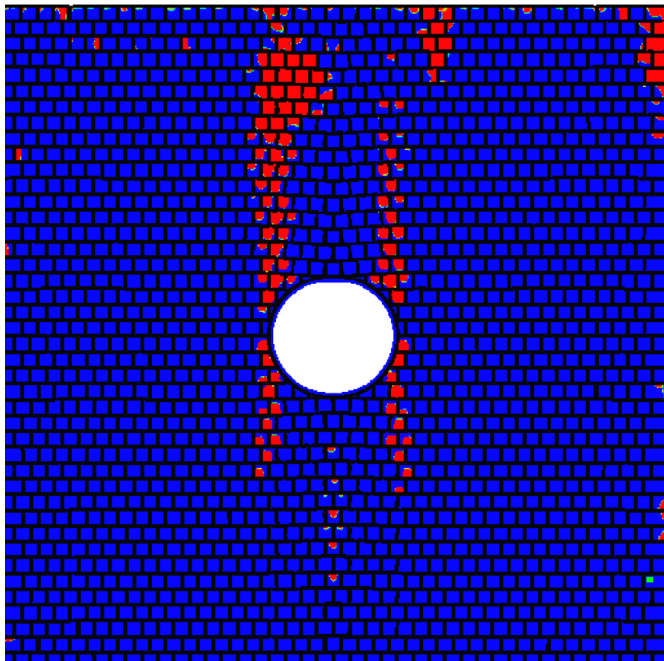
- **Brittle material model**
 - tensile and shear failure
 - w/strain softening
- **Boundary condition**
 - velocity boundary data
- **Aluminum liner**
 - Continuum elements
 - Elastic-plastic response

— = Individual Elements
— = Contacts

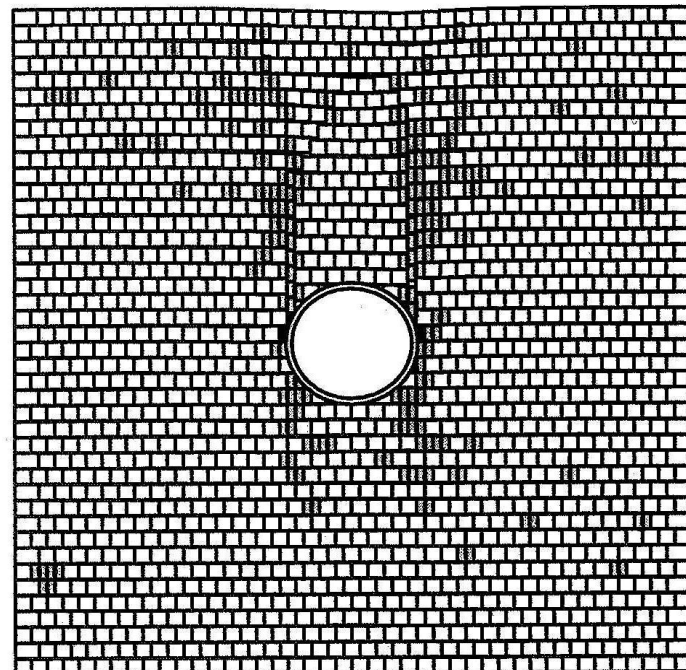
2-D Model Response- Rock Response



- Brittle cracking/failure
- Block movement within “chimney”



