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Title: Deformation and Flow in Granular System from Impact and Blast Loading (U)

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Form 836 (7/06)

Deformation and Flow In Granular Systems from Impact and Blast Loading

Shock-Wave Profile and Pre-cursor in Granular Materials

- A granular material's shock response be represented by a Hugoniot – but is this representation capturing the meso-copic and physical processes occuring?

- Is a Hugoniot the best way to represent the shock response of a granular material?

- How does the shock-wave profile change with time?
  - What does the small –pre-cursor wave do?
  - Attenuation?
  - Dispersion?

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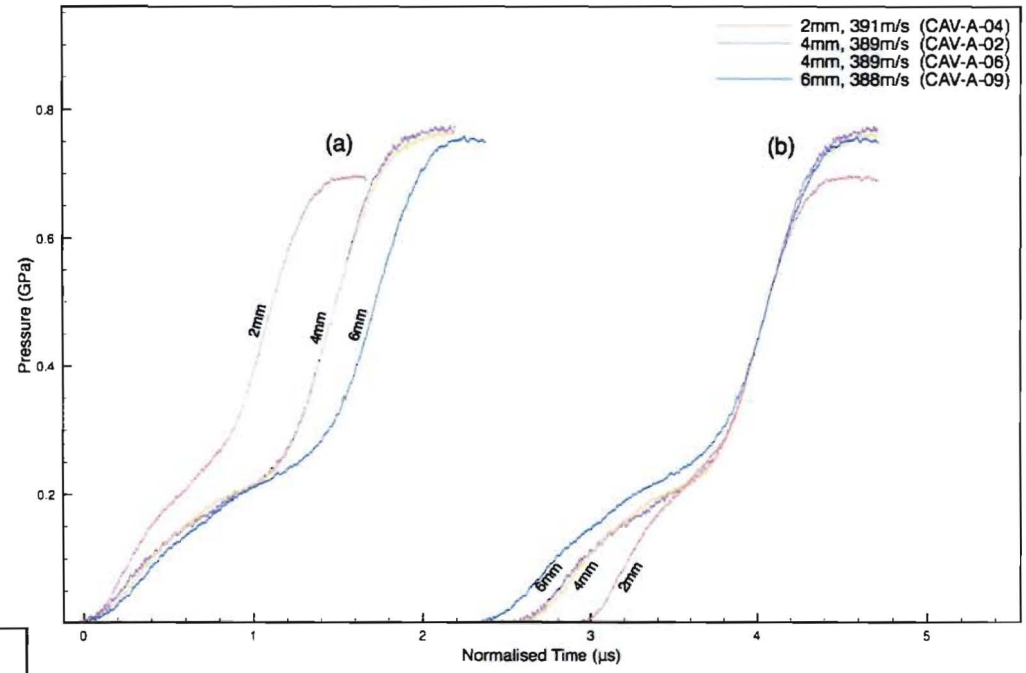
Shock Propagation in Sand - Wave Analysis

