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Title:	Deformation and Flow in Granular System from Impact and Blast Loading (U)
Author(s):	Proud, W.G., Schwartz, C.L., Williamson, D., Blemenfled, R., Collins, G., Neal, W.
Intended for:	Proton Radiography PAC and experimental development

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Form 836 (7/06)

Proton Radiography Proposal Form

Submit to: Los Alamos National Laboratory, LANSCE User Office, Los Alamos, NM 87545
UNCLASSIFIED materials to MS H831, CLASSIFIED materials to MS H803

Title:	*(To be completed by LANSCE)*	
Deformation and Flow in Granular System from Impact and Blast Loading (U)	**Number**	**Date Received**

Name of Shot Series

Number of shots previously fired in this series: 0 Classification level: Unclassified

Number of dynamic shots proposed: 8-12 Needs proofing [X] Has been proofed [ ]

Number of static measurements proposed (describe):

½ to 1 day of beam for focus of a mockup of the Polyethylene box of sand

Principal Investigator: W. G. Proud Citizenship: UK

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Co-Investigators (attach additional sheets if necessary)	**Institution**	**Citizenship**	**E-mail Address**
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Primary pRad Team Contact: **C.L. Schwartz**

Estimated amount of beam time for static and dynamic experiments: **6 days**
Dates Desired: **July 2011** Impossible Dates:
Milestone requirements from external programs (describe):

For statistical purposes, please categorize your proposal:

RESEARCH AREA (check all that apply)	**FUNDING AGENCY (check all that apply)**
[ ] Defense Science	[X] DOE/DP (campaign) NNSA C3 (User Facility funding)
[ ] Engineering	[ ] LDRD (title)
[X] Materials Science	[ ] DOD
[ ] Medical Applications	[ ] Industry (describe)
[ ] Nuclear Physics	[ ] Other US Gov't:
[X] Other: Academic scientific collaboration on topic of interest to LANL community	[X] Other: external University funding

KHKHI

PROTON RADIOGRAPHY SAFETY & EXPERIMENTAL DETAILS (Continued)

Diagnostics

- [ ] VISAR (minimum number of measurement points):
- [ ] Pins (specify material, type number and readout requirements):
- [X] Other:
  PDV at covering at least two radial points.

Safety

- [ ] Proposed experiment known to be outside existing authorization basis (if yes, explain):
- [ ] Proposed experiment introduces known hazards outside existing HCP (if yes, explain):

Status

- [ ] Parts have been designed. (SOME)
- [ ] Parts have been designed, not fabricated. Specify expected fabrication date:
- [ ] Parts have been fabricated, ready for proof or experiment.

Pre-shot Calculations

- [ ] Pre-shot calculations have been completed (describe):
- [ ] Pre-shot calculations have not been completed (expected completion date):

I certify that the above information is correct to the best of my knowledge. **E-mail submission by the Principal Investigator constitutes signature. Do not follow up with a hard copy.**

Signature	W. G. Proud Printed name	1/16/10 Date

PROTON RADIOGRAPHY SAFETY & EXPERIMENTAL DETAILS

Shot Configuration

[X] Explosive Experiment

[ ] Gas handling systems (specify):

HE weight (TNT eqv.) Type:

Fire set requirements (specify proposed detonator and special fire set needs):
40mm gun uses an SE-1 detonator and Mild Detonating Fuse to ignite the powder charge or a penetrator launcher which will need design and proofing.
The standard fire set is required

Firing Temperature (specify acceptable range): no special requirements

Inert Materials

Material:	Quantity:
LEXAN	
Plexiglas	
Polyethylene	
Sand (Silica)	
Lithium Fluoride	

Radiographic Configuration

Minimum Field of View: 35mmX35mm FOV (X3 magnifier)

Minimum # of Frames: ~16, 19 high resolution

Timing requirements Explosive: Spacing: **~250 – 300ns ns over a maximum of 100 μs**

[ ] 4' vessel, -I system, two planes ~14-21 radiograph times, 120 mm FOV

[ ] 6' vessel, -I system, two image planes ~14-21 radiograph times, 120 mm FOV

[X] 6'vessel, -I X3 system, two image planes, 14-21 radiograph times, 40 mm FOV

Optical magnification (specify):
Standard optical setup for –I X3 system

Scintillator requirements (specify):
Must be fast enough to allow the ~250 ns – 300ns interframe time without significant latent image problems.

Static Measurements

Motion Control:
None.

Alignment:
Manual alignment on shot stand.

Describe Radioactive Materials:
None.

DETAILED DESCRIPTION OF THE EXPERIMENT OR ACTIVITY

(Describe the science of engineering research being addressed, importance, and a description of how this experiment campaign will contribute to the progress of this research.)

Deformation and Flow in Granular System from Impact and Blast Loading

Abstract

The study of particulate, sand-like materials has a wide scientific and applied relevance. The mechanical response of the material to external stimulus is complex with particle movement, friction, fracture and compaction playing major roles. The fundamental physics of many of these processes are not understood. Similarly, there are issues as to what physical model is appropriate for which length scale of system and which physical parameters dominate a given range of strain rates. The energy absorbing properties of porous media, however, is widely known and used in blast and ballistic mitigation in the commercial and military sectors.

