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Research reveals secret shared by comets and sand crabs

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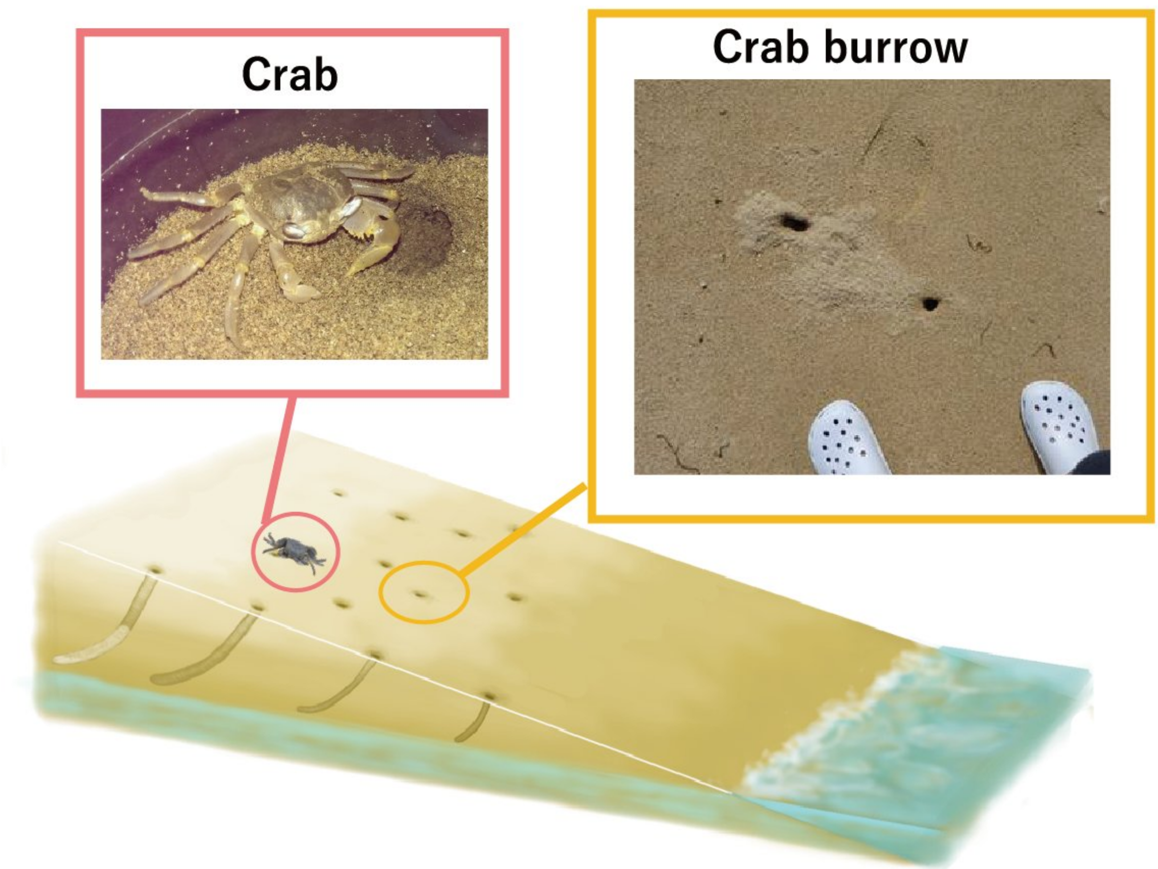


