Evolution of Earthquake Risk Modeling

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ABSTRACT

This paper reviews major milestones in the development of earthquake risk models over the past century, focusing on the developments of the past forty years and how catastrophe models benefit from the advances of many scientific disciplines. The paper concludes with current challenges faced by risk modelers, including assessing and improving the quality of input data to the models and expanding the scope of modeled losses.

KEYWORDS: insurance, risk, catastrophe, model, demand surge

1. INTRODUCTION

The problem of preparing for a great earthquake is not a new one. Around the world, governments, individuals, and businesses know that they should prepare for the 'big one'. Yet, they often do not take the necessary steps in advance of a disaster. Only after the disaster occurs does one recognize the importance of preparing for it. There are, however, some individuals who spend a great deal of time and energy modeling natural disasters and enlightening others on ways in which their impact can be managed – catastrophe modelers.

Along with the advance of computing power, catastrophe models were introduced in the U.S. in the 1980s, but they did not gain widespread attention until after Hurricane Andrew hit southern Florida in August of 1992. Nine insurers became insolvent as a result of their losses from the hurricane and many others suffered 'larger than expected' losses based on actuarial principles employed for risk management at the time. After the 1994 Northridge and 1995 Kobe earthquakes, insurers and reinsurers further realized that, in order to reduce the likelihood of a very severe loss relative to their surplus, they needed to estimate and manage their natural hazard risk more precisely. Many companies turned to the modelers of catastrophe risk for decision support.

Since this time, the catastrophe modeling business has grown considerably. In 2008, catastrophe models are in widespread usage throughout the insurance industry, assisting insurers, reinsurers and other stakeholders to manage their risk from natural disaster events in the U.S. and other regions of the world.

1.1 Catastrophe modeling framework

The most common (and basic) framework for modeling moderate-sized catastrophes is an 'engineering model' (Figure 1). The four-step process includes: (1) defining the hazard (i.e., scenario event or set of stochastic events); (2) assessing the hazard (e.g., ground motion); (3) calculating the damage to the exposure at risk; and (4) quantifying the direct and indirect financial loss, including allocating losses to the stakeholders at risk (e.g., property owner, insurer, reinsurer as applicable).

In moderate-sized catastrophes, losses are a consequence of the direct action of the hazard (e.g., the earthquake ground motion) on the exposure. The exposure—for example, the building or facility and its contents—is subject to damage, which takes some predefined cost to repair or replace. Damaged buildings tend to be individual and separate; the damage is discrete. Damage at a commercial or industrial facility can result in the interruption of business activities, which will further add to the losses. Where residential properties are badly damaged, people may incur additional costs if they relocate while their property is being repaired. However, this is usually the extent of economic losses. The cost is simply the sum of all the individual elements of damage and loss. This is the ‘engineering model’ understanding of a catastrophe, in which the total loss is the sum of the hazard multiplied by the exposure and the vulnerability at each location (For more information, see Grossi and Kunreuther, 2005).

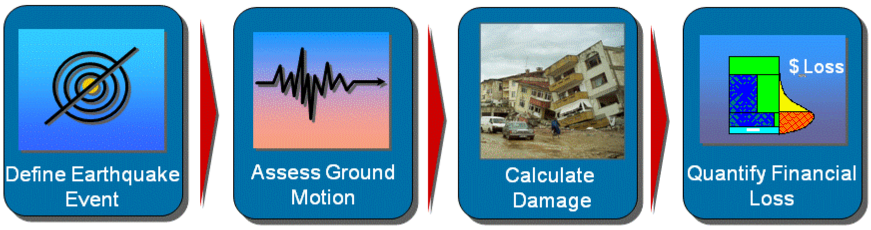

Figure 1 Catastrophe modeling framework for moderate-sized catastrophes

2. ROOTS OF CATASTROPHE MODELING

Catastrophe modeling is not rooted in one field or discipline. The science of assessing and managing catastrophe risk originates in the fields of property insurance and the science of natural hazards. Insurers may well argue that catastrophe modeling’s history lies in the earliest days of property insurance coverage for fire and lightning. In the 1800s, residential insurers managed their risk by mapping the structures that they covered. Not having access to the Geographic Information Systems (GIS) software of today, they used tacks on a wall-hung map to indicate their concentration of exposure. This crude technique served insurers well and limited their risk in the fire-prone urban areas.