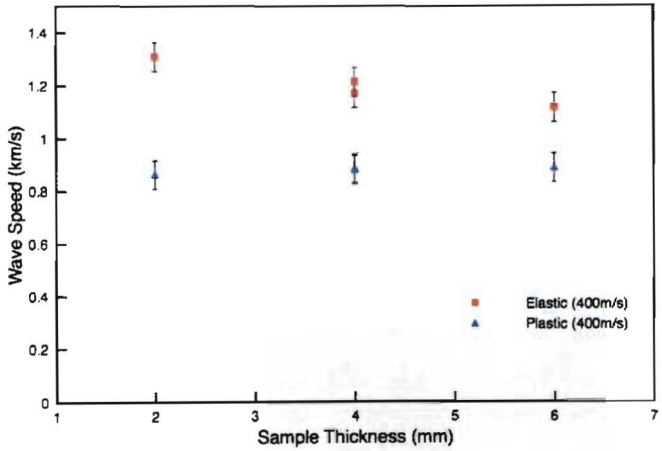
Precursor

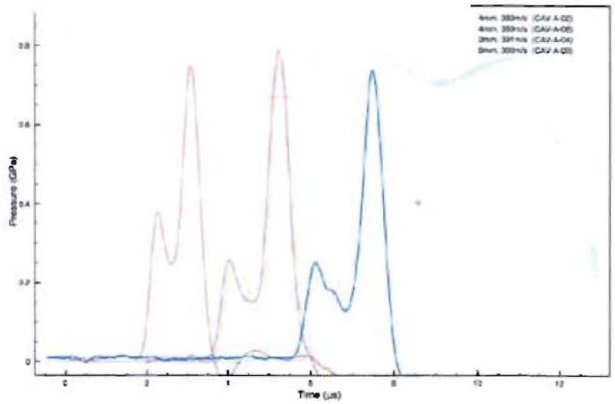
- Unsteady
- Faster than shock
- Decreasing in velocity
- Dispersion – force chains?
- Many theories need proof.

Shock

- Constant velocity
- No dispersion
- No attenuation







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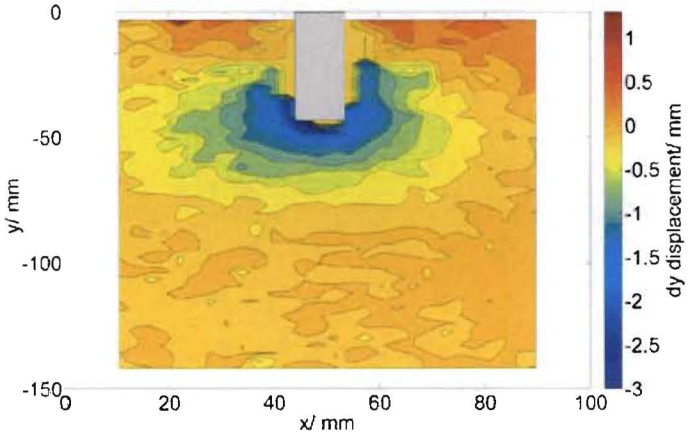
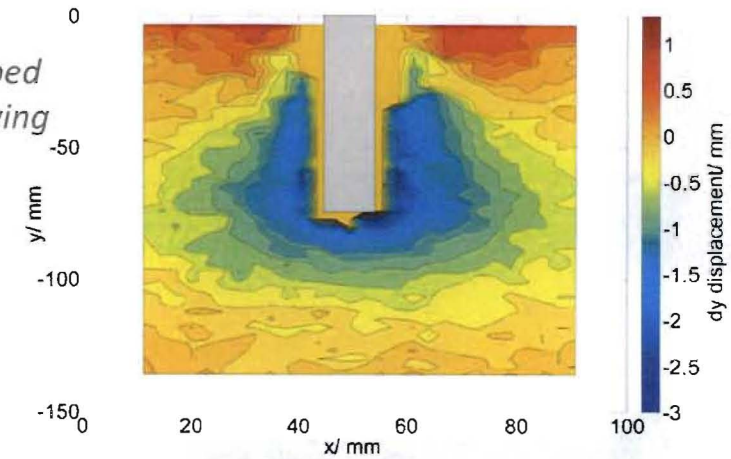
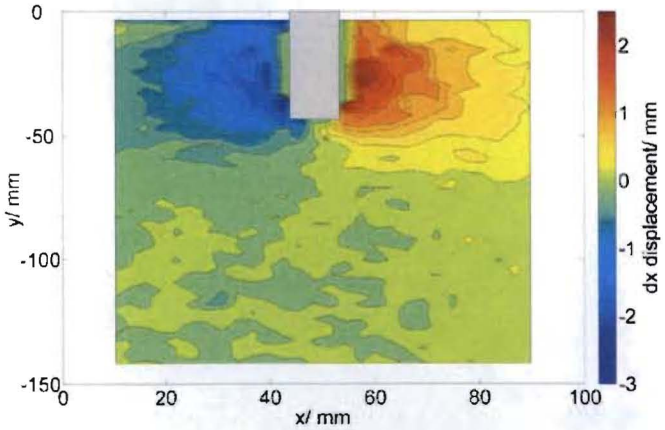
Stress Waves Longitudinal and Lateral components (2009)