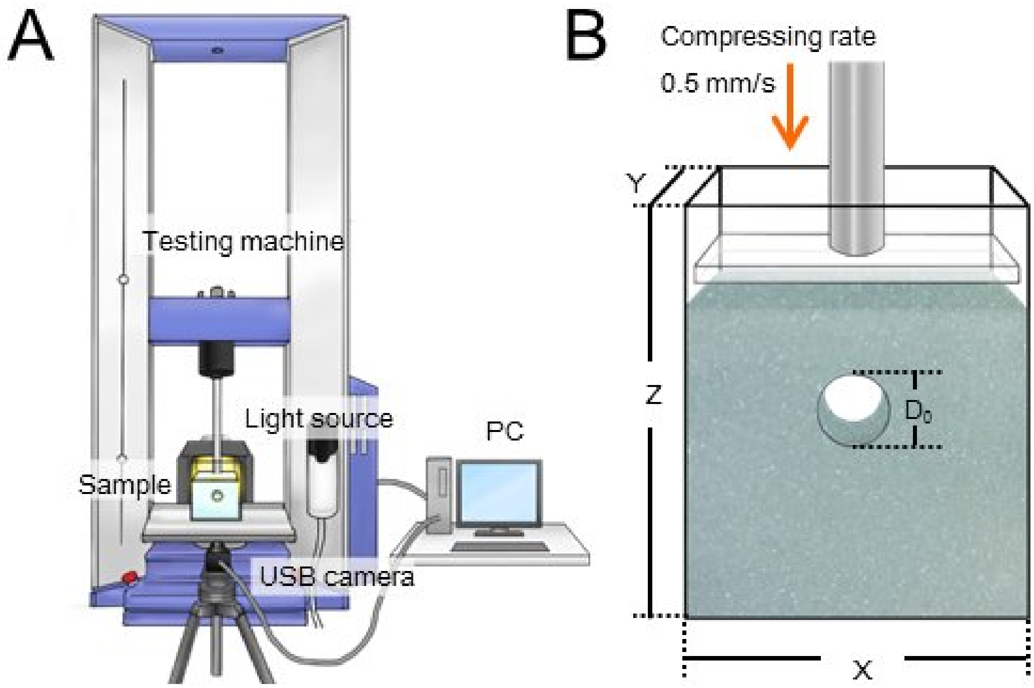
A burrowing crab and burrows found on sandy beach in Ishigaki, Japan; and a schematic diagram of a sandy beach with crab burrows. Credit: Hiroaki Katsuragi

Researchers at Nagoya University report a mechanical connection between sand crab burrow widths and widths of cometary pits using a simple granular experiment.

Holes on a sandy beach in the vicinity of the shoreline are often entrances to sand crab burrows (Fig. 1). It is striking that the sizes (entrance diameters) of the burrows have a typical value (about 2 to 3 cm). Moreover, there are no wide entrances (e.g., 10 cm in diameter). Why do crabs only dig narrow burrows? Of course, the crab's size is one factor—it doesn't need a large burrow if its carapace size is small. However, many types of crabs are much larger than sand crabs—why don't they dig burrows in the beach sand, too?

Another factor must be at work. Perhaps the size of sand crab burrows is determined by the mechanical constraint of the substrate: wet sand. This simple idea was the study's starting point. The researchers studied the stability and strength of burrow-like structures using a simplified model system. At the same time, they realized that the void (or hole) structure within cohesive granular matter is ubiquitous; for example, it is known that voids exist within comets.

Moreover, it is also known that voids can be prone to collapse. Therefore, a simple model system could be useful for explaining a variety of natural void-collapse phenomena, including those found on comets.

