Study says ancient Romans may have built “invisibility cloaks” into structures



Enlarge / The Roman Colosseum is an oval amphitheatre in the center of the city of Rome. French scientists suggest its structure might have helped protect it from earthquake damage. Alex Livesey/Danehouse/Getty Images)

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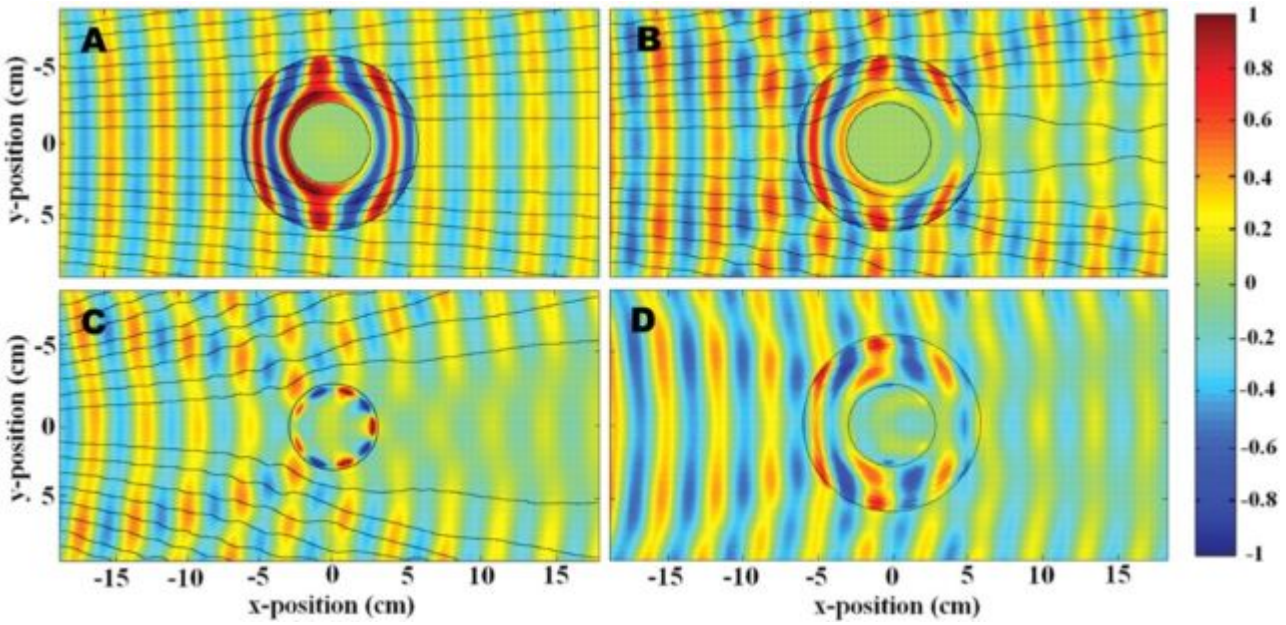
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Scientists are hard at work developing real-world “invisibility cloaks” thanks to a special class of exotic manmade “metamaterials.” Now a team of French scientists has suggested in a recent preprint on the physics arXiv that

certain ancient Roman structures, like the famous Roman Colosseum, have very similar structural patterns, which may have protected them from damage from earthquakes over the millennia.

Falling within the broader class of photonic band gap materials, a “metamaterial” is technically defined as any material whose microscopic structure can bend light in ways it doesn’t normally bend. That property is called an index of refraction, i.e., the ratio between the speed of light in a vacuum and how fast the top of the light wave travels. Natural materials have a positive index of refraction; certain manmade metamaterials—first synthesized in the lab in 2000—have a *negative* index of refraction, meaning they interact with light in such a way as to bend light around even very sharp angles.

That’s what makes metamaterials so ideal for cloaking applications—any “invisibility cloak” must be able to bend electromagnetic waves around whatever it’s supposed to be cloaking. (They are also ideal for making so-called “super lenses” capable of seeing objects at much smaller scales than is possible with natural materials, because they have significantly lower diffraction limits.) Most metamaterials consist of a highly conductive metal like gold or copper, organized in specific shapes and arranged in carefully layered periodic lattice structures. When light passes through the material, it bends around the cloaked object, rendering it “invisible.” You can see anything directly behind it but never perceive the object itself.