Abaqus Model

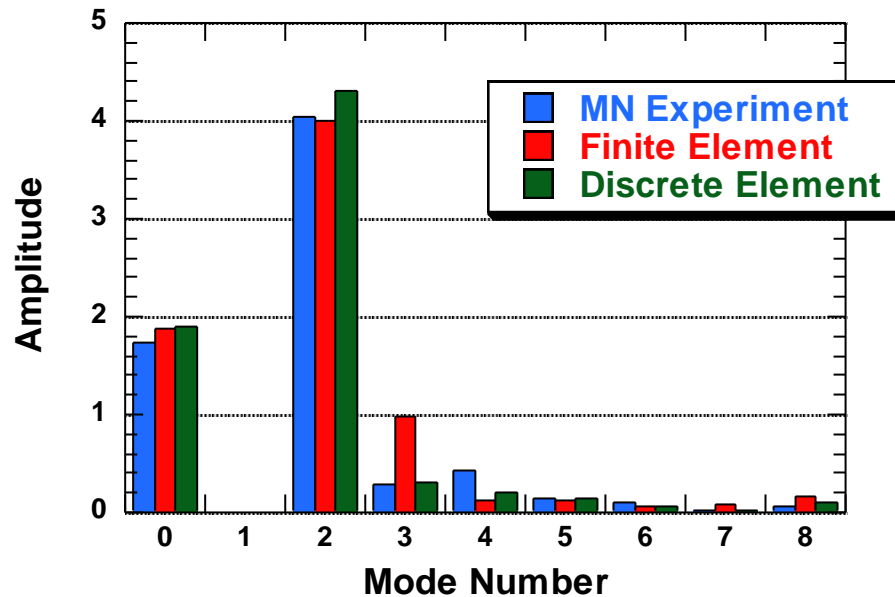


Deconstructed Test Bed

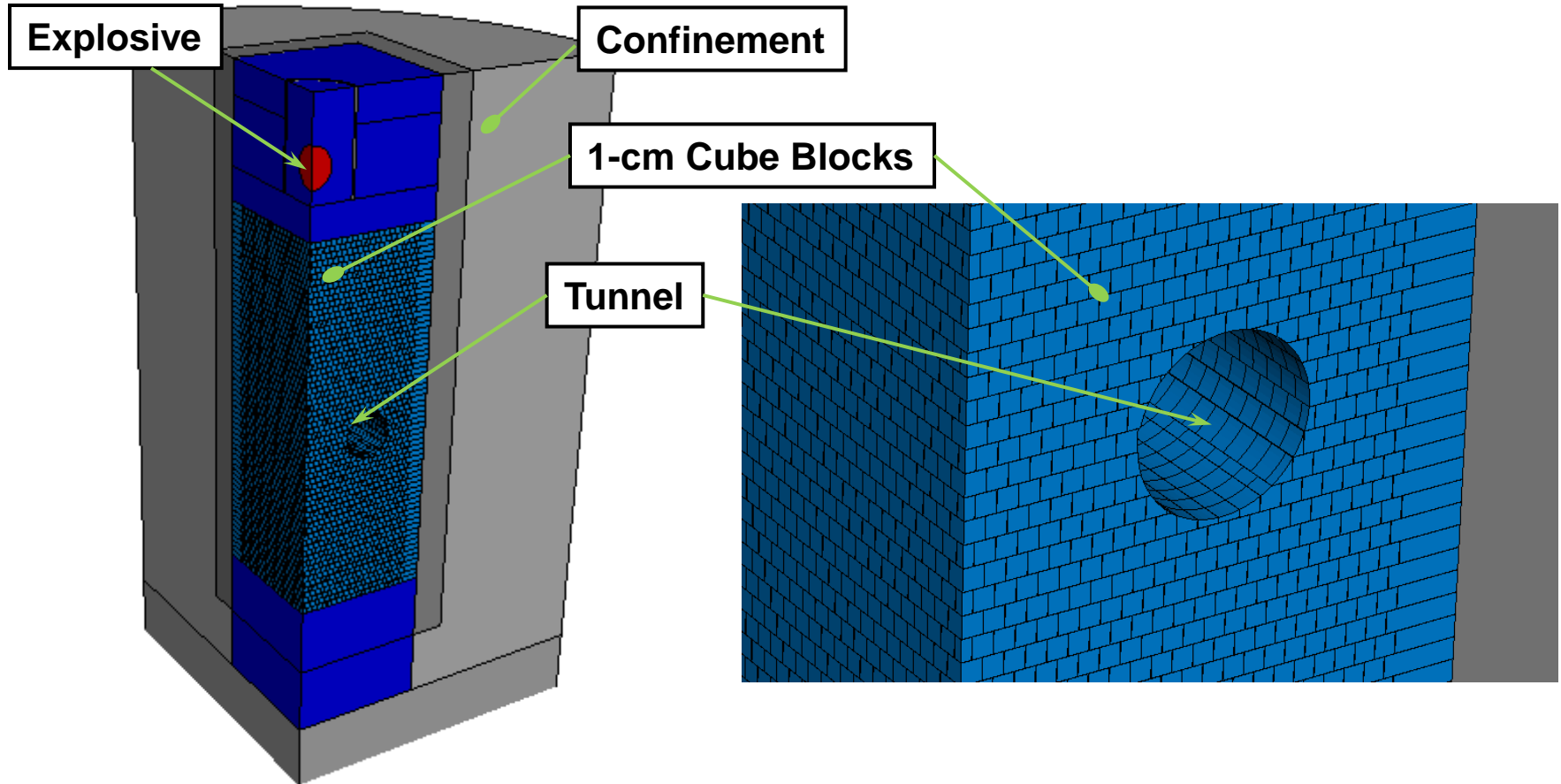
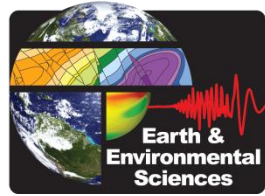
2-D Model Response- Liner Response

