Has Earthquake Engineering Broken the Power Law?

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Abstract

Investigation of the occurrence of reported deaths from individual earthquakes of the 20th century reveals that about half of the $2.8x10^6$ total deaths occurred in the 7 deadliest earthquakes. I show that the number of earthquakes N with n_d or greater deaths can be approximated by the power law, $N \approx (1.6 \times 10^5)\, n_d^{-0.86}$. This relationship implies that the majority of the deaths occurred in the most infrequent events. Although it is clear that most deaths occurred in structures that were far less earthquake resistant than are demanded by modern building codes, it is not known why the frequency statistics are approximated by a power law. Power-law frequency-size statistics are often observed for complex systems in which events are causally linked. For instance, epidemics can be modeled as power law systems since diseases are infectious. This contrasts with normal statistical systems that are appropriate to explain the aggregate behavior of independent random events (e.g., heart attacks).

The fact that the occurrence of earthquake deaths follows a power law indicates that individual deaths in an event are dependent on each other in some fundamental ways. Of course the earthquake event itself is a potential source of this power law behavior; the Gutenberg-Richter frequency magnitude relationship is a power law relationship that indicates that most of the seismic energy in earthquakes is released in the largest (and most infrequent) events. However, dis-aggregation of seismic shaking hazard models typically indicates that earthquakes in the M 6.5 to M 7 range comprise most of the seismic hazard. This is because most measures of shaking intensity saturate with increasing magnitude and larger earthquakes are very infrequent. That is, current hazard analysis indicates that most of the hazard comes from relatively frequent M 6.5 to M 7.0 earthquakes, whereas the catalog of earthquake deaths indicates that most people died in infrequent M > 7.5 events. Is it possible that poorly constructed cities experience power law statistical failures while well constructed cities have failure statistics that are closer to normal statistics?

I suggest that power law failure statistics can occur when construction mistakes are repeated within an urban area. That is, if ground shaking is such that a particular building style collapses, then the collapses are linked to each other by inherent common flaw in that style of building. For example, the same style of non-ductile concrete frame building failed for the same reasons over and over again in the Izmit earthquake. As another example, it has been mistakenly assumed that the strength of steel welds exceeds the plastic yield stress of steel in moment-resisting-frame buildings. Is it possible that numerous tall buildings might collapse as a result in a large (infrequent) earthquake in the United States? I will show the results of simulations of tall buildings in large earthquakes that suggest the potential for the catastrophic collapse of many modern tall buildings. Furthermore, it suggests that the number of collapses could be decreases by more than ½ if these welds were retrofitted.

If, in fact, most of the hazard is actually in the most infrequent events, then it may be very difficult to achieve Performance Based Engineering. That is, it may be that most of our risk is represented by the things that we know least about; if we knew about them, we would fix them. This suggests that it is important to build robust systems that are least susceptible to uncertainties in ground motion and building performance. I will show that the short-period motions from earthquakes are less uncertain than the long-period motions.

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