Wave 'invisibility cloak' could shield coastlines

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HANDS up if you think the "invisibility cloaks" produced recently lack a certain practicality. Then you might be pleased to hear that ideas originally applied to creating them could now have a more down-to-earth application: shielding coastlines from destructive waves.

By scaling up notions from semiconductor physics and so-called metamaterials, the technology behind "invisibility cloaks", it may be possible to create a zone in front of vulnerable coastlines where waves of certain frequencies cannot reach. Such a system could even double up as an energy plant.

Now you see me... (Image: Miyako City Officer / Rex)

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Metamaterials were first developed about a decade ago. They typically use arrays of tiny antenna-like resonators to bend and channel electromagnetic waves, leading to exotic behaviour. Most famously, in 2006, an Anglo-American team led by John Pendry of Imperial College London used such a set-up to create an invisibility cloak: a series of resonators that steered light around an object, effectively rendering it invisible, albeit only in the microwave spectrum. A year later, another team extended the design to work with visible wavelengths. However, that device could only shield two-dimensional objects no wider than 10 micrometres, which are barely visible anyway.

After that, acoustic invisibility cloaks that could hide submarines from sonar were also suggested. But it wasn't until 2008 that Stefan Enoch at the Fresnel Institute in Marseille, France, and Sebastien Guenneau at the University of Liverpool, UK, applied the idea to water. Their proposed structure uses fixed columns arranged in concentric circles to channel water waves around a vulnerable target such as a coastline. The same team has since extended the idea to protecting buildings from earthquake shock waves, in theory.

Now Xinhua Hu and colleagues at Fudan University in Shanghai, China, have come up with a way to create a no-go zone for some water waves that, unlike Enoch and Guenneau's set-up, could also double up as a wave-energy plant. Hu's team proposes using a rectangular array of stationary cylinders fixed to the sea floor in coastal waters. "The resonating cylinder array that we studied can be seen as a type of metamaterial for water waves," Hu claims.

Here's how it works. Each hollow cylinder would be split vertically into quarter-circle arcs that fill up with water, and discharge it, depending on the water level surrounding them (see diagram). Although the cylinders are completely still, this constant filling and discharging is a form of oscillation and so is analogous to the electromagnetic oscillators that interfere with light waves in an invisibility cloak.

By adjusting the width of the vertical slits, the size of the cylinders, and their spacing, Hu calculates that the array could be tuned to water waves of a particular frequency so that it drains the peaks and then discharges to fill in the wave troughs - in effect dismantling those waves.

Using several arrays with different spacing and various sizes of cylinder, it might even be possible to block waves of several different frequencies - and perhaps even tsunamis, Hu claims. The result should be a huge reduction in waves within the array, and as a result, protection for any coastline or shore behind it, he says.

This action alone will not remove the waves' energy - "reflection" waves would be produced, but in the opposite direction. Alternatively, Hu says the energy from the dismantled waves could be used to generate power, if it was absorbed by a device inside the columns. Based on an idealised scenario in which waves are all one frequency, Hu calculates that 90 per cent of wave energy could be reflected or absorbed by the array (*Physical Review Letters*, in press).

Hu's team has demonstrated this idea using computer simulations and a table-top experiment. The researchers placed 15-millimetre-tall model resonators in water 8 mm deep, spaced 12 mm apart. When they tested waves of different frequencies on the mini-array, they were able to create a wave "no-go zone" at a frequency of 4.2 waves per second. Hu likens this zone to the band-gaps found in semiconductors, which are out-of-bounds for electrons thanks to quantum mechanics.

"This proposal is a nice twist on the invisibility cloak for water waves," says Guenneau, who is now testing a version of his shore-protection system at an indoor wave facility near Marseille.

Others are sceptical, however. Chiang Mei, emeritus professor of ocean engineering and fluid physics at the Massachusetts Institute of Technology doubts that Hu's proposal will work when scaled up to life-sized waves, let alone tsunamis. "Even if you get such an effect at the small scale, to predict it at the large scale in the ocean is extremely difficult."

Mei also questions whether the behaviour of light in metamaterials translates easily to ocean waves, due to friction in the water passing through the split tubes and vortices forming as the water interacts with the tubes. "Real fluids are not so easy to predict from a theoretical or mathematical point of view," he says, adding that building the structure would be expensive. Hu acknowledges that effects such as friction and vortices must be considered.

Solomon Yim, who works in ocean engineering at Oregon State University in Corvallis, says that using resonators to block waves and tsunamis is a "smart way to do it", but that implementation could be tough.

Pendry thinks Hu's design could probably work for regular waves, but not for tsunami defence. "Given the energy content of a tsunami, and also the very low frequency of the wave, it is definitely not a practical proposition," he says. Hu agrees that tsunami defence would require an "unprecedented" engineering effort: columns would need to be placed every 100 metres and be strong enough to survive the tsunami.

Hu adds that arrays of buoys already used to generate wave energy could be adjusted to double up as coastal shields.

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