- Primary modal response matched
- Deformation:

Liner Deformation	Measured (mm)	Computed (mm)
Crown to Invert	11.4	12.9
Springline to Springline	3.5	3.5



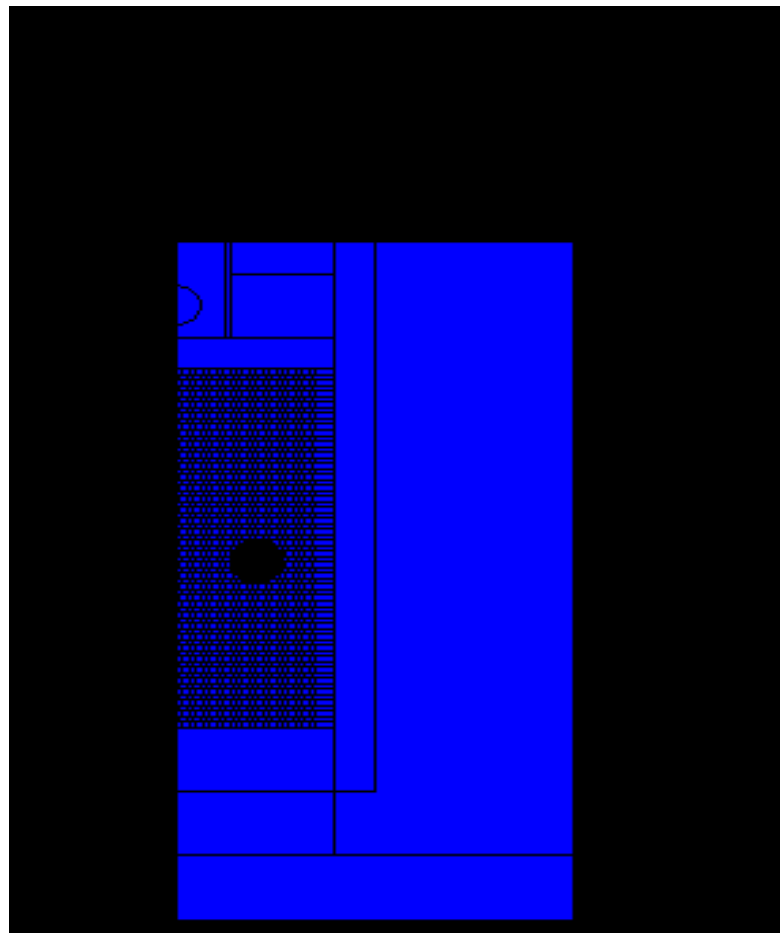
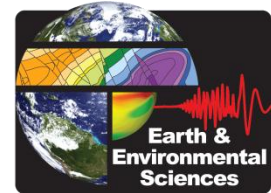
3-D Dynamic Lab-Scale Test



