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**A Semi-annual insight into the Civil Engineering World**

# CIVIL O NEWS

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## **500-year-old Leaning Tower of Pisa mystery unveiled by engineers**

Why has the Leaning Tower of Pisa survived the strong earthquakes that have hit the region since the middle ages? This is a long-standing question a research group of 16 engineers has investigated, including a leading expert in earthquake engineering and soil-structure interaction from the University of Bristol.

Professor George Mylonakis, from Bristol's Department of Civil Engineering, was invited to join a 16-member research team, led by Professor Camillo Nuti at Roma Tre University, to explore this Leaning Tower of Pisa mystery that has puzzled engineers for many years.

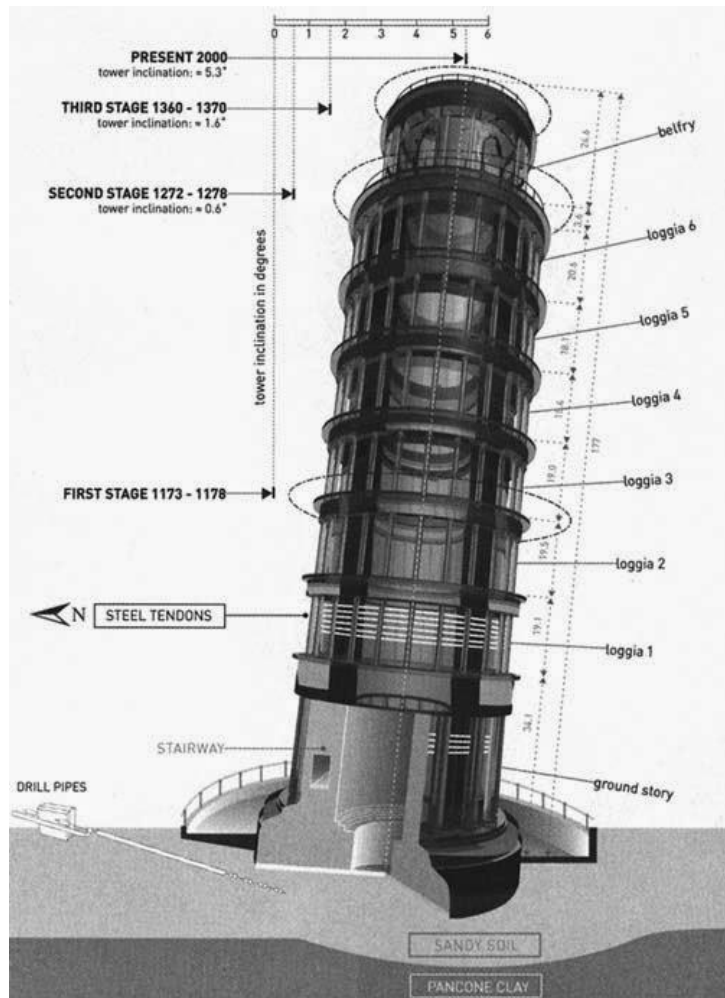
Despite leaning precariously at a five-degree angle, leading to an offset at the top of over five metres, the 58-metre tall Tower has managed to survive, undamaged, at least four strong earthquakes that have hit the region since 1280.

Given the vulnerability of the structure, which barely manages to stand vertically, it was expected to sustain serious damage or even collapse because of moderate seismic activity. Surprisingly this hasn't happened and until now this has mystified engineers for a long time. After studying available seismological, geotechnical and structural information, the research team concluded that the survival of the Tower can be attributed to a phenomenon known as dynamic soil-structure interaction (DSSI).

The considerable height and stiffness of the Tower combined with the softness of the foundation soil, causes the vibrational characteristics of the structure to be modified substantially, in such a way that the Tower does not resonate with earthquake ground motion. This has been the key to its survival. The unique combination of these characteristics gives the Tower of Pisa the world record in DSSI effects.

Professor Mylonakis, Chair in Geotechnics and Soil-Structure Interaction, and Head of Earthquake and Geotechnical Engineering Research Group in the Department of Civil Engineering at the University of Bristol, said: "Ironically, the very same soil that caused the leaning instability and brought the Tower to the verge of collapse, can be credited for helping it survive these seismic events."

Results from the study have been presented to international workshops and will be formally announced at the 16th European Conference in Earthquake Engineering taking place in Thessaloniki, Greece next month [18 to 21 June 2018].