On the other hand, a seismologist or meteorologist may well argue that the origin of catastrophe modeling lies in the modern science of understanding the nature and impact of natural hazards. In particular, the common practice of measuring an earthquake’s magnitude and a hurricane’s intensity is one of the key ingredients in catastrophe modeling. A standard set of metrics for a given hazard must be established so that risks can be assessed and managed. This measurement began in the 1800s, when the first modern seismograph (measuring earthquake ground motion) was invented and modern versions of the anemometer (measuring wind speed) gained widespread usage.

2.1 Early 20th Century Developments

In the first part of the twentieth century, scientific measures of natural hazards advanced rapidly with the occurrence of damaging events. The 1906 San Francisco Earthquake marked a new era in awareness of California earthquake risk with the establishment of the State Earthquake Investigation Commission. The commission, led by Professor Andrew C. Lawson of the University of California, Berkeley, published a report in 1908 (commonly referred to as the Lawson Report) which was the first ‘reconnaissance report’ of a U.S. earthquake (Lawson, 1908). The report—with photographs, detailed maps, and survey data—summarized over 20 scientists’ investigations into the earthquake’s damage, as well as gave new insight into the geology of Northern California and the movement of the San Andreas Fault. It served as a benchmark for later reports written following other California earthquakes over the years.

Then, following the 1923 Great Kanto Earthquake, the Earthquake Research Institute of the University of

Tokyo was formed and in 1924, the first seismic building code law was established in Japan. In 1929, U.S. researchers attended the World Engineering Congress in Tokyo, building relationships with Japanese researchers working on the same problems in earthquake engineering. This collaboration among international researchers culminated in the John R. Freeman publication on earthquake damage and earthquake insurance (Freeman, 1932), which is acknowledged as being a groundbreaking volume, containing everything there was to know about earthquakes at the time. More importantly to the development of earthquake risk models, Freeman, who was an insurance executive concerned about earthquake preparedness and referred to as the 'founding father of the strong ground motion program in the United States', outlined the concepts of risk allocation, risk concentration, and average annual loss (AAL).

3. THE FORMATIVE YEARS – PROBABILISTIC MODELING: 1968 THROUGH 1987

While concepts of earthquake insurance risk were developed in the early 1930s, insurance risk models were not introduced until the 1960s. In 1968, C. Allin Cornell, who is acknowledged as the father of modern seismic risk analysis, published his definitive work on probabilistic seismic hazard analysis (PSHA) in the Bulletin of the Seismological Society of America (Cornell, 1968). The basic structure of his PSHA approach is utilized in modern-day catastrophe models. Then, in 1971, the San Fernando Earthquake occurred and in 1973, Robert V. Whitman of the Massachusetts Institute of Technology presented the concept of the Damage Probability Matrix (DPM) at the 5th World Conference on Earthquake Engineering (Whitman et al., 1973). Utilized in the modern-day HAZUS catastrophe model developed by the Federal Emergency Management Agency (FEMA) of the United States (see FEMA, 2002), DPMs estimate the probability of experiencing different building damage states as a function of ground motion intensity.

In the late 1960s and early 1970s, Don Friedman of Travelers Insurance Company developed computer simulation models that recreated economic impacts from past historical events on present-day exposures (Friedman, 1972). He additionally performed simulations of past events with different physical characteristics, illustrating the sensitivity of losses to various input parameters. Through the 1970s and early 1980s, studies theorizing on the source and frequency of events were also published, along with approaches to gathering loss information post-disaster. For example, Ted Algermissen and his colleagues published a study on gathering loss information immediately following an earthquake (Algermissen et al., 1978). These developments led U.S. researchers to compile hazard and loss studies, estimating the impact of earthquakes, as well as other natural disasters. One notable compilation on earthquake-related losses was Karl V. Steinbrugge's anthology of losses from earthquakes, volcanoes, and tsunamis, which was published in 1982 (Steinbrugge, 1982). Within this volume, damage ratios as a function of Modified Mercalli Intensity are presented, along with the concept of Probable Maximum Loss (PML) and a zoning map of California for earthquake underwriting purposes.