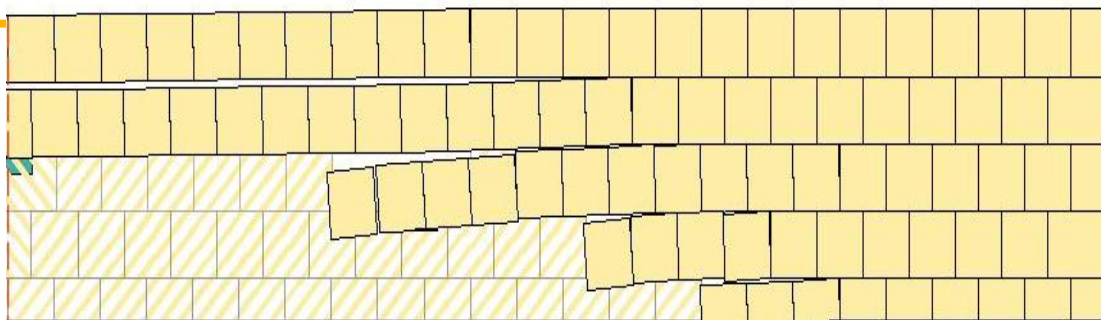
$\frac{1}{4}$ -symmetry Abaqus Model

Close-up of Tunnel Region

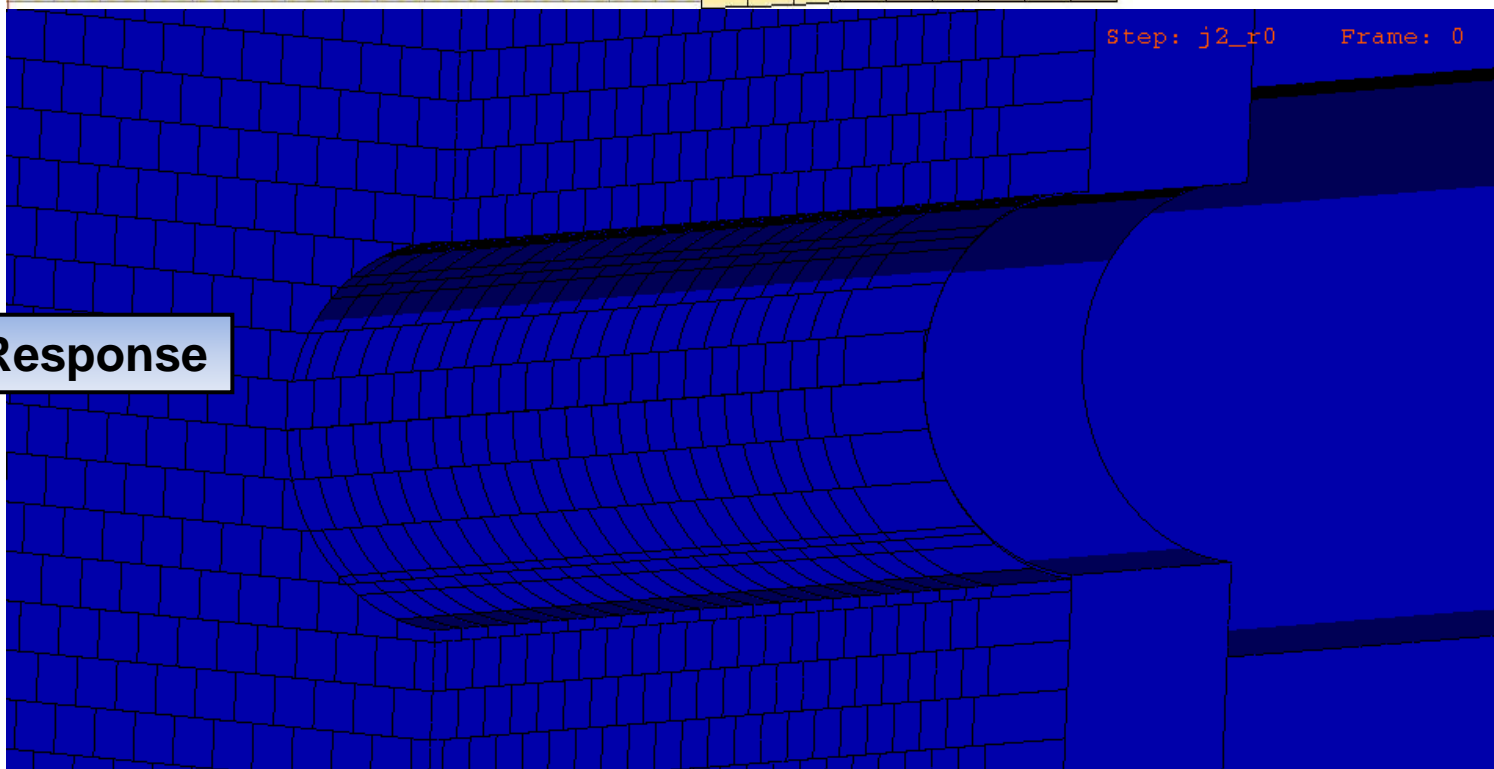
3-D Test Response– Full Model



3-D Test Response– along Tunnel Axis

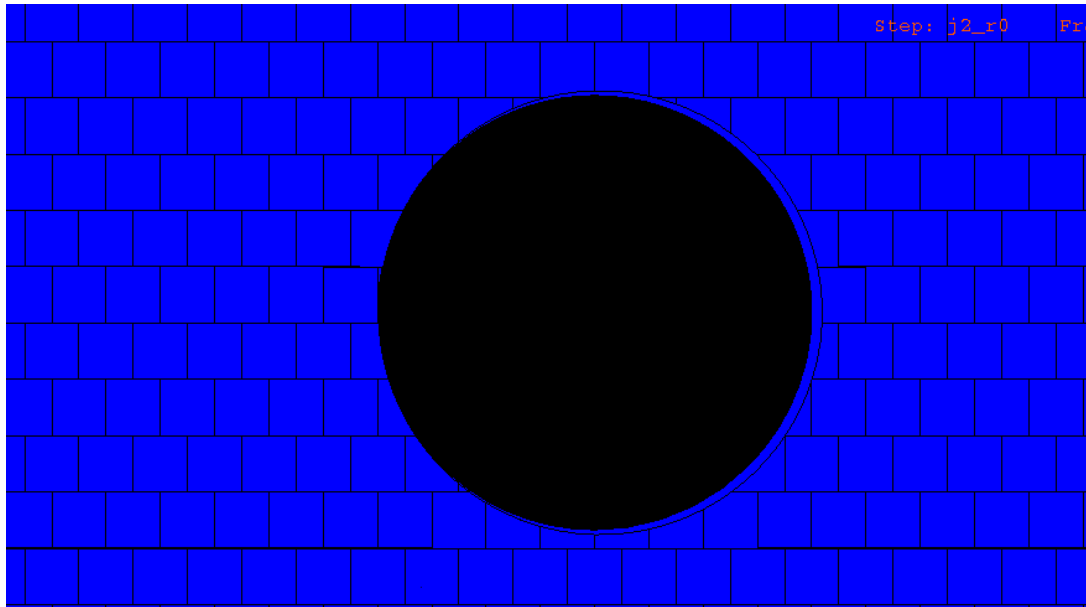


Damage Map



Computed Response

3-D Test Response– End On



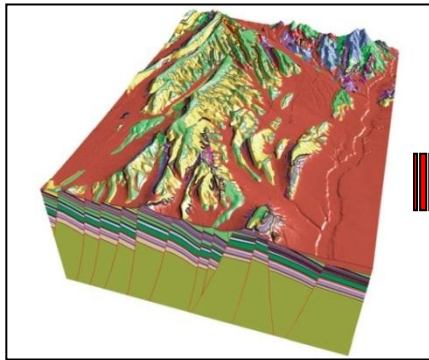
