Thesis

John W. Addiss

Measurement of Displacements in Granular Systems in Response to Penetration and Compaction

Cambridge University (United Kingdom)

Contact: smw14@cam.ac.uk

The research reported in this thesis is concerned with the flow of granular systems in response to penetration and compaction. The technique of Digital Speckle Radiography (DSR), which involves analysis of flash X-ray images, has been applied to measure the internal displacement fields within large opaque granular samples. Large samples are desirable as the measured displacements are more representative of the bulk.

Current DICC algorithms were found to be unsuitable for analysis of X-ray images of large samples. The large contrast variations present in such X-ray images, due to the X-ray beam profile, sample geometry and the high X-ray absorbance of metal penetrators, are shown to cause significant errors in the calculated displacement fields. A study of image normalisation techniques was carried out, and the effect of each technique on the accuracy of the measured displacements was investigated. A new DICC algorithm for use in DSR was produced which includes image normalisation techniques to correct for uneven contrast in the images. This new DICC algorithm was shown to be far more effective at analysing X-ray images of large samples.

This improved DSR technique was applied to measure the internal displacements within a large sample of sand during penetration by projectiles with different nose-shapes (flat, ogive-2 and hemispherical) and at different rates (1.5 mm/min to 200 m/s). The improved technique was found to provide high-resolution displacement data illustrating the response of the material. The dominant material response at low rates (1.5 mm/min) was found to be splitting of the material ahead of the projectile tip, followed by bulk reverse-flow of material towards the penetration face. At the higher rates (200 m/s), the dominant response was compaction of the material ahead of the projectile tip. The transition between the two regimes was found to occur between velocities of 5 and 19 m/s.

The streamlined ogive-2 projectile nose-shape was shown to be the most effective for penetration, in that it caused less disruption of the material ahead of the projectile, lost less energy during the early stages of penetration in the dynamic experiments and more effectively split the material ahead of the projectile tip, a process which was shown to be important at all rates of penetration.

The compaction properties of a particulate mixture and a granular material, including the effect of factors such as porosity, initial particle arrangement and force chain formation, were investigated. Samples which were conducive to the formation of force chains spanning the whole sample were discovered to have anomalously high strengths. Small amounts of added water were shown to increase the compactability, by lubricating the grain contact points, but larger amounts of water decreased the compactability.

www.dymat.org