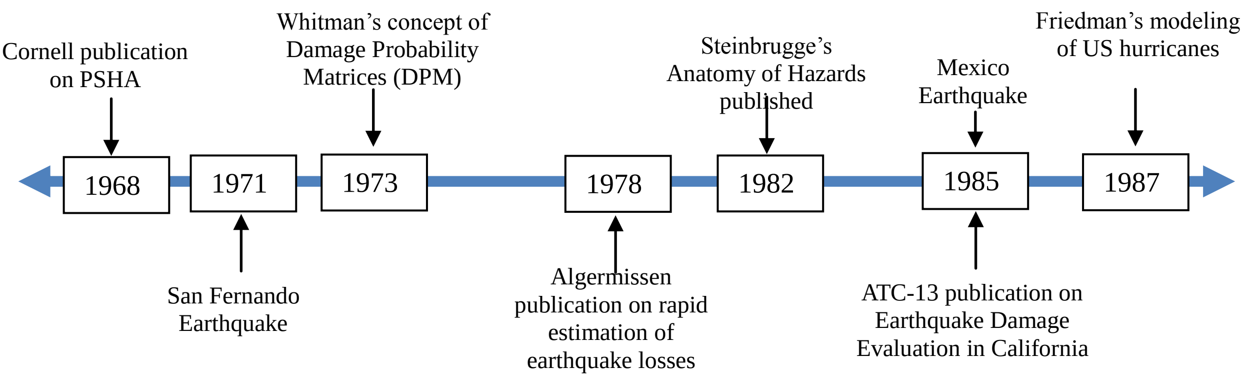

Figure 2 The formative years of catastrophe modeling history (1968-1987)

Following the 1985 Mexico Earthquake, reinsurance companies became more aware of their global earthquake risk and the need to manage catastrophe risk much better. Methods for alternative risk transfer were developed, leading to the securitization of insurance risk following future disaster events (e.g., Hurricane Andrew in 1992 and the 1994 Northridge Earthquake). During the same period, the Applied Technology Council report of Earthquake Damage Evaluation Data for California was published (ATC-13, 1985). In this report, 71 earthquake engineering experts were asked to indicate their low, best, and high estimates of damage ratios for 78 types of structures subject to earthquakes with Modified Mercalli Intensity (MMI) levels of VI through XII. Catastrophe model developers used these estimates in their earliest versions of their earthquake loss software.

In 1987, Don Friedman published the proceedings from an insurance workshop on modeling losses from U.S. hurricane and windstorms (Friedman, 1987) that summarized his work. He utilized a main frame computer to assess scenario losses to insurance portfolios. While the analysis was not fully probabilistic, it did illustrate the usage of insurance claims data to develop damage curves. These advancements over the span of twenty years (Figure 2) were a necessary and formative step in earthquake risk modeling.

4. THE EVOLVING YEARS - RESPONSE TO DISASTERS : 1988 THROUGH 2005

The developments of the 1960s through the mid-1980s gave way to the emergence of the first generation of modern-day probabilistic catastrophe models in the mid to late 1980s. Since this time, numerous natural disasters have occurred, allowing the evolution of the models (Figure 3). With each new natural disaster, lessons are learned and observations are made that allow catastrophe modelers to strive for the next generation in modeling.

In the beginning, there were only a handful of catastrophe modelers and the use of the models was not widespread. For example, in 1988, Risk Management Solutions, Inc. was founded at Stanford University and a publication on the RMS catastrophe modeling software (IRAS) was part of the proceedings from the 9th World Conference on Earthquake Engineering (Dong et al., 1988).