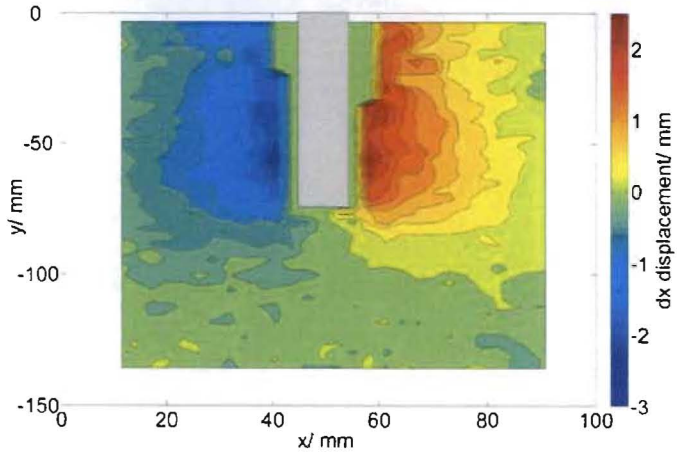
1. *Expanding cone shaped area of material moving longitudinally*
2. *Fixed angle of cone through all images*





250us after impact

1. *Lateral displacement roughly uniform along rod*
2. *Same lateral extent of deformation throughout*



450us after impact

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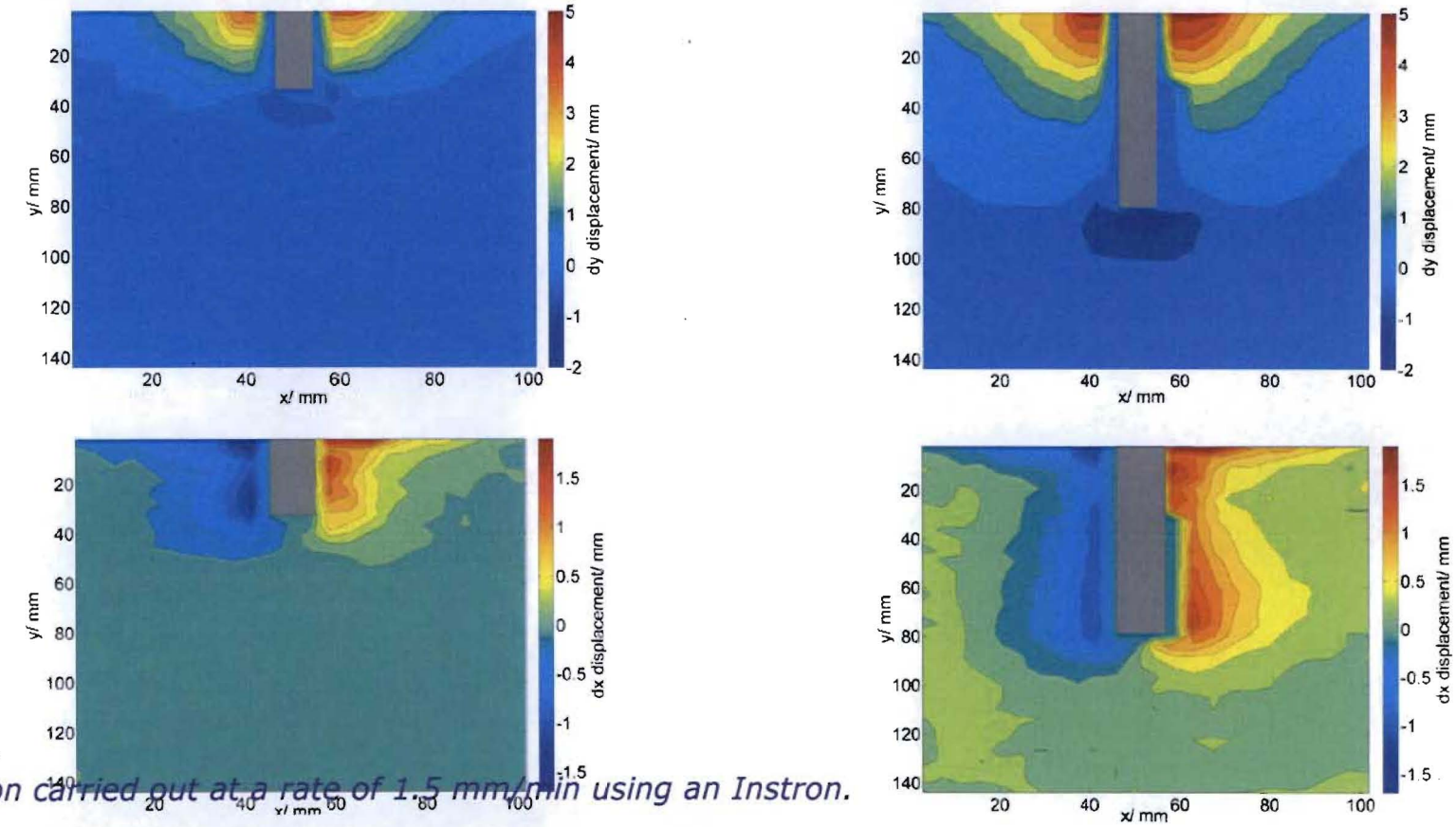
Quasi-static - Longitudinal and Lateral components