1. Experimental Programme

Several groups have produced high-quality research, in the static and quasi-static regimes [1-4]. This proposal will complement this research by extending the range of strain rates and by developing new techniques to produce a robust set of data suitable for modelling and for comparing different theoretical predictions. Proton radiography adds the ability to produce multiple short-exposure, high-resolution images, which can then be cross-correlated to show the internal structure and flow within the granular bed. This represents a unique opportunity to study the physical phenomena and parameters in depth – flow fields, local densification and the effect of grain size and porosity.

Beds of quartz sand particles will be subjected to loading, images captured during the impact process and image correlation techniques used to study the displacement within the system and the extent of stress transmission through the bed. Both mono- and multi-modal (polydisperse) distributions of particle sizes will be studied. The response of the system will be tracked by analysing the images using image cross-correlation techniques to examine the displacement, both translational and rotational, movements within a bed. The technique is based on a seeded layer in the target, a technique pioneered by this group [5].

The load will be applied either by using 2 shapes of either plate, conic, triangular or spherical penetrators launched from a gun or penetrator launcher. The images will be captured during the impact and penetration process. The material of the impactor will be of sufficient hardness and rigidity to avoid bending or significant erosion by the sand. The deformation field produced by the impactor will show the effect of stress transmission, compaction and, most importantly material flow. In a second set of experiments a small explosive charge will be placed within the granular bed and detonated. The will produce both stress *and* high-pressure product gas which will percolate in the bed and so providing a significant additional effect compared to the impactor system. The penetrator size may be varied from that of a few particles in diameter to a size approximating the particle bed, similarly a range of explosive charges will be used to produce a range of impact velocities. Experiments will be conducted over a range of impact velocities as previous research has shown the response, compaction and flow, varies greatly with stress level [6].

Other factors such as the correlation of the displacement maps with force chains will be investigated. Given the fragility of the particles it is expected that significant force chain redistribution will correspond to small movements within the bed

2. Proton Radiography details

The pRad experiment series will consist of 8-12 shots using the powder gun driver or a penetrator launcher, and the 3X magnifier lens. The parameters to be varied will consist of the geometry of the penetrator, including its face's shape and its diameter, and the impact velocity. The possible impactor face shapes may include flat, conic, triangular or spherical. The impactor diameters will be 5 mm and 20 mm. A range of impact velocities will be explored from 500 m/s to 1000 m/s. The requested number of shots thus, two chosen shapes for two diameters with up to three impact velocities, with a maximum possibility of 12 shots.

For every shot, the same target design will be used: a polyethylene cube, 50 mm on a side, packed full of sand. The target walls will be 1/8 inch Lucite or similar, except for the side which the impactor hits, which will be as thin as possible.

All the shots will require the full suite of pRad diagnostics, including at least 19 high resolution images using the cameras at image location 1, PDV velocimetry to measure the speed of the impactor prior to impact, and voltage pins to trigger the radiography system. Typical proton pulse lengths will be 50 to 100 ns, with 20 to 40 pulses in the chain separated by about 350 ns.

3. Data Analysis and Method

Analysis using correlation schemes, as shown schematically in figure 1 has been optimised to deal with granular systems. The technique has been applied to polyester, cement, sand and glass materials [7-10]. This correlation algorithm was developed in collaboration with Sjödahl [11,12]. The results of image processing and the resulting displacement map are illustrated in the two scenarios shown in figure 2. The experimental process requires a reference image, taken before the impact and an image taken during the impact process experiment. A layer of random radio-opaque particles are used to produce the speckle pattern to ensure that the array is a random pattern with no two areas being alike. A sub-image is taken from the reference image and a similar, but smaller, region is taken from the deformed image. Moving the deformed sub-image pixel by pixel across the reference sub-image, and calculating a correlation value at each step, creates a correlation surface. A clear peak in the correlation stands out from the background noise when pattern overlap occurs. By locating this peak the displacement in the deformed sub-image relative to the reference sub-image has been calculated. The location of the correlation peak can be obtained to sub-pixel accuracy and can be as good as 0.001 pixels of displacement