In 1989 and 1992, however, a few large-scale disasters in the U.S. instigated a flurry of activity in the advancement and use of these models. On September 21, 1989, Hurricane Hugo hit the coast of South Carolina. Less than a month later, on October 17, 1989, the Loma Prieta Earthquake occurred at the southern end of the San Francisco peninsula. Then, in August of 1992, Hurricane Andrew came ashore and set records for storm surge levels for the southeast Florida peninsula. With an estimated $23 billion in damage at the time (of which $15.5 billion was insured), it was then the most expensive natural disaster in U.S. history. A month later, Hurricane Iniki struck the Hawaiian island of Kauai and proved to be one of the costliest hurricanes in the Eastern Pacific.

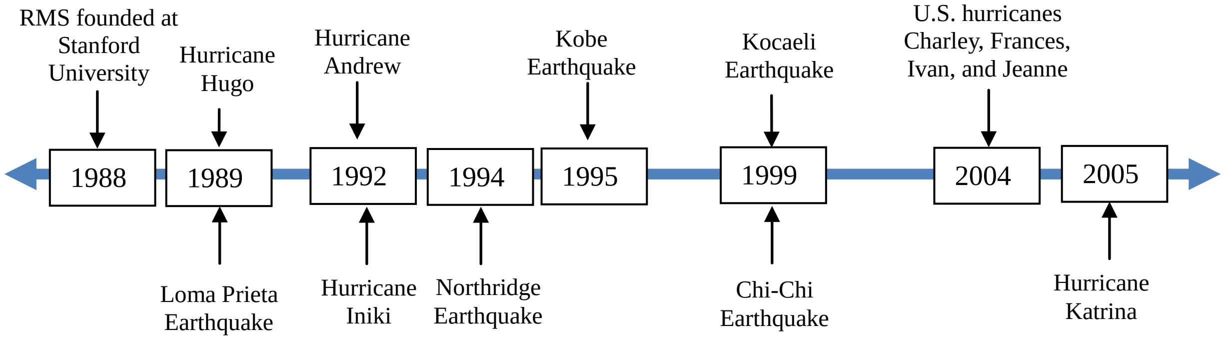

Figure 3 The evolving years of catastrophe modeling history (1988-2005)

4.1 The 1990s

Over 65% of the homeowners in Florida filed claims following Hurricane Andrew and insurance rates in south Florida increased 300% while the rest of the state increased 100%. As a result, there was over $4 billion in capital invested in 12 new reinsurers between Hurricane Andrew and January of 1994, when the Northridge Earthquake occurred in southern California. It was an emergence of a new generation of technical reinsurers founded on the concept of catastrophe modeling. In essence, Hurricane Andrew illustrated that the actuarial approach to managing catastrophe risk was insufficient; a more sophisticated modeling approach was needed. Moreover, it highlighted the importance of high resolution data in accurately estimating catastrophic losses.

The Northridge Earthquake in 1994 definitively marked the end of the loss experience approach to assessing earthquake risk in California, as the event occurred along an unknown blind thrust fault beneath the highly populated San Fernando Valley. For example, if one compares the volume of collected earthquake premiums to insurance loss payments in California from 1970 through 1994, the loss ratio (i.e., ratio of premiums to loss) is only 26% excluding the Northridge Earthquake. However, the Northridge Earthquake losses cause the overall ratio to increase to 207%. Up until this point, a probable maximum loss (PML) approach to managing earthquake risk was done, focusing on accumulation of insured exposure across the whole Los Angeles basin. Within the accumulation zone, risk was assumed to be 80% commercial structures. However, 60% of the insured loss was to the residential line of business.

This event additionally highlighted issues of incomplete or inaccurate exposure data. For example, appurtenant structures were found to be twice the value and twice as vulnerable to shaking damage. There were also widespread welding failures at the beam-column connections of 2,000 steel moment-resisting frame structures across the region. The total losses were 28 times the collected 1993 premiums and took 18 months to reach $15 billion. A huge amount of claims data became available for catastrophe modelers to calibrate damage curves, as well as develop new functions for additional sources of damage (e.g., earthquake sprinkler leakage). In March of 1994, an estimated 10% to 12% of property insurers used catastrophe models. In 2008, an estimated 90% of insurers utilize catastrophe models.

