Do earthquake hazard maps predict higher shaking than actually occurred? Research finds discrepancy

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A new study by Northwestern University researchers and coworkers explains a puzzling problem with maps of future earthquake shaking used to design earthquake-resistant buildings. The research was published May 1 in the journal *Science Advances* in a paper titled "Why do seismic hazard maps worldwide appear to overpredict historical intensity observations?"

Although seismologists have been making these maps for about 50 years, they know very little about how well they actually forecast shaking, because large damaging earthquakes are infrequent in any area.

To learn more, the Northwestern research team compiled shaking data from past earthquakes. These include CHIMP (California Historical Intensity Mapping Project) which combines data from seismometers with historical data (termed seismic intensity) that measures ground shaking caused by earthquakes from how it affected man-made structures and objects within the quake area. Intensity information can be gleaned from photographs of damage, first-hand or newspaper accounts, and oral history.

"We found a puzzling problem," said geophysicist Leah Salditch, the study's lead author and a recent Northwestern Ph.D. graduate. "Hazard maps for California as well as Japan, Italy, Nepal and France all seemed to overpredict the historically observed earthquake shaking intensities. The hazard maps were made by groups in different countries, but they all predicted higher shaking than observed."

In analyzing the possible causes, the research team discovered the issue was with the conversion equations used in comparing hazard maps predicting future earthquakes with actual shaking data, rather than systemic problems with the hazard modeling itself.

Salditch, who was in the research group of co-author Seth Stein, William Deering Professor Emeritus of Earth and Planetary Sciences at Northwestern, is now a geoscience peril advisor at Guy Carpenter & Company. Other Northwestern authors are Molly Gallahue and James Neely, also recent Ph.D. graduates from Stein's group.

Seismologists often say that "earthquakes don't kill people, buildings kill people"—most deaths in an earthquake are caused by collapsing buildings. As a result, society's best way to reduce deaths in future earthquakes is to construct buildings that should withstand them. However, because earthquake-resistant construction is expensive, communities need to balance its costs with other societal needs. For example, they can decide to put more steel in school buildings or hire more teachers.

To make these tough choices and design appropriately, policymakers and engineers use earthquake hazard maps that predict how much shaking to expect with certain probability over the many years buildings and other structures will be in use. These maps are based on assumptions about where and how often earthquakes in the area may happen, how big they will be and how much shaking they will cause.

In delving into the puzzle of why hazard maps from five different countries all predicted higher shaking than observed, the research team figured there had to be a problem with the maps, the data or both.

"We looked at a number of possible problems with the maps, including the extent that ground shaking depends on local geology, but none of these were big enough to explain the problem," Gallahue said.

If the problem wasn't in the maps, was it in the historical data?

"Probably not," said co-author Susan Hough from the U.S. Geological

Survey. "The shaking data in the different countries were compiled using different techniques but were all lower than the maps predicted. If anything, historical intensities are expected to be inflated because historical sources tend to emphasize the most dramatic effects of shaking."

If there were no problems with the hazard maps and shaking data, why didn't they agree?

"There's a subtle problem," said co-author Norman Abrahamson of the University of California, Berkeley. "Hazard maps are quoted in physical units, whereas intensities are measured on a different scale, so one must be converted to the other. It turns out the conversion equations don't work that well for very strong shaking, so converting the map values overpredicts the intensity data.

"The problem isn't the maps but in the conversion," he said. "Changing the conversion solves most of the misfit between the maps and data. Moreover, a better description of the ground shaking should make things even stronger."

"This is an important and satisfying result," said co-author Neely, now at the University of Chicago. "Maps and data that seemed not to agree were both right. The problem was in comparing the two."

"We started this project 10 years ago and thought there might be serious problems with the hazard maps," Stein said. "Now it looks like there's no fundamental problem with them.

"Maps for some areas may not be that good for various reasons," he said.

"For example, in some places we don't know enough about the earthquake history or the shaking that large earthquakes produce because

of the relatively short time span available. In others, the rate and size of earthquakes may be changing or just poorly understood. So, in some places, maps may overpredict future shaking and in others they may underpredict.

"Nature will sometimes surprise us. However, because the basic hazard mapping method looks sound, we can expect these maps to be fairly good and get better as we learn more."

More information: Leah Salditch, Why do seismic hazard maps worldwide appear to overpredict historical intensity observations?, *Science Advances* (2024). DOI: 10.1126/sciadv.adj9291. www.science.org/doi/10.1126/sciadv.adj9291

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