Block Motion Photo



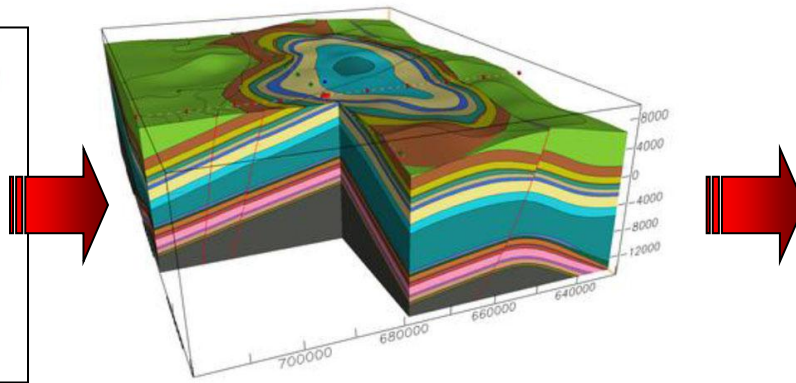
Computed Block Motion

The GAMUT Tool for Geologic Models

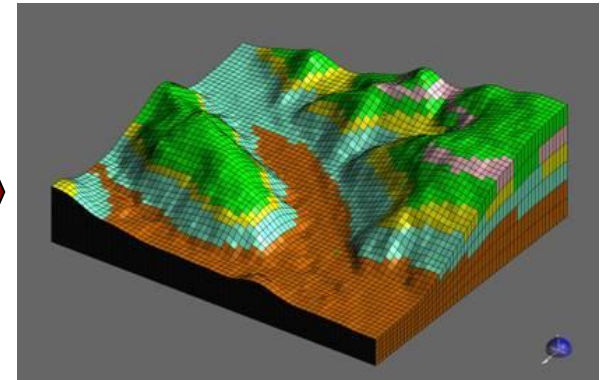
- **Geologic Assessment Methodology for Underground Targets**
- **Input = geologic information**
- **Output = geometric volumes**
- **Import to CAE for model building and meshing**