Through the late 1990s, the modeling companies grew and catastrophe models increased in number, availability, and capability. Other significant earthquake events, which highlighted needed improvements in the hazard and damage assessment steps of a model, included the 1995 Kobe Earthquake, the 1999 Kocaeli Earthquake, and the 1999 Chi-Chi Earthquake. With each event, catastrophe modeling advancements ensued, such as in the modeling secondary perils (e.g., fire following earthquake) and loss amplification resulting from indirect consequences of the event. The recent 2008 Wenchuan Earthquake in Eastern Sichuan, China will assist in the evolution of catastrophe modeling methodologies as well.

4.2 The 2004 and 2005 U.S. Hurricane Seasons

Hurricanes Charley, Frances, Ivan, and Jeanne in 2004 and hurricane Katrina, Rita and Wilma in 2005 had a major impact on catastrophe modeling. With U.S. insured losses totaling $22.9 billion at the time, the 2004 hurricane season caused a larger insured loss than Hurricane Andrew and the largest loss to the industry since the U.S. terrorist attacks of 2001. It highlighted the significance of clustering and seriality in catastrophe losses. In Florida, a second storm following closely behind an earlier storm further damaged weakened structures and exacerbated demand surge throughout the region.

In 2005, Hurricane Katrina also revealed widespread ambiguity and complacency around flood losses and coverages in the U.S. Following the 2005 hurricanes, the National Flood Insurance Program (NFIP) became technically bankrupt and, in 2006, borrowed over $20 billion from the U.S. Treasury in order to meet the estimated 225,000 claims from the season’s hurricanes. In the aftermath of Hurricane Katrina, over 80% of the metropolitan area of greater New Orleans was flooded, including 65% of the 147,000 residential properties. Of these 95,000 properties, 55% sustained over 4 feet of water, meaning that the building was effectively a write off for insurance recoveries.

5. CURRENT DEVELOPMENTS IN CATASTROPHE MODELING AND RISK MANAGEMENT

Hurricane Katrina was a modern-day 'Super Catastrophe' and sparked the incorporation of new approaches to catastrophe modeling. As catastrophes increase in magnitude, some of the simple assumptions of independent loss generation start to break down, as the cost of repair rises in response to external economic, behavioral, and political pressures. Delays in making repairs, due to the unavailability of builders or the difficulties of accessing the property, can mean that the amount of damage itself increases. Business interruption (BI) losses can be contingent on what happens elsewhere in terms of damage to lifelines or impacts on supply and distribution chains.

As illustrated in Figure 4, for the largest catastrophes, secondary processes triggered by the direct damage become additional sources of damage and loss through a concept known as loss amplification. Situations of this character are termed a 'cascade of consequences.' At the extreme, the cascade of consequences can become a significant factor in loss generation and can even become as large or even larger than the original initiating event—a situation known as a 'Cat following Cat.' Events in which a cascade of consequences starts to generate significant proportions of loss are termed Super Catastrophes (Super Cats).

To have a cascade of consequences become a major component of loss generally requires that there are concentrations of exposure, so Super Cats are predominantly of significance in major cities. There is no sudden transition between ordinary catastrophic and Super Cat loss. However, as the catastrophe gets larger, and as the average level of damage increases across a major city, one can expect to see an increasing potential for cascades of consequences to become additional factors of loss (For more information, see Grossi and Muir-Wood, 2006).

