Computer simulation offers clues to when a pedestrian bridge will wobble

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(Tech Xplore)—A trio of researchers with Georgia State University in the U.S. and Volga State University of Water Transport in Russia has developed a computer simulation to help engineers avoid designing pedestrian bridges that wobble. In their paper published on the open access site *Science Advances*, Igor Belykh, Russell Jeter and Vladimir Belykh, describe the factors they used to construct their simulation and why they believe it could be used as a safety guideline by bridge engineers.

The design of pedestrian bridges is very different from bridges meant for use by cars and trains—pedestrian bridges are generally much lighter and flimsier. Less weight means engineers are free to add more artistic touches. But sometimes, such designs can result in bridges that wobble when a lot of people use them at the same time—this was famously demonstrated shortly after the Millennial Bridge was opened in London back in 2000—as the bridge filled, it began to wobble dangerously. Such wobbles are usually in the form of back and forth movements, not up and down, and result from the pressure of people's feet against the bridge below them. In this new effort, the researchers sought to better understand why it is some pedestrian bridges wobble despite the application of basic engineering principles—and to come up with a tool for preventing it from happening in the future.

To understand what happens when a bridge wobbles, the researchers took a novel approach—rather than focusing exclusively on conditions that arise due to timing of footfalls or the amount of force each exerts, they added both to the math that went into their simulation. They also, of course, added in all of the other variables that are used for such bridges. Once their simulation was built, they used it to study the conditions that lead to wobbling. They report that they found that with such wobbling, there appears to be a "magic number" of people that cause bridge movement to reach a tipping point. More importantly, they found that the most critical factor leading to a dangerous increase in wobbling was people reacting to minor wobbling. In adjusting to the wobbling, people would begin to walk in sync, which caused the bridge to wobble more strongly due to the combined exerted force in one direction or the other at the same time. The researchers acknowledge that before their simulation can be used as an engineering tool, it must first pass testing under real world conditions.

More information: Igor Belykh et al. Foot force models of crowd dynamics on a wobbly bridge, *Science Advances* (2017). DOI: 10.1126/sciadv.1701512

Abstract
Modern pedestrian and suspension bridges are designed using industry standard packages, yet disastrous resonant vibrations are observed, necessitating multimillion dollar repairs. Recent examples include pedestrian-induced vibrations during the opening of the Solférino Bridge in Paris in 1999 and the increased bouncing of the Squibb

Park Bridge in Brooklyn in 2014. The most prominent example of an unstable lively bridge is the London Millennium Bridge, which started wobbling as a result of pedestrian-bridge interactions. Pedestrian phase locking due to footstep phase adjustment is suspected to be the main cause of its large lateral vibrations; however, its role in the initiation of wobbling was debated. We develop foot force models of pedestrians' response to bridge motion and detailed, yet analytically tractable, models of crowd phase locking. We use biomechanically inspired models of crowd lateral movement to investigate to what degree pedestrian synchrony must be present for a bridge to wobble significantly and what is a critical crowd size. Our results can be used as a safety guideline for designing pedestrian bridges or limiting the maximum occupancy of an existing bridge. The pedestrian models can be used as "crash test dummies" when numerically probing a specific bridge design. This is particularly important because the U.S. code for designing pedestrian bridges does not contain explicit guidelines that account for the collective pedestrian behavior.

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