TKK Young Scientist Award in Earth Sciences

Are Soil Desiccation Cracks Mostly in Square Shape, or Hexagon?

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The 2020 TKK Young Scientist Award in Earth Sciences went to Prof. TANG Chaosheng for his important contributions to drought-related engineering geology, particularly in developing an artificial climate simulation system that has been used to study the behaviors of drought-induced soil desiccation cracking.

The formation of desiccation cracks on soil surface due to the loss of water is a common scene in times of drought. These drought-induced cracks can break up the integrity of the soil mass and impact all sorts of constructions built on or in the ground, including houses, roads, railways, dams, liners and covers for landfill, and even barriers for nuclear waste isolation, because desiccation cracks greatly reduce the soil's strength, as well as increase the hydraulic conductivity (the rate and the velocity at which water can get in or out) of a soil mass.

As a result, the geotechnical aspects of construction can be affected directly or indirectly by the presence of cracks in a soil mass. For example, in 2007, deep desiccation cracks appeared in more than 1,200 reservoir dams in Chongqing, China, because of an extreme drought. A subsequent rainfall threatened the stability of several dams. In other cases, desiccation cracks can greatly reduce the stability of natural slopes or reduce the bearing capacity of foundations due to the drawdown of groundwater.

The influence of drought on engineering geology has been long underestimated, and can be easily overlooked because it appears to be subtler compared with other formidable extreme climate events, such as storms and earthquakes. However, when you take a deep look into geological disasters, you can usually spot the liability linked to drought-induced desiccation cracking.

Considering the high frequency of droughts in China, as well as its broad influence in other parts of the world, there is an urgent need to study behaviors of soil desiccation cracking and find ways to prevent these cracks from triggering disasters upon the presence of other extreme climatic events, such as storms or earthquakes.

TANG's study on soil desiccation cracking started around twenty years ago, when, one day, his supervisor came to him with a question – Are the soil cracks mostly in square shape, or hexagon?

"Since then, I embarked on the road of 'mud-playing', and there is no turning back," recalled TANG in a public talk after receiving the TKK Young Scientist Award.

Through years of effort, TANG's group developed an artificial climate simulation system, which can be tuned to create precise experimental conditions. Based on this system, they developed a mature methodology to investigate the many aspects of soil behavior, including water evaporation, volume shrinkage, crack initiation and propagation, as well as the involved coupling process. Moreover, they equipped this system with powerful technologies of image processing, which can be used to monitor the dynamic process of desiccation cracking, as well as automatically quantify crack patterns and run strain field analyses on the soil surface.

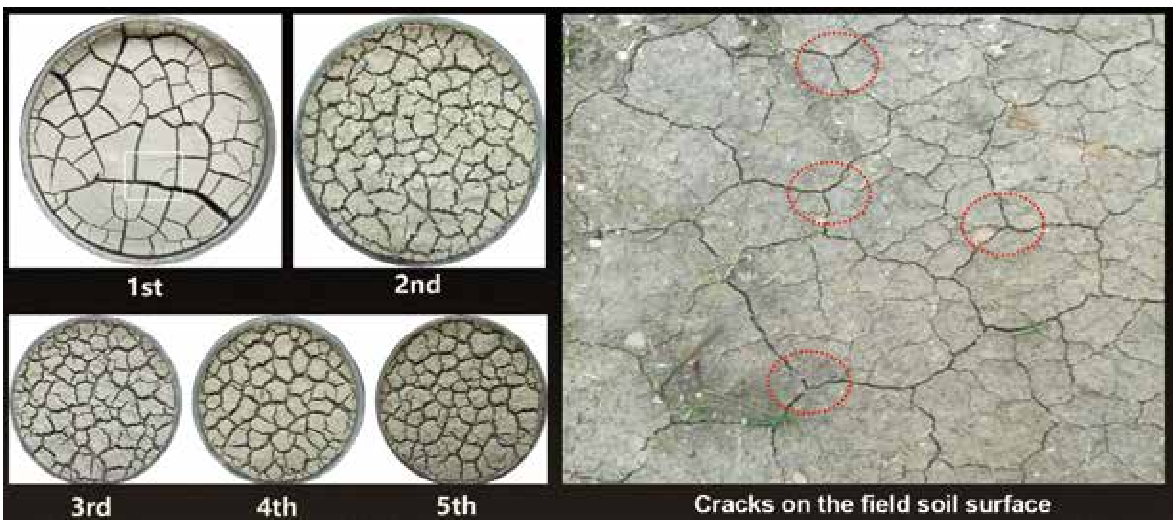
Using this self-made system, TANG and his coworkers have made numerous interesting discoveries. For example, they found that the surface cracks start to appear in the early stage of drying when the soil is still fully-saturated with water, contradicting common sense that cracking forms on the soil surface after drying out. They also found that the newly formed sub-cracks are usually perpendicular to the previously formed primary cracks. So, the cracks mostly intersect at right angles, like the letter 'T', and the final crack pattern is dominated by square shapes.

