Colorful math reveals how forces transmit through granular materials

June 22 2005

Using color-changing plastic cylinders as a stand-in for a mass of granular material, Duke University physicists have created a computer-testable method to predict, particle-by-particle, how pushes, nudges and shoves at the edges transmit across large assemblages.

Masses of unpredictable granular particles -- from the ice chunks that make up avalanche-prone snowfields to the coal in gigantic coal bins -- can abruptly change behaviors with sometimes catastrophic results. Such shifts occur because granular materials can change "phases" from having solid to liquid properties, according to circumstances.

The new technique represents "a major step in a long-term goal to have an accurate model that describes how granular materials interact from the smallest grain scale on up," said Robert Behringer, www.phy.duke.edu/~bob/, a Duke physics professor.

In a report in the Thursday, June 23 2005 issue of the journal Nature, Behringer and his graduate student Trushant Majmudar described a mathematically nimble way to follow how forces ripple across a laboratory version of a granular mass -- a two-dimensional rectangle containing about 2,500 "grains" -- in this case special "photoelastic" cylinders.

These cylinders are so named because they become "birefringent" when pressured. Such birefringence means that wherever forces are applied to their surface, when viewed through a light-polarizing filter, their compressible plastic surfaces undergo harlequin-like color changes.

In work supported by the National Science Foundation and NASA, the Duke researchers built an experimental frame with movable sides to variably compress the grain field from top to bottom and side to side.

Majmudar then painstakingly plotted how colors shifted from translucently neutral to greens, reds and blues in parts of each of the cylinders as the forces transferred from the moving frames bent transmitted light waves.

In a two-year effort, the graduate student used these experimental photoelastic observations to develop a mathematical model that described the phenomena.

Using a set of 19th-century equations as a framework, he added his own calculations of the stresses inside and between the cylinders. He then mathematically "reversed time" to trace how forces should have been transmitted from cylinder to cylinder back to the initial nudge from a frame edge.

The Duke researchers tested Majmudar's enhanced equations -- known as an inverse algorithm -- by running it on a computer. An illustration in their Nature paper showed that the computer-calculated picture of the transferred grain stresses was very similar to the experimental results.

Both the calculated and experimental results showed that stresses have long-range effects across the entire bed -- transferring jaggedly from particle to particle via extended "force chains" -- when the confined cylinders were squeezed in one direction but relaxed in the other.

Conversely, only short-range force chains were created when top-to-bottom pressure increases were the same as those from side-to-side.

Behringer's Duke laboratory previously created and studied force chains in the late 1990s, using similar photoelastic cylinders. But at that time researchers were unable to do more than measure the average forces on particles, he said.

"The mathematical roots of this whole algorithm have been known since the 19th Century," Majmudar added. "And the photoelasticity aspects have been known for 50 years. But the approach before for doing these calculations was manual, with pen and paper. That's not very useful for the kind of studies we want to do.

"Making it work in an automated fashion so that a computer can run it, and applying it on a large enough scale to ask the questions that physicists want answers to, that's the tricky thing."

Added Behringer: "This is the first set of studies to determine the forces at the contacts between each of large numbers of particles. It's the ability now to do that efficiently on a very rapid scale that has taken this research from the realm of being something visual -- seeing force chains -- to something that is truly quantitative. In some sense, this is as good as you can get it."

With this new perspective "we are now in a position to address a variety of important issues like the nature of jamming transition and the response function of a granular system," the two authors wrote in their new Nature paper.

The term "jamming transition" refers to changes that transform granular material interactions from a liquid-like to a solid-like state in a way that makes them "jam" in containers such as coal hoppers, said Behringer, who also holds a secondary faculty appointment at Duke's Pratt School of Engineering.

"The long-term goal is to have an accurate model that describes granular materials starting with the smallest scale and going up to a scale large enough to be useful, for instance to someone who wants to design hoppers."

The new Nature report follows another www.physorg.com/news4000.html by Behringer and his post-doctoral researcher Karen Daniels published April 29, 2005, in the journal *Physical Review Letters*. That paper described a controlled, measurable method to make granular materials alternate between their "solid" and "liquid" states.

Source: Duke University

Citation: Colorful math reveals how forces transmit through granular materials (2005, June 22) retrieved 24 April 2024 from
https://phys.org/news/2005-06-math-reveals-transmit-granular-materials.html