RISK MANAGEMENT AND LOSS ESTIMATION LESSONS FROM THE REAL WORLD

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Abstract

Earthquake hazard and loss estimation and earthquake risk management practices have been rigorously tested in recent years by earthquakes in Japan, Chile, New Zealand, and Italy. These countries all have state-of-the-art earthquake engineering technologies and practices, and they provide crucial real-world lessons on the state of hazard and loss estimation and risk management.

These earthquakes indicate that most of the current best practices for hazard and loss estimation, including insurance modeling, are inadequate. All resulted in estimates for earthquake hazard and damage that were either severely underestimated, or sometimes, grossly overstated.

This paper shares lessons learned from the authors' investigations of these recent earthquakes, and their experiences with risk assessments and the risk management practices of individual companies, nuclear power stations, government agencies, large metropolitan areas, and entire countries around the world. It also outlines the authors' recommendations for addressing many of the identified issues, which involve placing more weight on real-world experience data and professional judgment.

Introduction

In the last three years, destructive earthquakes occurred in what are generally considering three of the four countries best prepared for earthquakes: the M8.8 earthquake in Chile in 2010; the M6.3 earthquake in Christchurch, New Zealand in 2011; and the M9.0 earthquake in Japan, centered east of Sendai. The Chile and Japan earthquakes also caused major tsunamis that affected the areas that experienced the strongest ground shaking. Other relevant earthquakes are the M5.9 Mineral, Virginia earthquake of 2011; the M8.0 Sichuan (Wenchuan), China earthquake of 2008; and the M6.3 L'Aquila and M5.8 Emilia Romagna, Italy earthquakes of 2009 and 2012. The authors conducted field investigations of seven of the eight earthquakes, and both tsunamis. Collectively, the earthquakes present valuable data and lessons for risk management and loss estimation practices from some of the world's most advanced areas for the practice of earthquake engineering.

Earthquake Hazard Maps, Ground Motion, and the Codes

The Chile, Christchurch (NZ), and Japan earthquakes of 2010 and 2011 are striking examples of the inadequacies and weaknesses of the state-of-the-art of hazard mapping and ground motion prediction. All three earthquakes dramatically exceeded the strength of the ground motion as predicted by the maps and models. Consequently they also greatly exceeded the requirements of the relevant building codes, given

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that the codes are partly based on those hazard maps. In our opinion, these earthquakes occurred in three of the four countries in the world with the most advanced practices for earthquake engineering and earthquake risk management. The fourth country is the United States – specifically California – which was not embarrassed in the last two years only because it did not experience a major earthquake in its metropolitan areas.

The Christchurch earthquakes are particularly important and instructive for earthquake hazard mapping, as the maps indicated that Christchurch was in a "low seismic risk" zone of New Zealand, which clearly it was not.

An excellent summary of what went wrong and why is presented by Stein et.al. (Reference 1). The conclusions closely match our thinking, except that they come from the seismological perspective, whereas we come more from the engineering perspective. According to Stein et.al. :

> *"The 2011 Tohoku earthquake is another striking example - after the 2008 Wenchuan and 2010 Haiti earthquakes - of highly destructive earthquakes that occurred in areas predicted by earthquake hazard maps to be relatively safe. Here, we examine what went wrong for Tohoku, and how this failure illustrates limitations of earthquake hazard mapping. We use examples from several seismic regions to show that earthquake occurrence is typically more complicated than the models on which hazard maps are based, and that the available history of seismicity is almost always too short to reliably establish the spatiotemporal pattern of large earthquake occurrence. As a result, key aspects of hazard maps often depend on poorly constrained parameters, whose values are chosen based on the mapmakers' preconceptions. When these are incorrect, maps do poorly. This situation will improve at best slowly, owing to our limited understanding of earthquake processes. However, because hazard mapping has become widely accepted and used to make major decisions, we suggest two changes to improve current practices. First, the uncertainties in hazard map predictions should be assessed and clearly communicated to potential users. Recognizing the uncertainties would enable users to decide how much credence to place in the maps and make them more useful in formulating cost-effective hazard mitigation policies. Second, hazard maps should undergo rigorous and objective testing to compare their predictions to those of null hypotheses, including ones based on uniform regional seismicity or hazard. Such testing, which is common and useful in similar fields, will show how well maps actually work and hopefully help produce measurable improvements. There are likely, however, limits on how well hazard maps can ever be made because of the intrinsic variability of earthquake processes."*

We would like to stress two of the points made by Stein et.al. Hazard maps are traditionally constructed using hard instrumental data, little of which is more than 100 years old. For many areas of the world, and certainly Italy and China, we have reliable documentation on the effects of earthquakes going back two thousand years or more. Much of that data are also available in a rough form in the archaeological record. The data are not used adequately with the excuse that it is not scientific data. From an engineering perspective, the data are "close enough" and their addition might give us substantially better results than the more pure science and mathematics have given us to date. We cannot begin to understand earthquake risk by only considering 100 years of data, which in geological terms is only an instant and for recorded human history is very short.

