Capturing the energy in ocean waves

MIT researchers are working with colleagues in Portugal to design a pilot-scale device that will capture the energy in ocean waves and use it to power an electricity-generating turbine. The MIT team's simulations of the project have shown ways—some unexpected—to tailor the device to catch significantly more of the energy in the incident waves.

Wave energy is a large, widespread renewable resource that is environmentally benign and readily scalable. In some locations—the northwestern coasts of the United States, the western coast of Scotland, and the southern tips of South America, Africa, and Australia, for example—a wave-absorbing device could theoretically generate 100 to 200 megawatts of electricity per kilometer of coastline. But designing a wave-capture system that can deal with the harsh, corrosive seawater environment; handle hourly, daily, and seasonal variations in wave intensity; and continue to operate safely in stormy weather is difficult.

Chiang C. Mei, Ford Professor of Engineering in the Department of Civil and Environmental Engineering, has been a believer in wave energy for decades. "I started working on wave energy at the end of the 1970s—a long time ago, when the gasoline price was only 50 cents per gallon," he recalls. Now with soaring oil prices there is renewed interest in harnessing the energy in ocean waves.

The best means of harnessing that energy is not obvious. As a result, many types of devices are being developed, including simple buoys and oscillating structures that run parallel to the shore or snake out into the ocean. All are designed to extract energy from the surface motion of ocean waves. In general, the force of the waves causes the device to oscillate, and that motion is translated into force to turn an electricity-generating turbine.

To help engineers design such devices, Mei and his colleagues develop numerical simulations that can predict wave forces on a given device and the motion of the device that will result. The simulations not only guide design decisions that will maximize energy capture but also provide data to experts looking for efficient ways to convert the captured mechanical energy into electrical energy.

Designing a pilot plant for Portugal

One country with a good deal of expertise in wave energy research and development is Portugal. For the past three years, Mei has been working with Professors António Falcão, António Sarmento, and Luis Gato of Instituto Superior Tecnico, Technical University of Lisbon, as they plan a pilot-scale version of a facility called an oscillating water column, or OWC. (See the diagram to the right.) Situated on or near the shore, an OWC consists of a chamber with a subsurface opening. As waves come in and out, the water level inside the chamber goes up and down. The moving surface of the water forces air trapped above it to flow into and out of an opening that leads to an electricity-generating turbine. The turbine is a special design in which the blades always rotate in the same direction, despite the changing direction of the air stream as the waves come in and out.

The Portuguese plan is to integrate the OWC plant into the head of a new breakwater at the mouth of the Douro River in Porto, a large city in northern Portugal. Ultimately, the installation will include three OWCs, which together will generate 750 kilowatts. As a bonus, the plant's absorption of wave energy at the breakwater head will calm the waters in the area and reduce local erosion.

OWCs have been installed elsewhere, but tailoring a system to a given site is key to maximizing power output. To help, Mei and graduate student Hervé Martins-Rivas of the Department of Civil and Environmental Engineering formulated a numerical model that shows what happens to the incoming waves, outside and inside the OWC. Millions of calculations simulate how the waves behave in the region; how they interact with the complex surfaces of the breakwater, the head of the breakwater, and the OWC structure itself; how the elevation of the water inside the OWC changes; and how the column of air moves and interacts with the turbine.

Their results show that the distance the water surface inside the chamber rises and falls depends on the frequency of the incoming waves, but the relationship between the two factors is not always the same. "When we chart frequency against change in elevation, there's a peak—a wave frequency that resonates with the chamber, causing an especially large change in elevation," Mei explains. "And the more the water surface moves up and down, the more the air is compressed—and the greater the power for turning the turbine and generating electricity."

