Multi-Length Scale Algorithms for Failure Modeling in Solid Mechanics

LDRD
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Sandia National Laboratories
Benjamin Spencer, Martin Heinstein, Jason Hales

Introduction

- Explicit dynamics is widely used in solid mechanics, especially for modeling failure
  - Smallest elements in model control critical time step for stability
  - Explicit dynamics does not work well with models that span length scales because the time step is too small
- A multi-length scale technique has been developed for transient dynamics
  - A coarse mesh is used in conjunction with the fine mesh of the actual model.
  - Coarse mesh controls time step
  - Fine mesh models geometry in detail

Methodology

- Dynamic equilibrium (a is acceleration, M is mass, R is residual):

$$Ma = R$$

- Decompose a into high and low frequency parts a_{hf} and a_{lf} represented on fine and coarse meshes where Φ is an interpolation matrix:

$$a = a_{hf} + \Phi\, a_{lf}$$

- Orthogonal decomposition in M yields equation for acceleration from high, low frequency components:

$$a = \Phi M_c^{-1} \Phi^T R + M^{-1}(R - M\Phi M_c^{-1} \Phi^T R)$$

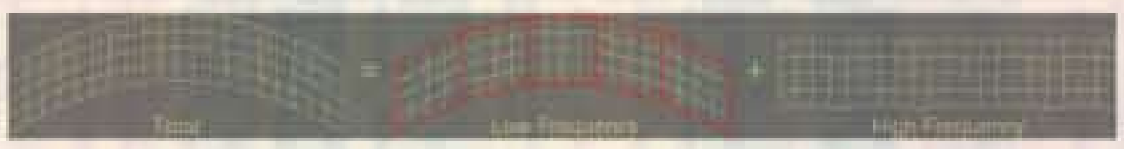
where M_c is the mass on the coarse mesh, and is computed as:

$$M_c = \Phi^T M \Phi$$

- Scale mass only on high frequency response using diagonal scaling matrix, α, to allow integration at time step of coarse mesh

- This yields the following dynamic equilibrium equation:

$$a = \Phi M_{lf}^{-1} \Phi^T R + (\alpha M)^{-1}(R - M\Phi M_{lf}^{-1} \Phi^T R)$$

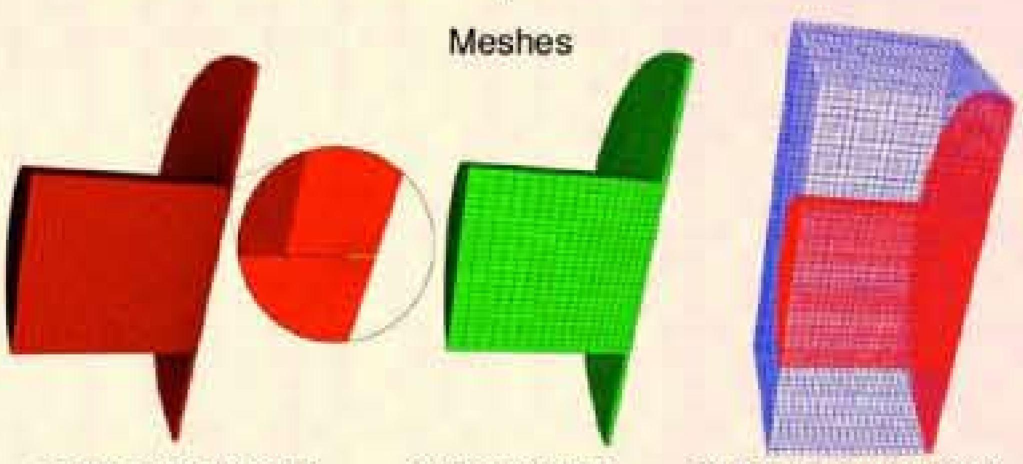


Applications

Laser Weld Test

- This explicit multi-length scale technique has been used to model an experimental test of laser welds on a weapon component
- The test consists of a "plug" laser welded to a base plate. The base plate is bolted to an assembly that is dropped. When the assembly hits the bottom, the inertia of the plug loads the laser weld.
- An extreme amount of mesh refinement is required to model failure in the welds