Secondly, we may not understand the earthquake processes adequately, but we have a relatively good understanding of the effects of ground motion on structures and of structural dynamics. These can be verified through testing and post-earthquake analyses when instrumental building records are available. Thus, we can take a more conservative approach and just assume that future ground motion will be stronger than what we expect today, especially if it is based on instrumental data.

We recently took this approach in a project for the World Bank in Albania. Part of the project required the use of an earthquake hazard map for the entire country. The map would be used to assign site-specific ground motion (intensity) to any structure anywhere in the country. The problem is that there is no general agreement on a hazard map for Albania that can be used with some confidence. The code and different government and academic sources (many of whom we interviewed), including the U.S. Geological Survey, differ substantially on the strength of the expected ground motion. However, all of the sources rely primarily on recent and well-documented data. It quickly became obvious to us that most of the 2,500 year history of the country was not being used because the data quality was not considered acceptable. We felt, however, that our map would be of inferior quality if we neglected those data. The compromise was to take a more conservative approach and increase the expected intensities (MMI in this case) by one- to one- and a half units and to simplify and generalize the ground motion map contours and remove pockets of low intensities that were surrounded by higher intensities.

The above strategy addresses another important lesson from the earthquakes of 2010 to 2012. Both ground motion/hazard mapping and the development of engineering code requirements are and have always been re-active processes. Much of the reaction has taken place after major earthquakes when new lessons were learned. This is true for the recent earthquakes as well. Over the years, and after every major earthquake, we have typically ratcheted up the code requirements. This has been the case for conventional structures and for critical structures, such as nuclear power plants. Perhaps it is time to become significantly more pro-active. The earthquakes of the last few years, and especially those in Japan, China, Italy, Chile and New Zealand, imply that we have plenty of room to improve the system without being overly conservative. We believe, based on much experience, that the benefits of this approach outweigh the costs – from both the life safety and the property risk perspectives.

Earthquake Damage and Property Loss Modeling Practices

One of the most useful projects, and possibly the least appreciated considering its impact, to come out of the Applied Technology Council (ATC) is ATC-13, *Earthquake Damage Evaluation Data for California,* 1985. It helped expand the stage for deterministic and probabilistic modeling of structures and portfolios of structures. It developed some of the first damage (fragility) functions for a variety of conventional buildings and structures. It became a stepping-stone in the development of earthquake damage and property loss modeling. At first it was used for the modeling and loss estimation of individual structures and small portfolio of structures, and shortly afterwards, in the late 1980s it began to be used for modeling large portfolios, such as insurance industry portfolios (properties at risk) and government-owned property portfolios.

Today, modeling is used widely throughout the world to estimate the risk to individual buildings, single site portfolios of structures, insurance and reinsurance companies' portfolios (which may include tens of thousands of structures), and government portfolios as well as the modeling of metropolitan areas for loss estimation, emergency planning, etc.

The major earthquakes of the last few years extensively highlighted the strengths and the weaknesses of earthquake damage and property loss modeling, and of the industry associated with it. We briefly summarize some of our observations and conclusions, based on the above earthquakes and numerous projects that involved the use of modeling.

Based on data provided by reinsurers, it appears that the overall insurance industry predicted loss in the 2010 Chile earthquake, excluding tsunami losses, were comparable to the expected losses that were based on modeling. However, the individual company losses, and especially individual industrial losses, were widely inaccurate.

The losses in Christchurch illustrate best the inadequacies of today's modeling practices and associated loss predictions and estimates. Because the earthquake hazard in the city was grossly underestimated, any model that relied on then-current hazard maps would have predicted losses that would have been a small percentage of what happened. Further, building practices in that part of New Zealand, partly because it was not perceived to be a high-hazard area, are quite different from other parts of the world with higher known hazards. Therefore damage functions based on the latter types of buildings would have been largely inappropriate for Christchurch.