## Southeast Asian forest loss greater than expected, with negative climate implications

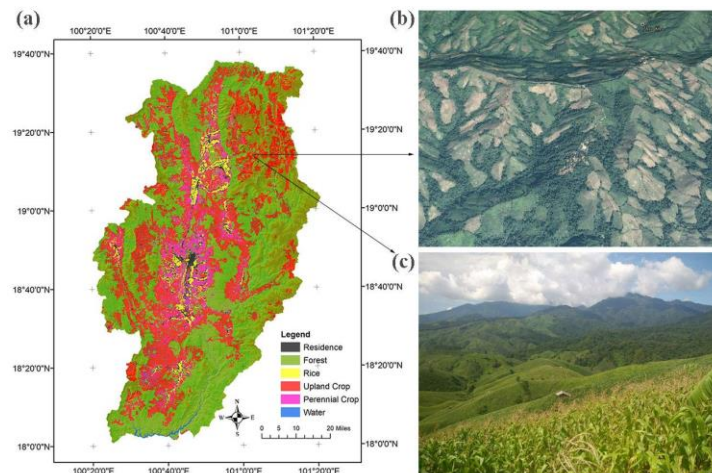
Researchers using satellite imaging have found much greater than expected deforestation since 2000 in the highlands of Southeast Asia, a critically important world ecosystem. The findings are important because they raise questions about key assumptions made in projections of global climate change as well as concerns about environmental conditions in Southeast Asia in the future.

Zhenzhong Zeng, a postdoctoral researcher at Princeton University and the lead author of a July 2 article describing the findings in *Nature Geoscience*, said the researchers used a combination of satellite data and computational algorithms to reach their conclusions. The report shows a loss of 29.3 million hectares of forest (roughly 113,000 square miles or about twice the size of New York State) between 2000 and 2014. Zeng said that represents 57 percent more loss than current estimations of deforestation made by the International Panel on Climate Change. He said most of the forest has been cleared for crops.

Because forests absorb atmospheric carbon, and burning forests contribute carbon to the atmosphere, loss of forests could be devastating. An accurate estimation of forest cover also is critical for assessments of climate change. Zeng also said transformation of

mountainous regions from old forest to cropland can have widespread environmental impacts from soil retention to water quality in the region.

Eric Wood, the Susan Dod Brown Professor of Civil and Environmental Engineering and a member of the research team, said the results were troubling in that farmers are carving new agricultural frontiers from the highland forests of mainland Southeast Asia. "These forests are an important source for sequestering carbon as well as critical water sources for adjacent lowlands," he said.



In addition to Wood and Zeng, researchers involved in the project included: Lyndon Estes, of Clark University; Alan Ziegler, of the National University of Singapore; Anping Chen, of Purdue University; Timothy Searchinger, a research scholar at Princeton's Woodrow Wilson School; Fangyuan Hua, of the University of Cambridge; Kaiyu Guan, of the University of Illinois at Urbana Champaign; and Attachai Jintrawet, of Chiang Mai University. Support for the project was provided in part by Lamsam-Thailand Sustain Development.

## Fungi can help concrete heal its own cracks

Infrastructure supports and facilitates our daily lives – think of the roads we drive on, the bridges and tunnels that help transport people and freight, the office buildings where we work and the dams that provide the water we drink. But it's no secret that American infrastructure is aging and in desperate need of rehabilitation.

Concrete structures, in particular, suffer from serious deterioration. Cracks are very common due to various chemical and physical phenomena that occur during everyday use. Concrete shrinks as it dries, which can cause cracks. It can crack when there's movement underneath or thanks to freeze/thaw cycles over the course of the seasons. Simply putting too much weight on it can cause fractures. Even worse, the steel bars embedded in concrete as reinforcement can corrode over time.

