Counterintuitive math of high speed impacts

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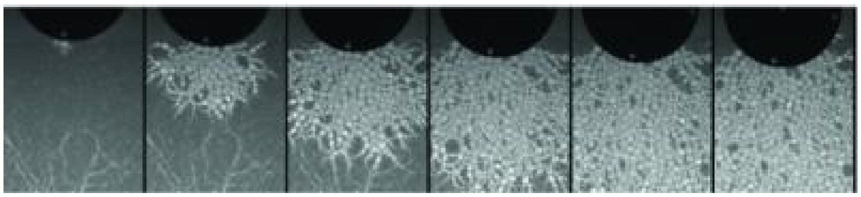

Video frames of an experiment showing how a dense, resistant force-chain network is created almost instantly when a metal object impacts a granular bed of photoelastic beads at high speed.

It seems to contradict common sense—that greater speed for a missile or meteorite does not necessarily mean deeper penetration into the ground upon impact. But that's the finding confirmed by NJIT Professor Lou Kondic, Department of Mathematical Sciences, and colleagues affiliated with Duke University's Department of Physics and Center for Nonlinear and Complex Systems.

If the area of impact has a granular structure, speed can actually impede penetration, as the researchers report in a recent *Physical Review Letters* article entitled "Nonlinear Force Propagation During Granular Impact."

"Think about what often happens when you walk on a sandy beach," Kondic says. "The same grains of sand that pour so easily through your fingers behave like a dense solid underfoot because of your weight." And the resistance to penetration increases as a function of the force applied.

The work leading to the results reported by Kondic and Duke co-investigators Abram H. Clark, Alec J. Petersen and Robert P. Behringer was funded in large measure by the U.S. Defense Threat Reduction Agency, part of the Department of Defense. Offensively, the insight gained into the phenomena studied could help to make "bunker busting" weapon systems more effective with respect to targets relatively deep in the ground. The same understanding could lead to the development of better materials for protecting against certain types of impact, not only in military action but in daily life as well.

A Forceful Portrait

Kondic's contribution to this effort has been numerical simulation and modeling of the phenomena, essential for research going forward. The analytical tools he has provided reflect experimental data obtained at Duke when a small metal projectile was dropped from a height of seven feet into a bed of clear photoelastic beads of varying hardness, which allowed simulating impacts at speeds ranging from 67 to 670 miles per hour.

Ultra slow-motion videography using polarizing filters revealed that increasing impact speed creates denser, more extensive "force chain" networks among the beads, strengthening the material collectively as the beads are pressed together. As Kondic and his colleagues discovered, the potential for penetration is thus greatly reduced because the impact energy transferred to the beads moves away from the point of impact and dissipates much more quickly than previous models predicted.

Knowledge of how force chains could leave a lasting imprint in appropriate geologic formations may even aid in identifying and characterizing the sites of meteorite impacts—such as locations showing evidence of especially forceful impacts that could have dramatically influenced climate and the evolution of life in Earth's distant past.

Fluid and Granular Interests

An NJIT faculty member since 1999, Kondic has long had an interest in two- and three-dimensional simulations of granular systems. His work in this area includes several years of investigation at Duke before joining NJIT.

Granular materials are commercially important in industries as diverse as pharmaceuticals, agriculture, and energy production. By one estimate, they are the second most manipulated material in industry, the first being water.

Kondic is also very much interested in fluid dynamics, including numerical analysis related to the flows of thin liquid films on a very small (nano) scale. Important applications include the use of solvents in the production of microelectronics, and surface patterning with metal particles in the production of solar cells.

Helping to put mathematical science to work in the multidisciplinary environment encouraged at NJIT is especially gratifying for Kondic. "We're focused on efforts that produce useful results in many fields," he says of his department's real-world orientation. "It's a good feeling."

More information: "Nonlinear Force Propagation During Granular Impact." *Phys. Rev. Lett.* 114, 144502. journals.aps.org/prl/abstract/ … ysRevLett.114.144502

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