The problems outlined above for Christchurch were also observed in all of the earthquakes addressed in this paper, including Japan and its nuclear power plants. In the latter case, earthquake models (not tsunami models) would have overestimated the expected damage, based on the performance of plants like Onagawa that experienced light damage, because the industry has not studied adequately the margins that exist in their facilities. However the tsunami modeling in the case of the Fukushima nuclear power station was grossly inadequate.

Modeling was originally developed for use by highly trained engineers with a thorough understanding of earthquakes and structural engineering. About 30 years after the original models were developed in the early 1980s, most earthquake modeling, and particularly in the insurance industry, is done by staff who have no training and no experience in earthquake and structural engineering. While the overall quality and capabilities of the major models have steadily increased, the capabilities of the users of the models and the quality of their results have decreased steadily.

The following is one of many examples from recent projects where we were asked to review the modeling of commercial and industrial facilities and make recommendations on how to manage the risk. We reviewed the earthquake risk analyses (modeling results) of a large industrial facility located in Mexico very near the California border and a few miles from the Imperial Fault – the fault responsible for some of the most famous earthquakes in earthquake engineering. The modeling company, one of the largest in the industry, concluded that the main risk to the facility, based on probabilistic modeling, was from faulting offshore of San Diego – more than 100 miles (160 km) away. That error was compounded by the loss-control company that developed the modeling input data for the structures and their contents, for use by the modeling company. As is typical in the insurance industry, the company that did the data collection employed fire-protection engineers (and/or others without significant earthquake and structural engineering experience) to survey the buildings. The main structures, which are typical tilt-up reinforced concrete construction with interior non-ductile steel frames, were modeled as base-isolated steel structures with fire-resistant concrete walls. We are unaware of a single base isolated building in all of Northern Mexico, let alone a large, single story and sprawling industrial building (actually several adjacent buildings, to complicate the errors further). The overall loss estimates were completely unrealistic and irrelevant, but the owners had purchased their insurance on the basis of these results and were planning loss control activities and retrofits based on the results.

Sadly, this example is not atypical of analyses we have reviewed in the United States, Japan, and elsewhere. At a minimum, the modeling companies should have fail-safe features in their software and processes to identify these types of fundamental, avoidable errors so that knowledgeable engineers can review and correct them.

In summary, we have observed the following lessons for risk modeling and loss estimation over the last few years:

- The best practices are not very good – at least not in the real world.
- The results are only as good as the models, which are deficient in hazard, structural, and, particularly in non-structural modeling. Almost all modeling of business interruption due to damage from equipment systems and other non-structural effects has little to do with our observations in the real world, unless done by competent earthquake/structural engineers.
- Modeling, as conducted today, is insufficient for smaller portfolios. It can, and most often is, grossly insufficient for single-site analysis (no matter how large or small the site). The only good modeling analyses that we have observed were based on detailed walk-downs and observations by competent earthquake/structural engineers.
- Modeling results can rarely be used to make business decisions regarding business continuity, loss control programs, business interruptions, market-share loss, etc., unless, again, are based on competent engineering
- Typically, the people running the models and the people supplying the modeling data are not qualified to do either, especially in the insurance industry.
- Most models are proprietary and the modeling companies are extremely reluctant to divulge even basic information on the models. Therefore it is absolutely necessary to have independent reviews of the results produced by the models. Again, the independent reviewers must have adequate experience in real-world earthquake and structural engineering, and they must understand the effects of real earthquakes on the types of properties being analyzed.

In summary, we have also observed that all of the above issues can be resolved, with the possible exception of hazard modeling. Even that, however, can be improved. Some of the key improvements that can be accomplished easily are:

- Use qualified engineers to develop the input data and to run the models. The input data must be developed by highly trained earthquake (structural or mechanical) engineers with substantial design experience, meaning (if possible) complemented by direct experience from earthquake investigations.
- Good modeling requires extensive experience with different types of structures and their non-structural features. This especially includes equipment systems, which contribute substantially to overall losses and often control the overall business interruptions. Judgment and experience are more important than anything else except the correct input to the models.
- Good modeling also means keeping up with new lessons from recent earthquakes and leaving a lot of room for interpretation of the results. Modeling results are not black or white – they need extensive interpretation and re-working that must be based on experience and judgment. In short, modeling and loss estimates need reality checks.

References

Stein, S., R.J. Geller, and M. Liu (2012), "*Why earthquake hazard maps often fail and what to do about it*". *Tectonophysics* 562-563, 1–25, 2012.