HOW WILL YOUR BUILDING FARE IN AN EARTHQUAKE? TERJE HAUKAAS IS INVESTIGATING HOW PROBABILITY AND COMPUTER-BASED 3-D SIMULATIONS CAN PROVIDE A BETTER PICTURE

SEISMIC SHIFT

It happened in the early morning hours of January 17, 1994. A small rumble from the depths of the earth steadily grew in strength and intensity to unleash a tremor that would crack cement, crumble brick, bend steel and reduce many "earthquake resistant" buildings and overpasses to dust. Within minutes, 51 people were dead and 9,000 more injured. From San Fernando Valley to Anaheim to Santa Monica, just one shift in the earth's crust left a path of destruction with few structures unscathed. Although it had a moderate magnitude of 6.7, the 1994 Northridge earthquake proved to be the most costly quake in US history based on the dollar amount of damage. With most earthquake design codes, damage is implied to allow the structure to dissipate seismic energy. How much damage, no design code is capable of predicting, leaving serious questions about their efficacy. "The Northridge earthquake in 1994 was interesting because the design codes did exactly what they were supposed to, namely ensure life safety because there wasn't a lot of loss of life," says Dr. Terje Haukaas, assistant professor at UBC Vancouver's Department of Civil Engineering. "But the damage was in the billions and this was at odds with owners' and public's expectations." The financial repercussions of the damage sustained in the 1994 Northridge earthquake prompted researchers at the University of California, Berkeley, to pioneer a performance-based approach to seismic-engineering design. Haukaas was among this new generation of structural engineers who abandoned a complete reliance on design codes and began investigating how computer analysis could more accurately simulate the actual behaviour of a building in an earthquake. "I don't think people realize just how much of an impact those analysis models will have on our opportunity to actually simulate the behaviour of a building," Haukaas explains. "I'm interested in the performance of the building instead of that it only conforms to code. I feel that performance-based engineering should complement the codes by adding to its minimal requirements." In 2006, Haukaas and his research partner Dr. Ken Elwood took a giant leap towards securing the future of performance-based engineering by procuring a real-time hybrid-testing model through a $0.9-million Canada Foundation for Innovation New Opportunities grant. As one of the first of its kind in Canada, the hybrid-testing system combines physical testing and model-based simulations in the form of 3-D numerical models that enable large-scale testing of structural systems. Because there is instant communication between the computer and the real

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structure in the lab, data can be calibrated from both the numerical model and the physical element for a more accurate account of a building's global performance. Unlike the hybrid system, current earthquake-engineering experiments rely on data produced by shake tables or hydraulic actuator tests. Shake tables produce ground motion similar to an actual earthquake, but due to sheer size limitations these experiments can only consider individual structural components, like a column or a wall. Tests with hydraulic actuators are even more limited because they can only subject the structural component to varying static loads even though earthquakes subject entire structural systems to dynamic loads. The fact that traditional earthquake-engineering experiments don't factor in uncertainty is of particular interest to Haukaas. Uncertainties in the structural properties of

a particular building, its material properties, its non-structural content such as furniture, and the amount of force created by the tremors all affect the probability of a real-life building behaving exactly as replicated in a lab. This limits the usefulness of deterministic simulations and predictions. Instead of taking a deterministic approach to seismic design, Haukaas' research utilizes probability to link computer-simulated numerical models with reliability (the consideration of uncertainties); sensitivity (the response to change); and optimization (the balance between cost and safety). By taking these three aspects into account, Haukaas says models calibrated by hybrid testing provide a more complete and realistic picture of the extent of damage expected to a structure: "Instead of saying the building will behave in such and such a way, there's a probability distribution here. It may be less satisfying to tell the owner that there is a five per cent chance of certain damage happening but in reality, you can never be sure about the actual outcome." For those living on the West Coast where earthquake hazard is ubiquitous, building owners can benefit from more specific information about how their building will perform in the event of an earthquake, allowing them to make essential decisions about insurance coverage and the necessity for structural upgrades. Haukaas' research into performance-based engineering also provides a prescription to revise building codes without having to wait for an earthquake to highlight the weaknesses of the current system. "Imagine if that Northridge earthquake scenario happened here in Vancouver, being the port to the massive Asian market. It's going to have ripple effects from here to Chicago," he suggests. "But earthquake hazard isn't something you can touch and feel. As such, it can be a nasty animal because it can suddenly jump up and bite you. Then people realize, oh darn, we should've put some thought into how we design our building to make it as safe as possible and avoid business interruptions." The terrain treaded by Haukaas and his research team is still relatively new to the engineering community; his research has been warmly but cautiously received. Haukaas is optimistic his work will gain momentum as city planners and building owners begin to realize the advantage of understanding how structures will react in an earthquake. For now, Haukaas is content to look to a future where performance-based engineering will play a vital role in not only saving lives, but saving critical infrastructure and avoiding business interruption as well. In addition to the $0.9-million grant from the Canada Foundation for Innovation New Opportunities, Dr. Terje Haukaas also receives funding from the Natural Sciences and Engineering Research Council of Canada (NSERC) and the British Columbia Knowledge Development Fund (BCKDF).