Penetration carried out at a rate of 1.5 mm/min using an Instron.

Same sample geometry, projectile, x-ray setup etc. As dyamic study

Looking for rate dependence in the penetration process – will give a fuller understanding of the behaviour of the material.

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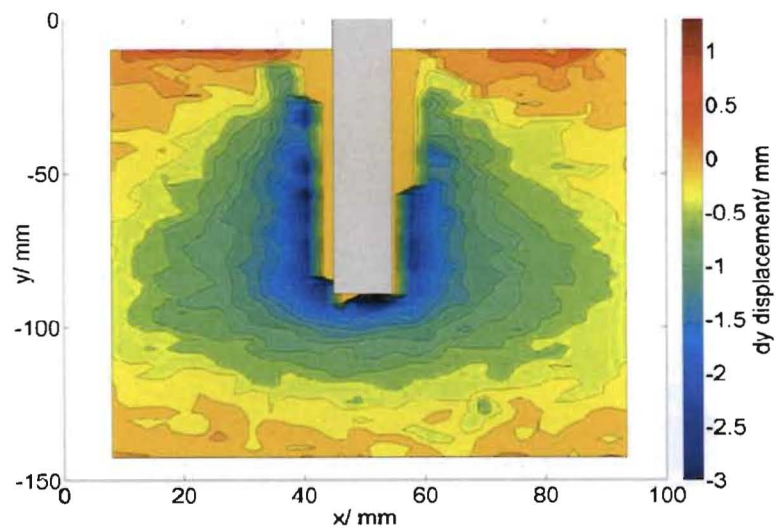
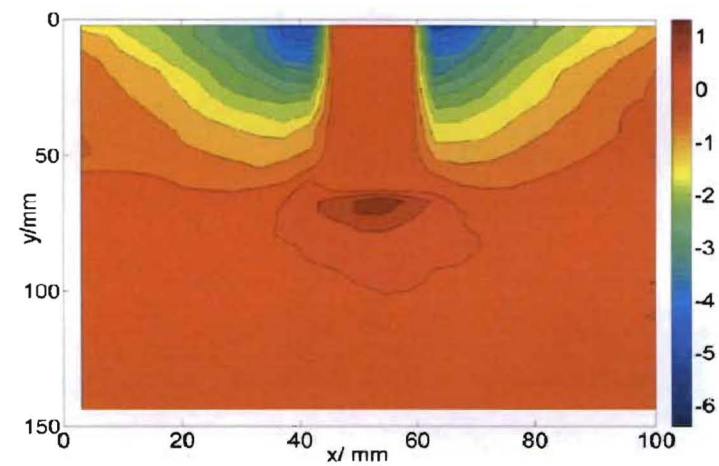
Comparison – At same depth of penetration





- *In the quasi-static case most of the material down to the rod tip is moving upwards*
- *There is no travelling compaction wave in the material*