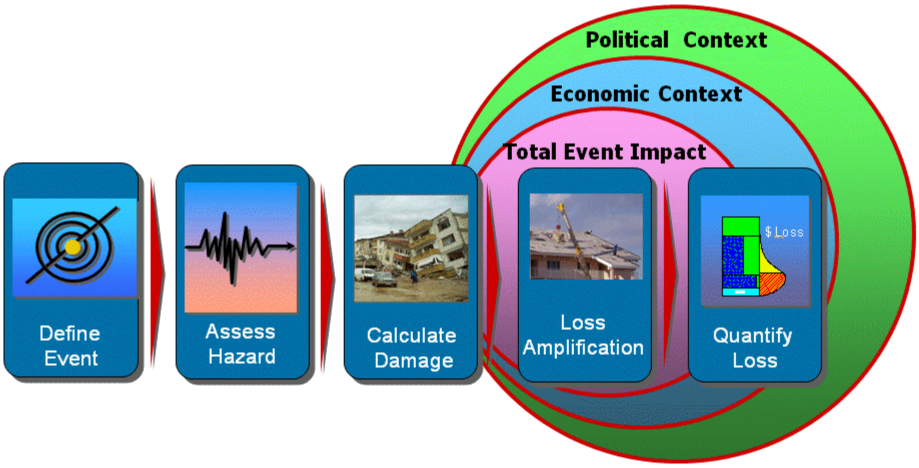

Figure 4 Catastrophe modeling framework considering loss amplification

5.1 Changes in the Insurance Industry

Beyond methodological advancements, Hurricanes Charley, Frances, Ivan, and Jeanne in 2004 and Hurricane Katrina, in particular, in 2005 had a major impact on how catastrophe models are viewed and being utilized by the insurance industry. Insurers are taking a closer look at their own underwriting practices and taking a more comprehensive approach to understanding and managing risk.

First, there is an intense focus on the underwriting process. For any model, recognizing the importance of input data is essential. The “garbage in, garbage out” principle holds irrespective of how advanced or state-of-the-art a model may be. Partial information on a structure’s characteristics can result in an inaccurate measure of risk. For example, is a residential structure coded as masonry when in fact it is wood frame? Is a commercial structure in fact a petrochemical refinery when it is coded as a chemicals processing plant? Are the structures’ and contents values underestimated? This type of misinformation in the underwriting process results in inaccurate measures of risk.

In addition, insurers are taking a more comprehensive approach to understanding catastrophe risk and the role of catastrophe models in their risk management process. There is a growing appreciation for the limitations of models. The science and impact of natural hazards are not completely understood and lead to uncertainty in estimating catastrophe risk. By recognizing the uncertainty associated with catastrophe models, insurers are more disciplined about managing their exposure and are beginning to take steps to protect themselves against losses that they may not have foreseen.

Finally, there is more attention being paid by insurers and reinsurers to the scope of modeled losses. A loss estimate from a catastrophe model often includes structural damage, contents damage, and other time-based impacts from a disaster, such as additional living expenses or business interruption. However, catastrophe models often do not explicitly model losses from the impact of an offsite power failure or mold, as seen in Hurricane Katrina. More specifically, the catastrophe models’ estimates of losses from Hurricane Katrina included direct wind damage and direct storm surge damage, but not mold infestation due to the levee failures in New Orleans. As insurers and reinsurers become more sophisticated in their use of models, there is increasing pressure on the modeling firms to develop more complete models that calculate all possible direct and indirect losses from a disaster.

6. CONCLUSION

Natural hazard catastrophe modeling has evolved considerably from the days when actuarial methods relying on past loss experience were used for risk assessment and management. Catastrophe modeling is now part of the ‘landscape’ of tools used by the insurance industry for a better understanding and management of risk, as it provides the means for incorporating additional information from a wide array of disciplines as it becomes available. Catastrophe modeling also provides a unified platform for decision makers to quantify the uncertainty associated with risk and incomplete information.

As the insurance industry relies more heavily on catastrophe modeling, there is more demand and greater challenges facing those that develop models. Modelers must devise methodologies for assessing and improving data quality. They must develop approaches that incorporate new scientific information and new ways to efficiently model uncertainties within each component of the model. They must quantify modeling uncertainties in ways that can be used by stakeholders who rely on these models.

Insured losses from catastrophic events have increased over the past 25 years, in part due to an increase in population and exposure in areas susceptible to catastrophic events. One thing is certain—this trend in losses and the associated global catastrophic risk will continue into the future. The modelers of catastrophe risk must face the challenges posed by the insurance industry to help mitigate and manage this risk.

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