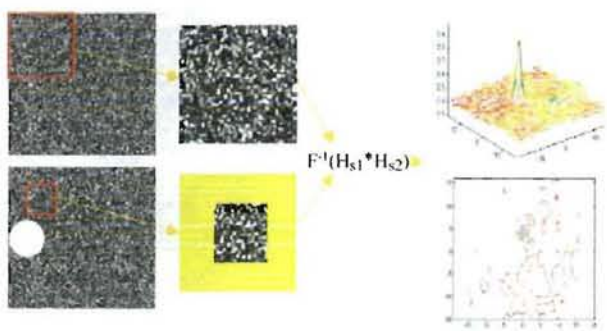
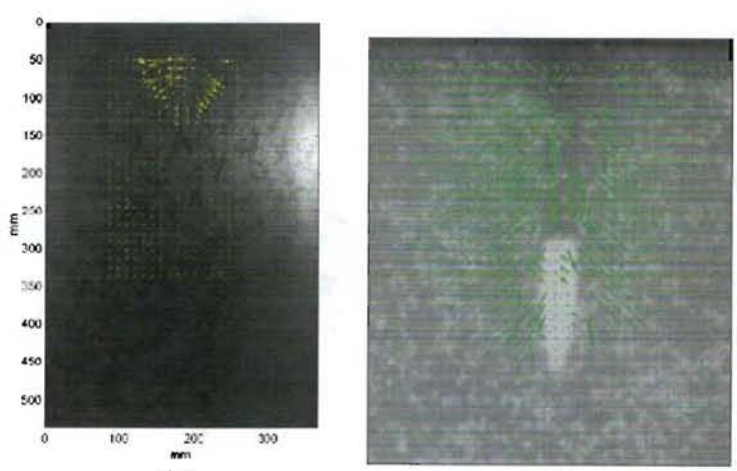


Figure 1. The stages of image processing



(a) *(b)*

Figure 2. Example of displacement field around (a)displacement copper shaped charge jet moving at 7 km s^{-1} through cement target, note – the quiver arrows are 10x magnification(b) flow pattern around a bullet fired into a cube of sand at 500 m s^{-1}.

Overall

The experimental techniques outlined above have been developed over a number of years. They have been applied over a range of systems including some porous and granular. Some novel experimental development will be required while other systems will need to be optimised, particularly the statistical analysis of the images of force chains.

The programme outlined here is to apply a range of techniques in a systematic fashion to granular systems over a wide range of rates and with close involvement of the theoretical and modelling communities.

Contribution made by UK-based researchers – Academic Input

The UK team would supply all sample materials and fabricate targets. In collaboration with pRad collaboration members the impactors would be jointly designed, then fabricated in the UK. The UK team includes a doctoral student who is currently funded to research the dynamic properties of Granular Materials who is in the early stages of his programme and who would benefit greatly from these results. All travel and subsistence costs would be met by existing funding within the UK team.

References

1. Majmudar, T.S., Behringer, R.P. "Contact force measurements and stress-induced anisotropy in granular materials" Nature, 453(23) (2005) 1079
2. Corwin, E.I., Jaeger, H.M., Nagel, S.R., "Structural signature of jamming in granular media", Nature 453 (23), (2005) 1075
3. Jamming and Fluctuations in Granular Drag, I. Albert, P. Tegzes, B. Kahng, R. Albert, J. Sample, M. Pfiefer, A.-L. Barabási, T. Vicsek, and P. Schiffer, Physical Review Letters 84, 5122-5125 (2000)" and
4. Granular physics: a bridge to sandpile stability, P. Schiffer, Nature Physics 1, 21-22 (2005)."
5. Goldrein, H.T., Grantham, S.G., Proud, W.G., Field, J.E., "The Study of Internal Deformation Fields in Granular Materials Using 3D Digital Speckle X-Ray Flash Photography", Proceedings of Shock Compression of Condensed Matter 2001, Atlanta, Georgia, AIP Conference Proceedings 620, 1105-1109
6. The behaviour of sand under shock wave loading: Experiments and simulations. K. Tsembelis, W.G. Proud, B.A.M. Vaughan, J.E. Field in Benitez FG, ed. Behaviour of Materials at High Strain Rates: Numerical Modelling. Saint-Louis, France, DYMAT, 2002. p. 193-203
7. Bragov A.M., Lomunov A.K., Sergeichev I.V., Proud W., Tsembelis K. and Church P. (2005) "A method for determining the main mechanical properties of soft soils at high strain rates (10^3-10^5 s^{-1}) and load amplitudes up to several gigapascals" *Tech. Phys. Letts* 31 530-531
8. Field J.E., Walley S.M., Proud W.G., Goldrein H.T. and Siviour C.R. (2004) "Review of experimental techniques for high rate deformation and shock studies" *Int. J. Impact Engng* 30 725-755
9. Synnergren, P., Goldrein, H.T., Proud, W.G., "*Application of digital speckle photography to flash x-ray studies of internal deformation fields in impact experiments*". Applied Optics, 38, 4030-4036, 1999.
10. Grantham, S.G., Proud, W.G., "*Digital Speckle X-Ray Flash Photography*", Proceedings of the 12th APS topical meeting on shock compression of condensed matter, 2001 Atlanta, Georgia, AIP Conference Proceedings 620, 803-807.
11. Sjödahl, M., Benckert, L.R., "*Electronic Speckle Photography: Analysis of an Algorithm Giving the Displacement with Subpixel Accuracy*", Applied Optics, 32, 2278-2284, 1993.
12. Sjödahl, M., "*Electronic Speckle Photography: Increased Accuracy by Non Integral Pixel Shifting*", Applied Optics, 33, 6667-6673, 1994.