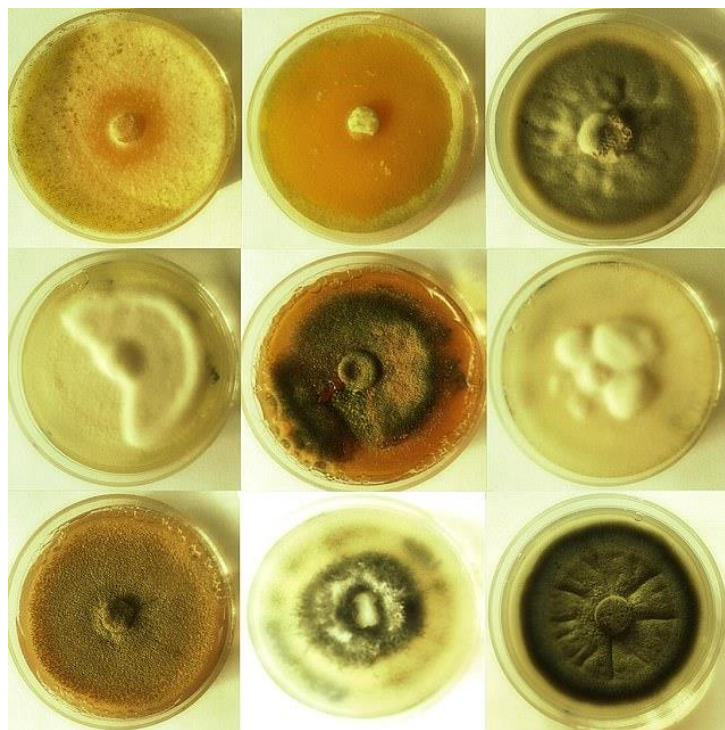
Very tiny cracks can be quite harmful because they provide an easy route in for liquids and gasses – and the harmful substances they might contain. For instance, micro-cracks can allow water and oxygen to infiltrate and then corrode the steel, leading to structural failure. Even a slender breach just the width of a hair can allow enough water in to undermine the concrete's integrity.

But continuous maintenance and repair work is difficult because it usually requires an enormous amount of labor and investment.



So since 2013, I've been trying to figure out how these harmful cracks could heal themselves without human intervention. The idea was originally inspired by the amazing ability of the human body to heal itself of cuts, bruises and broken bones. A person takes in nutrients which the body uses to produce new substitutes to heal damaged tissues. In the same way, can we provide necessary products to concrete to fill in cracks when damage happens?

My Binghamton University colleagues Guangwen Zhou and David Davies, Ning Zhang from Rutgers University and I have found an unusual candidate to help concrete heal itself: a fungus called *Trichoderma reesei*.



Researchers screened a number of fungi looking for a candidate that could help fill concrete cracks. Congrui Jin, CC BY-ND

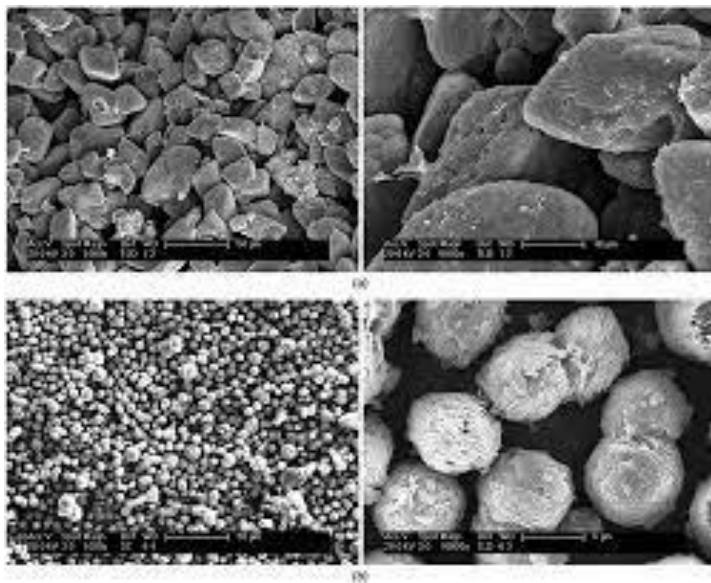
We initially screened about 20 different species of fungi in order to find one that could withstand the harsh conditions in concrete. Some we isolated from the roots of plants that grew in nutrient-poor soils, including from the New Jersey Pine Barrens and the Canadian Rocky Mountains in Alberta.

We found that as calcium hydroxide from concrete dissolved in water, the pH of our fungal growth medium increased from a close-to-neutral original value of 6.5 all the way to a very alkaline 13.0. Of all the fungi we tested, only *T. reesei* could survive this environment. Despite the drastic pH increase, its spores germinated into threadlike hyphal mycelium and grew equally well with or without concrete.

Once the spores (left) germinate with the addition of water, they grow into threadlike hyphal mycelium (right). Congrui Jin, CC BY-ND

We propose including fungal spores, together with nutrients, during the initial mixing process when building a new concrete structure. When the inevitable cracking occurs and water finds its way in, the dormant fungal spores will germinate.

As they grow, they'll work as a catalyst within the calcium-rich conditions of the concrete to promote precipitation of calcium carbonate crystals. These mineral deposits can fill in the cracks. When the cracks are completely caulked and no more water can enter, the fungi will again form spores. If cracks form again and environmental conditions become favorable, the spores could wake



up and repeat the process.