"After obtaining these primary results, we didn't rush to the conclusion; instead, we continued with our studies," recalled TANG. "Then we found that the desiccation cracking patterns can be affected by wetting-drying cycles. After subjecting these soil samples to cycles of wetting-drying condition, we found that the intersecting angles of the cracks become dominantly 120°, like the letter 'Y', and the square clods of the crack patterns transformed mostly into hexagonal ones, just like what we usually see in the field in times of drought."

So, TANG was then able to answer the question "are soil cracks mostly in square shape, or hexagon?" This is, however, not the end of this journey. His curiosity led him to ask another question – why it was like that and how to predict?

"Crack formation and evolution are, in nature, the consequences of tensile stress release," says Prof. TANG. "By running full-field strain analyses of the soil surface, we found that the observed cracking was restricted mostly to high stretching domains which are usually related to microstructure defects. We are now able to predict the starting locations of early cracks, as well as how they would evolve, such as where they will take turns and intersect with each other."

They also reported that, as desiccation proceeds,



Left: cycles of wetting-drying condition transform the soil desiccation patterns, from mostly square shape to mostly hexagon. *Right*: intersecting angles of the soil desiccation cracks found in the field are dominantly 120°. (Image by TANG's lab) however, the surface strain field ceases to provide useful information for predicting crack locations. They reckoned that although drying begins from the exposed material surfaces, late-generation cracks can initiate in the subsurface, propagate upward and express themselves subsequently at the surface. Their experimental results further validated that the coupled effects of substrate conduct conditions and soil layer thickness play a key role in governing the soil cracking behavior in the subsurface.

Notably, they also developed a powerful Crack Image Analysis System (CIAS) to automatically quantify crack patterns, which have been widely applied by many other research groups worldwide.

Apart from their impressive work on the behaviors of soil desiccation cracking, TANG's group also proposed a model for atmosphere-soil interaction, which illustrates the relationship between many aspects of soil behavior and the soil's engineering properties in times of catastrophic droughts. Moreover, they developed various soil improvement techniques, such as fiber reinforcement, chemical stabilization and bio-mediation, to increase soil's tensile strength, which thereby enhance the crack resistance in times of drought. They also developed a series of techniques, including distributed optical fiber sensing, X-ray computed tomography, electrical resistivity tomography (ERT), machine learning and optical imaging, to monitor/characterize soil deformation and desiccation cracking process. Their studies on the drought-related engineering geology are of great theoretical and practical significance for improving the decision-making ability to deal with extreme drought climate events and enhance the ability of disaster prevention and mitigation.

Last not least, drought-related studies on atmosphere-soil interaction provide insights to other related subjects, such as agriculture and ecology. Besides, the desiccation crack patterns preserved from ancient time may hold valuable information to the paleoclimate that, to some extent, forged these cracks.