Enlarge / A graph showing how a metamaterial “cloaks” an object by bending light around it.
David R. Smith/Duke University

Unlike Harry Potter’s invisibility cloak, metamaterials really do exist, at least in the laboratory, but they are typically limited to specific wavelengths: microwaves, for example, or infrared light, and even certain frequencies of sound waves. Getting them to work with visible light is a much tougher challenge, although in 2017, French physicists demonstrated a proof-of-principle metamaterial using thin layers of gallium nitride (the blue light-emitting element in LCDs) carved into pillars of varying shapes to delay the flow of visible light through the material. Metamaterials also sometimes cast a telltale shadow, since they do absorb some of the light shining through them.

It may also be possible to use metamaterials to lessen the damage caused to buildings and other infrastructure from earthquakes, by redirecting so-called Rayleigh waves, the more shallow, surface seismic waves that typically inflict the worst structural damage. Per *Physics World*, “The idea is to surround a building with a lattice of holes or solid objects within the soil. When seismic waves within a certain range of wavelengths pass through the lattice, multiple reflections in the lattice interfere with one another destructively to create

a band gap that results in a significant reduction in the shaking of the building."

Scientists described two such schemes for large-scale seismic control inspired by metamaterials at a recent meeting of the Seismological Society of America. One possibility is to design a surrounding landscape so that excavated holes and hills form a periodic array of barriers in areas prone to earthquakes. (Strategically placed rows of trees in a forest could also have a dampening effect.) Computer models indicate that this would be a better strategy for reducing ground motion than carving out deep, narrow canyons and hills. A second study used 3D simulations to demonstrate how designing buildings with varying heights and widths—and integrating that design with the surrounding mountains and valleys—could create a city-wide periodic structure similar to that of a metamaterial. In principle, such structures serve as resonators, removing energy from the shallow surface waves.

- Top view of a megastructure using periodic arrays of tall buildings as resonators to create a seismic cloaking effect.
  Stephane Brûlé et al.
- Analogy between an invisibility cloak and ancient Gallo-Roman theaters.
  Stephane Brûlé et al.

Co-author Stephane Brûlé, a civil engineer at a Lyon-based company called Menard, demonstrated the possibility of this kind of large-scale acoustic and seismic cloaking a few years ago with colleagues from the Fresnel Institute in Marseille. The researchers drilled a periodic array of boreholes into topsoil and discovered that sound waves reflected most of their energy back toward the source when they encountered the first two rows of holes. Brûlé noticed a similar foundational structure while on holiday in Autun (a town in central France), thanks to an aerial photograph of the semicircular

structure of a Gallo-Roman theater buried under a field.

When Brûlé superimposed a more detailed archaeological photograph of the theater's structure over an image of one of the invisibility cloaking metamaterials he and his Fresnel colleagues had made in the lab, the ancient theater's pillars lined up almost perfectly with the microscopic elements in the metamaterial. He discovered similar overlap with images of the foundational structure of the Roman Colosseum and other, fully enclosed amphitheaters from the same era.

> *"I doubt that the [Romans] intentionally designed their buildings to be earthquake resistant."*

Roman engineers may not have done this deliberately; they could have just been lucky, according to Brûlé. Or they might have noticed over the centuries that certain structures were more resistant to earthquake damage than others and modified their designs accordingly. "Rigorously, we cannot say more for the moment," he told *Physics World*.

"The introduction of archaeological metamaterials is a fascinating idea," said Greg Gbur, a physicist at the University of North Carolina in Charlotte. "I doubt that the builders of structures in that era intentionally designed their buildings to be earthquake resistant, or even that they were able to unconsciously evolve their designs over time to make them more secure—the time scales seem too short. I could imagine, however, that there might be a sort of 'natural selection' that occurred, where megastructures built with inadvertent earthquake cloaking might have survived longer than their counterparts, allowing us to see their remains now."

"There have been a few articles written in the past about the possibility of designing 'seismic cloaks' to protect buildings, but these were all focused on placing subsurface elements around an individual building to guide the waves,"

said Gbur. “This review illustrates how a well-designed urban area, consisting of multiple buildings, could use the buildings themselves as the elements of the cloak, using them to shield the most important or vulnerable buildings (schools, hospitals) from harm. I had my doubts about the feasibility of really designing practical seismic invisibility cloaks when the research first started coming out, but once again researchers have proven themselves more clever than I could imagine.”

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