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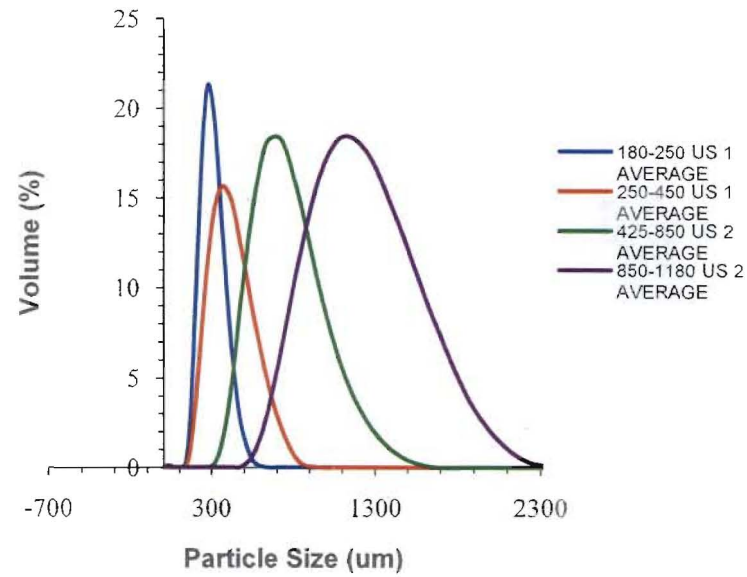
The Question – Does pre-cursor, wave reflection affect macroscopic repsonse and if so how?

Meso-structural Movement and Fracture

- Brittle grain fracture
- Linked to plastic/shock wave structure
- Rate dependant?

Particle Size

- Porosity is function of particle size
- Mono-modal vs multi-modal
- Fracture dependant?



Experiments

- LANSCE
- Samples with wave reflection from rigid, angled surfaces
- pRad
- Velocity interferometry
  - » Improved temporal resolution
  - » Multiple points/thicknesses
  - » Non-invasive

(a)

(b)

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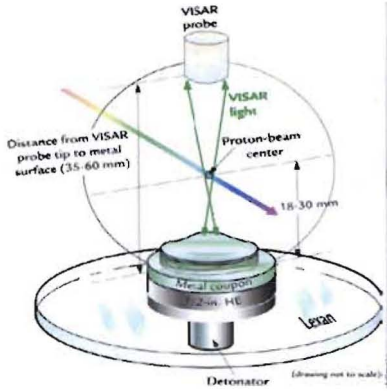
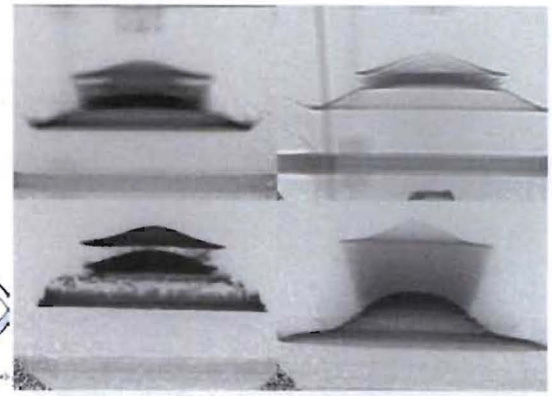
Proton Radiography

Summary

- Los Alamos Neutron Science Centre (LANSCE)
- Improved penetrability over X-rays
- 800MeV particle accelerator
- Measure density to ±4% (±1%)
- 19 dynamic images
- <60ns exposure

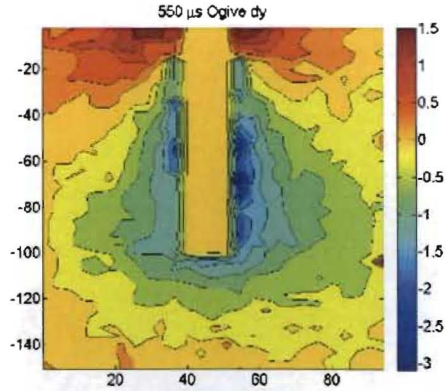




Schwartz - 2009

Experiments

- 1 week before October 2011
- Probe shock wave at high spatial resolution to quantify compaction processes
  - » Particle size
  - » Taylor wave decay/attenuation
- 3D granular flow
  - » Penetration
  - » Buried object



Conclusions

Partially Complete Investigation

- Hugoniot appears to be a good representation

Future Investigations

- Particle size effects
- Meso-structural deformation

- Proton Radiography
  - » Shock densification
  - » Complex granular flow problems