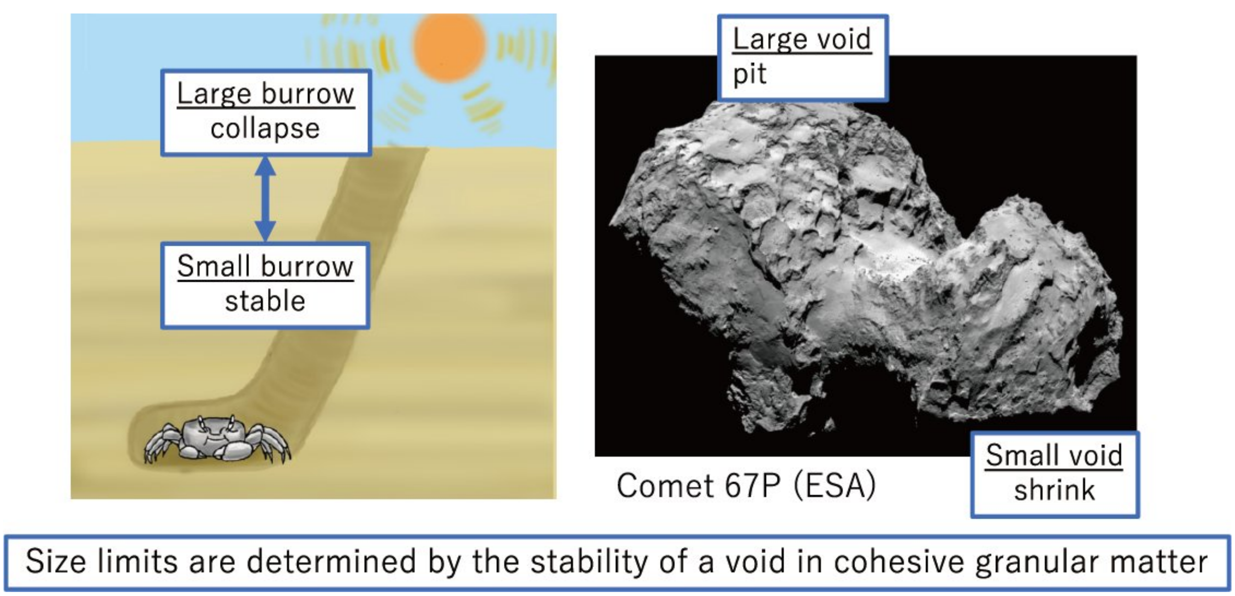


Tunnel compression experiment using a universal testing machine was performed in this study (A). A wet granular layer with horizontal tunnel structure was prepared in an acrylic vessel (B). The entire wet granular layer including the tunnel structure was uniformly compressed. Credit: Hiroaki Katsuragi

By simply compressing a horizontal tunnel structure in a wet granular layer produced by mixing water and glass beads (Fig. 2), the researchers observed three deformation modes: (i) shrinkage without collapse; (ii) shrinkage with collapse but no subsidence; and (iii) collapse with subsidence. Mode (i) can be observed when the initial tunnel diameter is sufficiently small. As the initial tunnel diameter is increased, the deformation mode becomes unstable. The loaded tunnel structure then experiences type (ii) or (iii) collapse depending on the experimental conditions (initial tunnel diameter and grain size). We found that the boundary between (i) and (ii, iii) is approximately 5 cm in diameter. Actually, this value is quite close to the upper limit of crab burrow sizes found in the field. This correspondence suggests that crabs make relatively narrow (small-diameter) burrows to prevent the collapse hazard—they must be smart!

In addition, through systematic experiments, the researchers defined and measured the strength of a tunnel structure in wet granular matter. The measured result was basically consistent with similar previous studies of wet granular mechanics.

Using the obtained strength values, the researchers also estimated the lower limit of size of pit structures found on the surface of comets. They focused on cometary surfaces covered with pit structures whose plausible origin is the collapse of voids due to sublimation of volatile materials inside the comet. The surface of a typical comet consists of a mixture of ice and solid particles. This type of mixture is also a sort of typical cohesive granular matter, like the wet granular matter used in the experiment.



To construct safety burrows, sand crabs dig relatively narrow tunnels. Large burrows are likely to collapse. The pit structures found on comet surfaces have a characteristic size range that is consistent with the collapse condition of void structures in cohesive granular matter. Therefore it appears that both crab burrows and cometary pits are governed by the stability of voids in cohesive granular matter. Credit: Hiroaki Katsuragi

Since a small void will shrink and not collapse, small pits are unlikely to be created by a void collapsing below the surface. Indeed, measured values of pits on comet surfaces appear to have a lower limit.

By combining all the experimental results and observational information (surface-material strength and gravitational acceleration that are significantly different from Earth material), the researchers confirmed that the shrink-collapse boundary model is roughly consistent with the observed lower limit of the size of comet pit structures. The experiment is summarized in Fig. 3.

In this experimental study, the model system was extremely simplified. Although the researchers believe that the essential behavior of tunnel structure in cohesive granular layer was properly understood in the study, much more realistic experiments are required to address the specific details. For one thing, the size thresholds might depend on grain shape. In addition, further crab studies in the field would improve the understanding of crab burrows. Furthermore, this type of void collapse in cohesive granular matter could be more universal than previously thought. The researchers suggest considering broader applications. For instance, in November 2016, a road in Fukuoka city in southern Japan collapsed suddenly. This also represents a type of collapse hazard of a void in a cohesive granular layer. That is, the findings might be relevant to disaster prevention techniques, as well.

More information: Ayuko Shinoda et al, Void structure stability in wet granular matter and its application to crab burrows and cometary pits, *Scientific Reports* (2018). DOI: 10.1038/s41598-018-33978-8

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