**Geologic
Structure**



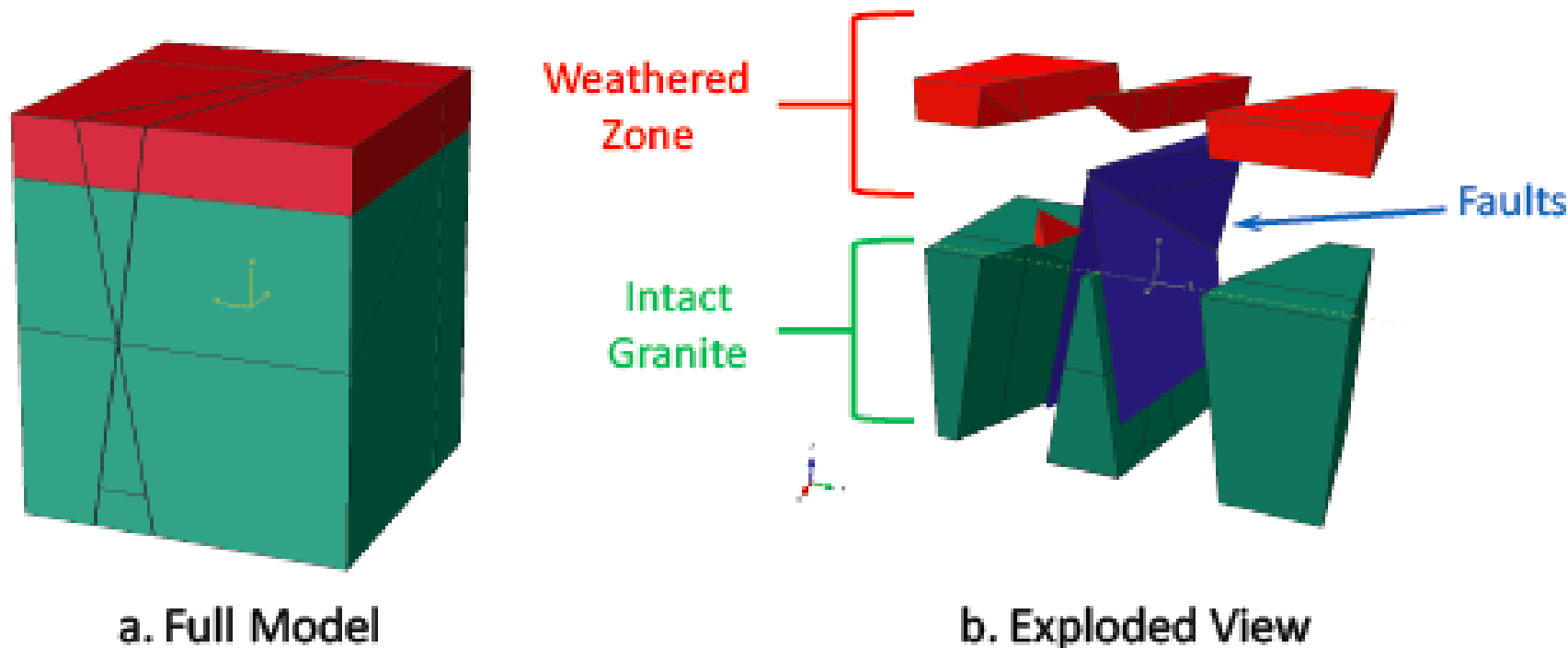
**Geologic
Framework
Model**



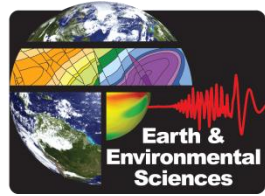
**Model for
Numerical
Analysis**

GAMUT Model for Field Test

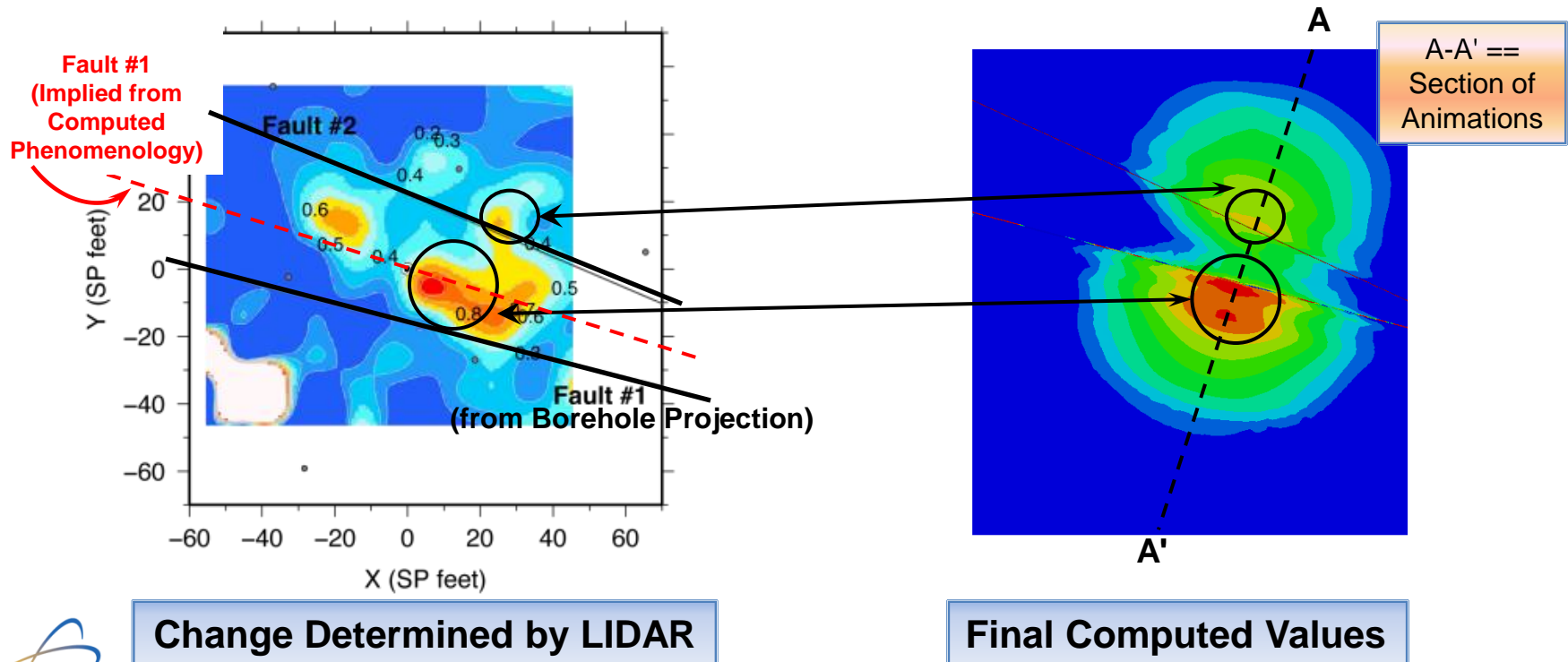
- Includes weathered/intact granite layers and near source faults
