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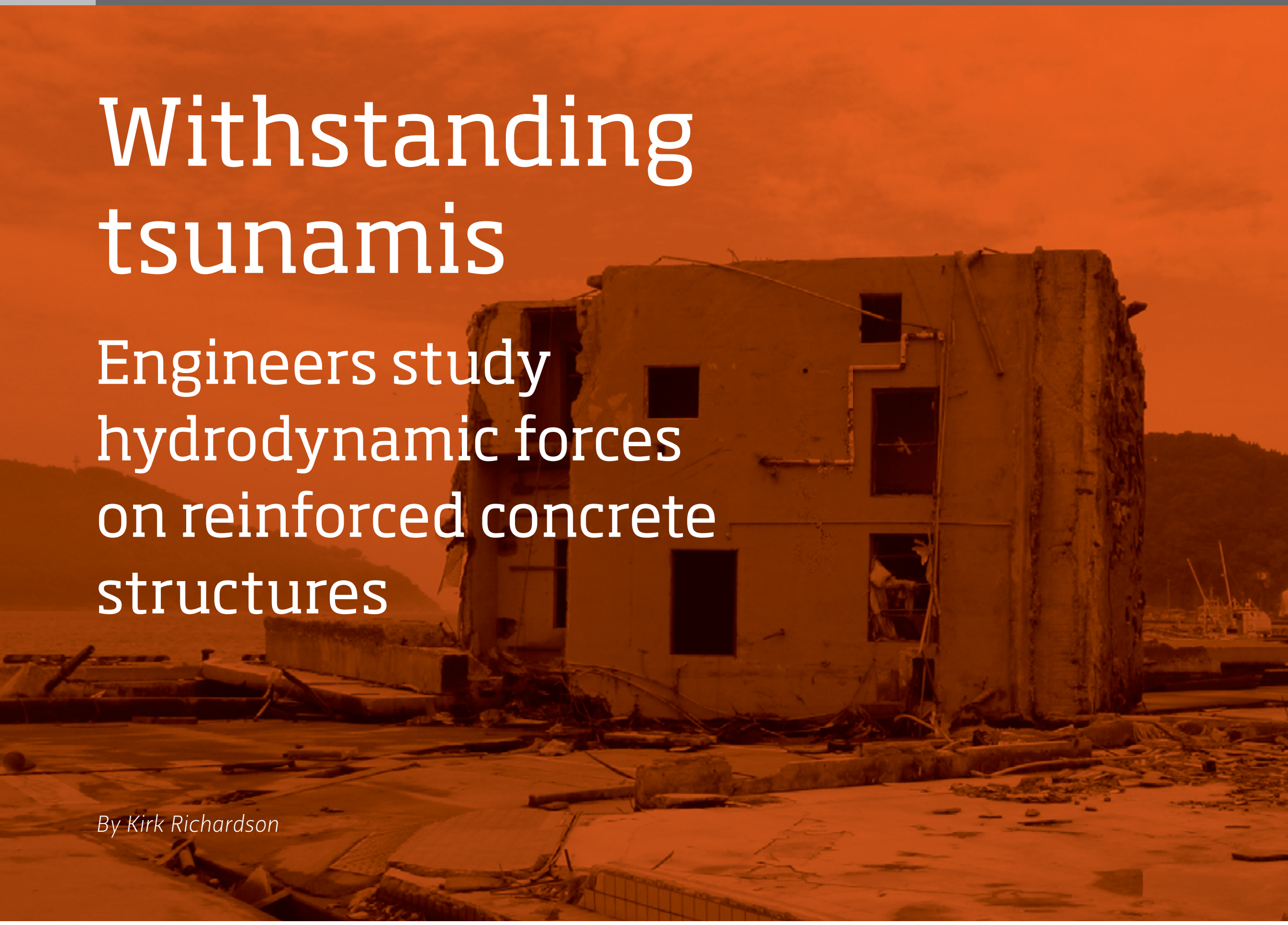

Withstanding tsunamis

Engineers study hydrodynamic forces on reinforced concrete structures

By Kirk Richardson

On March 11, 2011, a 9.0-magnitude undersea earthquake triggered a tsunami that devastated the Tōhoku region of Honshu, Japan. Running six miles inland, the tsunami scattered concrete-reinforced buildings like a child's toys and ultimately led to meltdowns at the nearby Fukushima Daiichi Nuclear Power Plant Complex. Thousands of lives were lost and more than one million structures were destroyed or damaged.