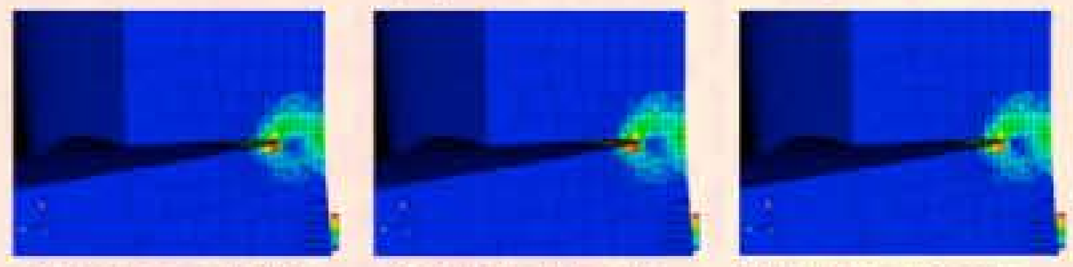
Meshes



a) Fine mesh (zoomed region shows mesh of laser weld) | b) Coarse mesh conforming to geometry | c) Regular coarse mesh of bounding box (blue), Fine mesh (red)

Applications

Results (Equivalent Plastic Strain)



a) Baseline model (a) critical dt= 3.6e-9s, run time = 205m (200 processors)

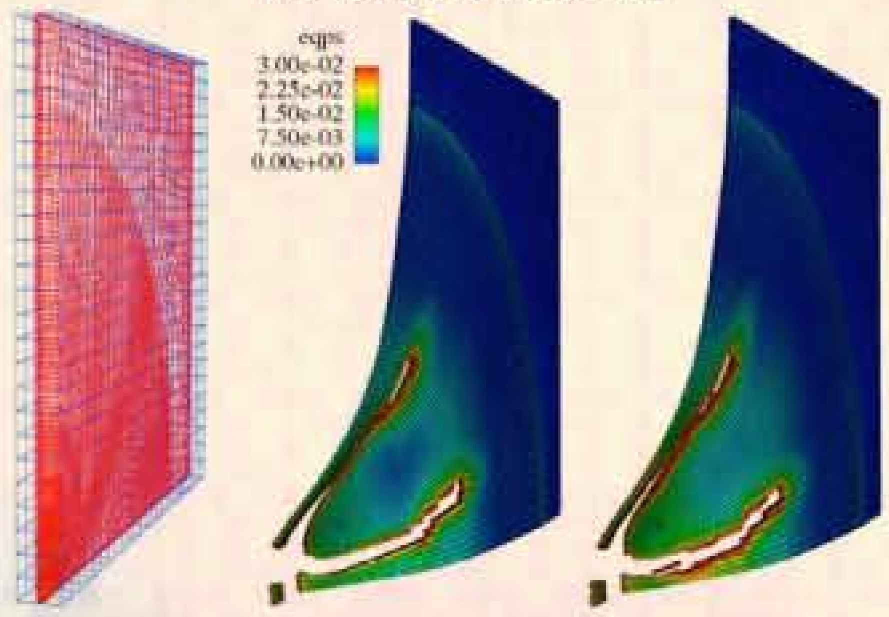
b) Multi-length scale model with conforming coarse mesh (b) critical dt= 1.2e-7s, run time = 8m (200 processors) 24x speedup

b) Multi-length scale model with regular coarse mesh (c) critical dt= 1.8e-7s, run time = 6m (200 processors) 36x speedup

Plate Blast Test

- A plate is subjected to a blast load at the center
- This test demonstrates that the explicit multi-length scale technique can model problems with large deformations and failure (element death)

Model and Results



a) Fine mesh of plate (red) with coarse mesh (blue)

b) Baseline model (colored by equivalent plastic strain)

c) Multi-length scale model (4.2x increase in critical time step, 2.2x speed-up)

Summary

- Multi-length scale technique for explicit dynamics permits the use of fine meshes that capture multiple length scales with reasonable time steps
- Accuracy and efficiency of this technique has been demonstrated
- Fine mesh is chosen to adequately capture geometry and solution gradients of interest without concerns for the effect of small elements on time step
- Coarse mesh is chosen to allow integration at a tractable time step. Dynamics of interest can be captured with a time step much greater than that dictated by stability considerations.

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department
of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.
SAND 2008-3846P CreativeArts 98429.LW.8.08

NNSA National Nuclear Security Administration

Sandia National Laboratories