- Modeled faults as a shell structure
- Material properties derived from tests on cores
- Includes Eulerian explosive region for fully coupled CEL* simulation



Displacement Contours Comparison

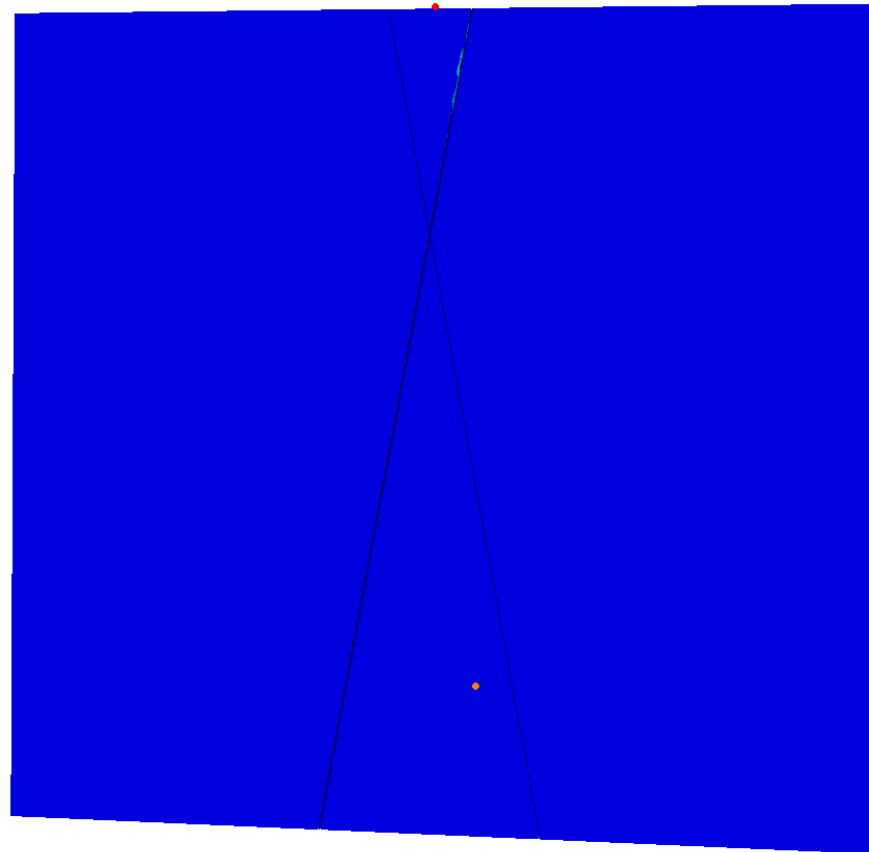
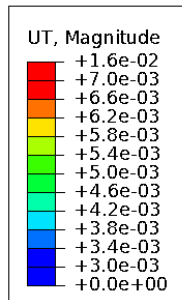