"This was the first time we had seen the effect of a tsunami on contemporary, modern communities," said Harry Yeh, professor of civil and construction engineering and a leading expert on the hydrodynamics associated with natural hazards. Yeh explained that prior to the Tōhoku tsunami, many believed that if evacuees climbed more than four floors in a well-engineered, reinforced concrete building, they would probably be safe. Unfortunately, that supposition collapsed along with the Japanese structures.

The natural disaster in Japan ultimately led Yeh and André Barbosa, a structural engineering assistant professor, to dig much deeper. While investigating the region, Yeh was surprised to find that the flooding or receding waters had dragged or rolled intact reinforced concrete structures up to 230 feet from their foundations.

Back on campus, Yeh and Barbosa and their engineering colleagues started searching for answers. Several of their findings were revealed in a paper entitled *Tsunami Loadings on Structures Review and Analysis,* which they co-authored with graduate students Harrison Ko and Jessica Cawley. The study covers a lot of ground, addressing the combined threats of buoyancy and hydrodynamic forces on at-risk buildings.

Buoyancy force is an upward pressure force under the building, which is caused by excess water weight on the ground surface and a resulting increase of pore-water pressure in the soil. "If you try to push a heavy building sideways, it's very difficult to slide, because it's more stabilized by its weight," explained Yeh. "If the net vertical weight becomes equal to zero as a result of the buoyancy effect, then it becomes really easy to push around." Hydrodynamic forces, proportional to the flow depth and velocity squared, are responsible for the pushing.

Buildings toppled by the 2011 tsunami in the port town of Onagawa, Japan. Some had matt foundations and others had pile foundations. (Page 6 photo by Harry Yeh; page 7 photo by Shunichi Yoshimura)

The study reports that the buoyancy effect depends on the duration, tsunami inundation, and burial depth of the building. "Structural engineers currently lack an in-depth understanding about the hydrodynamic forces developed by tsunamis," said Barbosa. "This paper is intended to help them understand the loads that should be considered when designing a structure to better withstand a tsunami, or to assess what happened to a structure after an event. It's helpful for design in addition to failure analysis."

Oregon State's research could ultimately save lives along Oregon's vulnerable coastline. Scientists are predicting a Cascadia subduction zone earthquake and tsunami in the not-too-distant future. "It's not a matter of if it's going to happen, it's when it's going to happen," said Barbosa. "We need to determine what to do to be prepared for it. With the information we've gleaned from our studies of similar events elsewhere, cities along the Oregon coast may want to assess the resilience of certain structures and rethink previous assumptions."

Yeh and Barbosa have plans to conduct additional studies at Oregon State's O.H. Hinsdale Wave Research Laboratory and possibly leverage recent Natural Hazards Engineering Research Infrastructure funding provided by the National Science Foundation. Barbosa suggested that the facility could help them better understand buoyancy effects on structures built on sand. "There is some physical evidence that provides a plausible explanation to what was observed, but we haven't done further experiments to validate these hypotheses, so these would be useful down the road," he said.

Someday, entire communities might be engineered to withstand tsunamis. "To make a tsunami-resilient community, you really have to think about regional designs," said Yeh, pointing out that this requires predicting things like flow pattern. "You cannot prevent the tsunami flow, but you might be able to guide the flow. You could design the streets to help channel the water and debris."

Engineering on this grander scale starts with a better understanding the forces at work, and Oregon State's engineers are continuing to add to the base of knowledge that will lead to more resilient infrastructure design. **M!**

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