*T. reesei* is eco-friendly and nonpathogenic, posing no known risk to human health. Despite its widespread presence in tropical soils, there are no reports of adverse effects in aquatic or terrestrial plants or animals. In fact, *T. reesei* has a long history of safe use in industrial-scale production of carbohydrase enzymes, such as cellulase, which plays an important role in fermentation processes during winemaking. Of course, researchers will need to conduct a thorough assessment to investigate any possible immediate and long-term effects on the environment and human health prior to its use as a healing agent in concrete infrastructure.

Future cement recipes may include fungi. Midtown Crossing at Turner Park, CC BY

We still don't fully understand this very young but promising biological repair technique. Concrete is a harsh environment for the fungus: very high pH values, relatively small pore sizes, severe moisture deficit, high temperatures in summer and low temperatures in winter, limited nutrient availability and possible exposure to ultraviolet rays from sunlight. All of these factors dramatically influence the fungi's metabolic activities and make them vulnerable to death.

Our research is still in the initial stage and there's a long way to go to make self-healing concrete practical and cost-effective. But the scope of American infrastructure's challenges makes exploring creative solutions like this one worthwhile.

## How do forensic engineers investigate bridge collapses, like the one in Miami?

On March 15, a 950-ton partially assembled pedestrian bridge at Florida International University in Miami suddenly collapsed onto the busy highway below, killing six people and seriously injuring nine. Forensic engineers are taking center stage in the ongoing investigation to find out what happened and why – and, crucially, to learn how to prevent similar tragedies in the future.

I'm not actively involved in this investigation, but I've been a forensic engineer for nearly 20 years and am the 2018 president of the National Academy of Forensic Engineers. Similar to forensic scientists, we visit scenes of disasters and crimes to determine what role engineering practices played in what happened. The first step in any forensic investigation, collecting evidence, often can't begin until survivors are rescued and victims are recovered. Those operations displace material and can damage evidence, which means forensic engineers must study the emergency response as well, to be able to tell whether, for instance, a support column collapsed during the event or was destroyed to reach a victim in need of help. During the FIU recovery efforts rescuers used large equipment to break up massive blocks of concrete so that victims' bodies could be recovered.

In Miami at the moment, forensic engineers and technicians from the National Transportation Safety Board are on the scene. Right now they're collecting samples of materials from the bridge to test for their physical properties. They're reviewing drawings and plans, and examining both industry standards and site engineers' calculations to understand what was supposed to be built – to compare with what was actually constructed. They'll look at photographs and videos of the collapse to identify the sequence of events and locations of key problems. Of course, they'll also talk to witnesses to find out what workers and passersby saw and heard around the time of its collapse.



Every element holds clues to what happened – including the cracks in the concrete and stress marks in the metal rods. AP Photo/Wilfredo Lee

Then they'll combine and analyze all that data and information to identify as clearly as possible what went wrong, in what order. Often there are many factors, each leading to or amplifying the next, that ultimately caused the disaster. Putting that puzzle together is a key part of the forensic engineer's role.

#### Weakness in partial structure

The FIU bridge was being built using a method called “accelerated bridge construction,” with separate sections that needed to be put together: The footings were installed beside the road and the span was built nearby and lifted into place just days before the collapse. In a plan like that, each piece must be able to withstand the forces acting on it as they're all being put together. A weakness in one place can cause problems elsewhere, ultimately leading to catastrophe.

Two key elements of the bridge design, the tall center pylon and pipe supports, were not yet in place when the structure collapsed. They hadn't been scheduled to be added until later in the process – and the bridge wasn't slated to open until next year, so it's likely that the

project's designers and engineers expected the bridge segment to hold while construction continued.



An artist's rendering of what the final bridge was supposed to look like. City of Sweetwater

Part of a forensic engineering evaluation will investigate whether that was a reasonable expectation, and whether those missing elements reduced the strength of what was there enough for it to collapse.

#### Searching for clues

There are some other publicly available clues, too, that shed light on avenues likely under investigation already. Dashcam video of the bridge collapse seems to indicate that the initial failure was very close to the north end of the structure. It has been reported that a couple of days before the collapse, a crack had been discovered near the bridge's north end. Additionally, the bridge span might have been either undergoing stress testing or other adjustments when it collapsed. It's too early to say now – but the inquiry will certainly reveal – whether the crack and the stress testing put too much load at the north end of the bridge.