- Qualitatively similar patterns
- Appear to correspond to location of faults
 - Fault locations based on projection from borings
 - Fault #1 may be incorrect based on simulation results



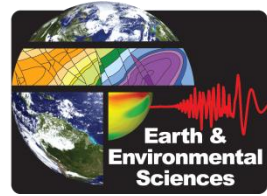
Abaqus Displacement Animation

- Development of the surface expression of displacement relative to the faults is seen

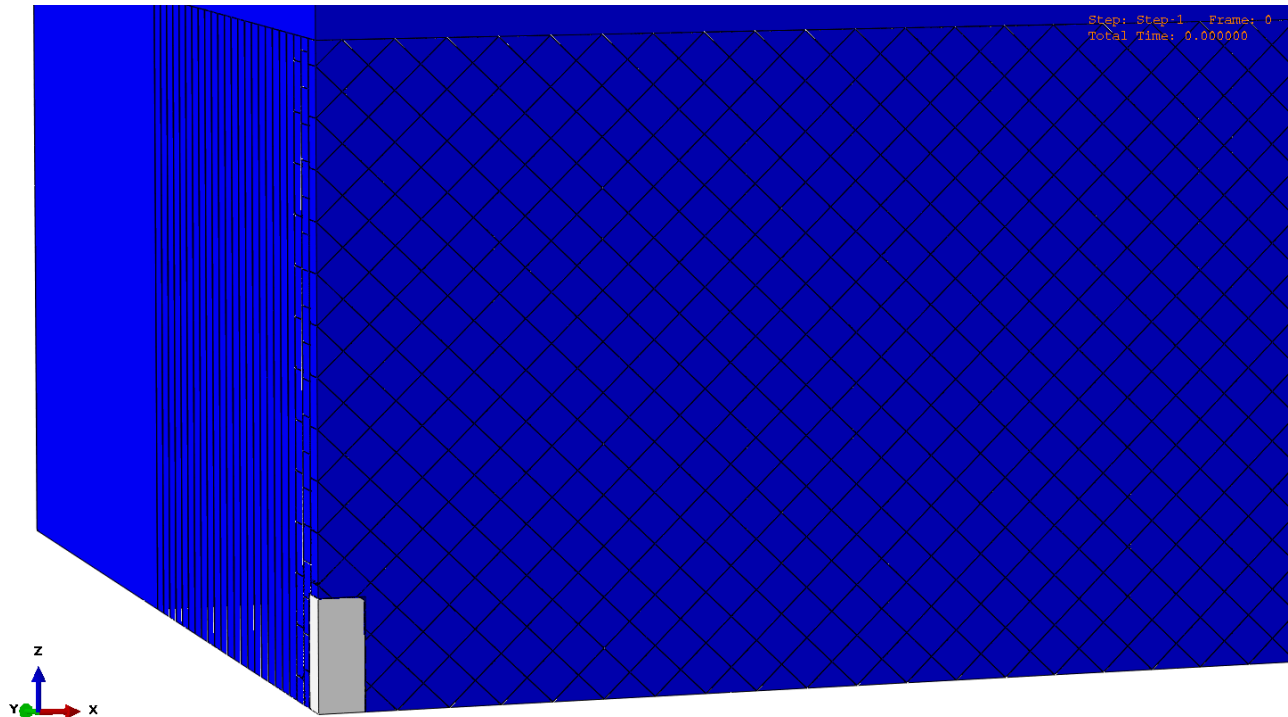


Step: Step-1 Frame: 0
Total Time: 0.000000

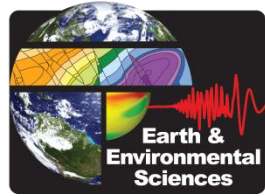
Simulation of Explosive in Jointed Rock



- Next step is to include joint sets
- Include material failure and element deletion to simulate expanding explosion product gases



Summary



- **The LANL Geodynamics Team has been applying Abaqus modeling to achieve increasingly complex simulations**
- **Advancements in Abaqus model building and simulation tools allows this progress**
- **We use Lab-developed constitutive models, the fully coupled CEL Abaqus and general contact to simulate response of realistic sites to explosively driven shock**