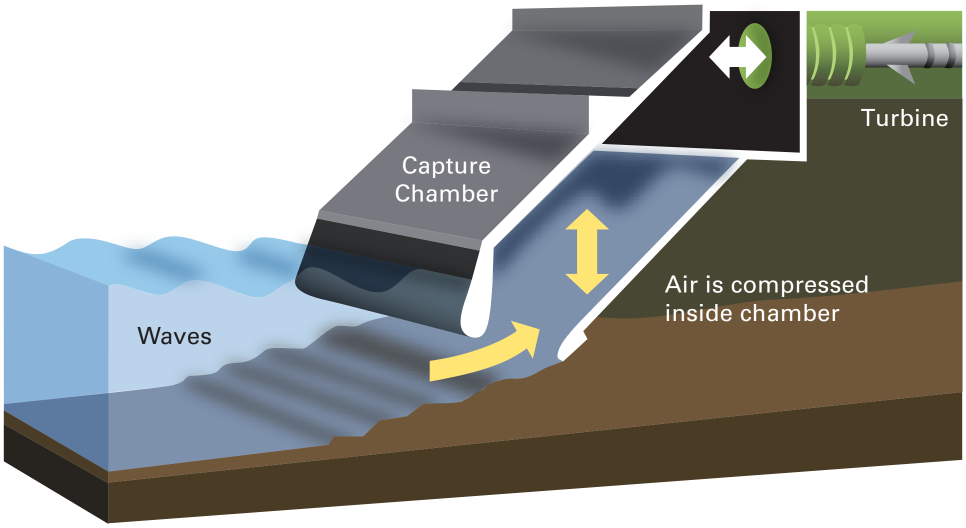
That finding was not a surprise. A wave-energy device always works best when its resonant frequency matches the natural frequency of the incoming waves. Think of pushing a person on a swing: the biggest result comes by pushing in time with the natural interval of the swing.

In reality, however, ocean waves are complex. Despite their appearance, they are not single-frequency waves. Waves form in the open ocean and come toward land from various directions and distances, joining together into a single wave as they approach shallow water. A wave coming onshore is therefore the sum (or superposition) of many waves—waves that have different frequencies. As a result, a device designed to match a narrow peak resonating frequency will fail to capture energy carried by the wave at other frequencies.

The challenge, therefore, is to design a device that resonates at a broad spectrum of wavelengths—and an unexpected finding from the MIT analysis provides a means of achieving that effect. The key is the compressibility of the air inside the OWC chamber. While that compressibility cannot be altered, its impact on the elevation of the water can be changed—simply by changing the size of the OWC chamber. The simulations showed that using a large chamber causes resonance to occur at a wider range of wavelengths, so more of the energy in a given wave can be captured. "We found that we could optimize the efficiency of the OWC by making use of the compressibility of air—something that is not intuitively obvious," says Mei. "It's very exciting."

Also exciting is a memorandum of understanding, signed in late May 2008 by the U.S. secretary of energy and the Portuguese minister of economy, that establishes formal cooperation between the two nations on the "policy, scientific, and technical aspects of wave energy generation and other renewable energy technologies."

Oscillating water column for capturing wave energy



In an oscillating water column, waves enter through a subsurface opening into the chamber with air trapped above. The wave action causes the captured water column to move up and down, pushing the trapped air into a turbine that generates electricity. The turbine turns continuously, despite the changing direction of the air stream as the waves come in and out.

Other approaches and plans

While work on the OWC continues, Mei is also looking at other wave-energy devices and situations. He and graduate student Xavier Garnaud of the Department of Aeronautics and Astronautics recently began working with Professor Ali Tabaei at the Masdar Institute of Science and Technology in Abu Dhabi on a project that focuses on energy-absorbing buoys and their deployment in buoy "farms." The MIT researchers' simulations are helping to optimize the size and spacing of the buoys so that each one will capture the most energy it can—without blocking the waves coming to its neighbors.

Mei continues to be enthusiastic about wave energy, but he is not unrealistic in his expectations about its future role. Although costs have been falling in recent years, wave energy is unlikely to be commercially viable for some time—perhaps several decades. Nevertheless, Mei is adamant that more attention should be given to this clean, renewable source of energy. "Given the future of conventional energy sources, we need lots of research on all kinds of alternative energy," he says. "Right now, wind energy and solar energy are in the spotlight because they've been developed for a longer time. With wave energy, the potential is large, but the engineering science is relatively young. We need to do more research." His vision? A team of MIT experts in different fields—from energy capture and conversion to transmission and distribution—who can work collaboratively toward making large-scale wave energy a reality.

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Research on the OWC was supported by the MIT-Portugal Alliance. Analysis of the wave-energy buoy farm is being supported by the MIT-Abu Dhabi Alliance. Further information can be found in:

E. Martins et al. *Cerdouro Project. Overall Design of an OWC in the New Porto Breakwater.* 6th European Wave and Tidal Energy Conference, Glasgow, United Kingdom, August 28, 2005.

H. Martins-Rivas and C.C. Mei. *Diffraction Effects Near Foz do Douro Breakwater.* 7th European Wave and Tidal Energy Conference, Porto, Portugal, 2007.