The 2008 Wenchuan Earthquake: Risk Management Lessons and Implications

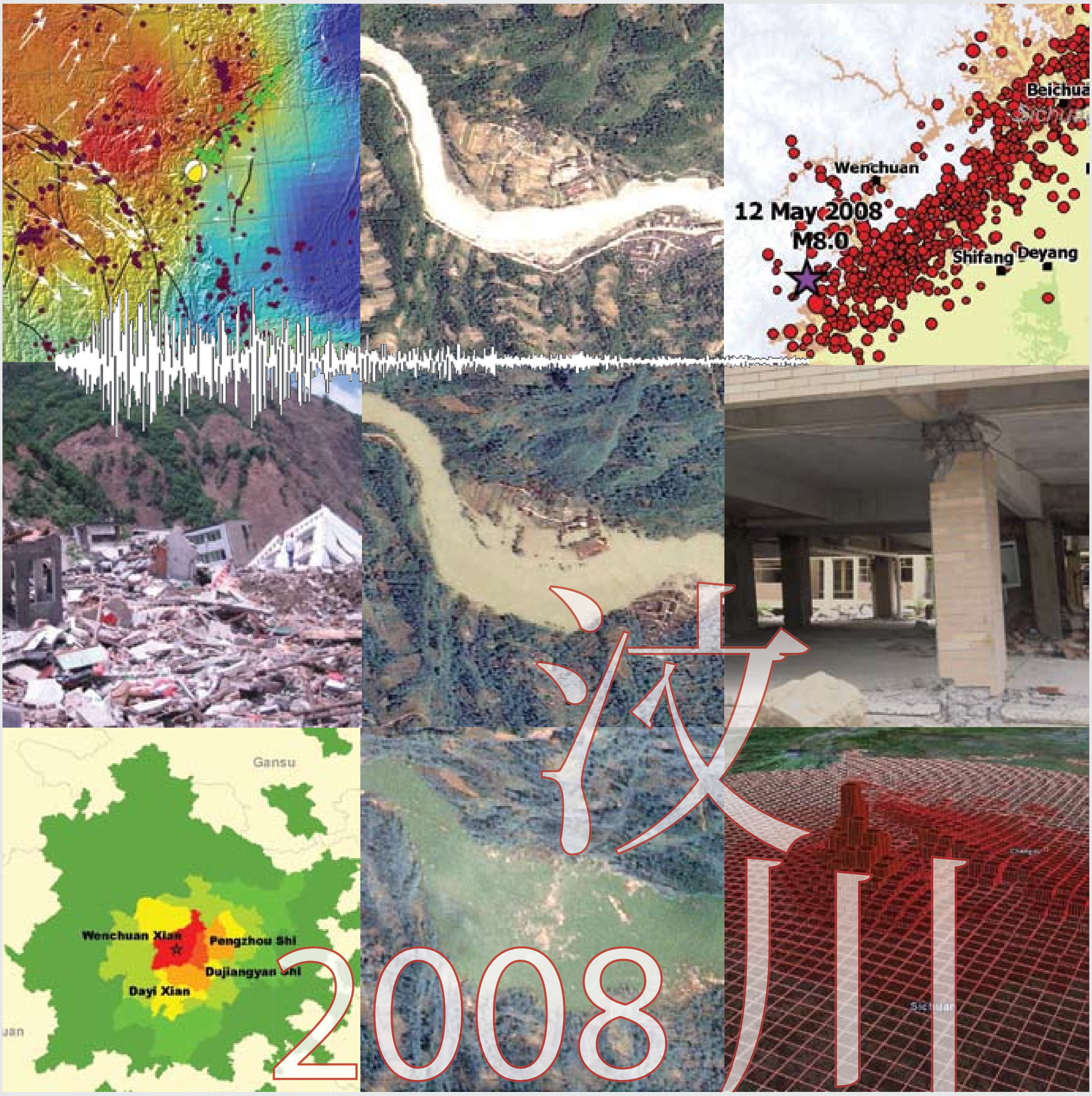

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TABLE OF CONTENTS

1 Setting and Damage of the Wenchuan Earthquake 1

1.1 Western Sichuan, Afternoon of May 12, 2008 1
1.2 Tectonic Setting 2
1.3 Property Damage: Surveys and Observations 2
Proper Seismic Design and Risk Mitigation 4
Effects of Long Duration Ground Motion 4
Poor Building Configuration 4
Impact on Industrial Buildings 5
Vulnerability of Schools and Hospitals 5
Vulnerability and Age of Buildings 5

2 Modeling the Wenchuan Earthquake 8

2.1 Deriving a Modeled Loss 8
2.2 Loss Estimates 8
2.3 Use of Modeled Results 9

3 Improving Modeling By Incorporating Observations 11

3.1 Location, Location … 11
3.2 Why Did This One Collapse? 11
3.3 Data Quality—Where to Begin? 12

4 Conclusions 14

FOREWORD 前言

The magnitude 8.0 Wenchuan Earthquake of May 12, 2008 had the largest impact of any earthquake to strike China since the catastrophic 1976 Tangshan Earthquake. The response of the Chinese people was worthy of the size of the event: the Chinese government responded with rapidity and strength, sending troops to the affected areas, no matter how remote, to save lives from under the rubble and provide relief to those displaced or made homeless by the earthquake. Individuals from all corners of China traveled to the affected region to offer help, or sent financial aid to the distressed. Today, close to six months after the earthquake, the wounds are slowly healing and the people of Sichuan are embracing the challenge of rebuilding their cities better and stronger. In Beijing, and in government offices across the country, the earthquake served as a harsh reminder that the great steps China has taken in the past decades have not sheltered the nation from the force and devastation of natural catastrophes, motivating another type of response—increased risk mitigation. Officials have been rehearsing emergency plans should the next earthquake happen in their city, in their town. In the office towers of the financial districts, the banks and insurance companies, relieved that their exposure to the event was small, have been offering financial assistance to hasten the recovery. In the boardrooms, however, questions have been raised: What if the next one is a direct hit to the economic sector? What is the largest loss we can manage?

The China Insurance Regulatory Commission (CIRC), the insurance regulator for China, recognizes that it is a key player in preparing the country for the next event. CIRC responded to the event by hastening the plans toward a natural hazard insurance scheme. The experience from other countries has shown that the first step in building a natural hazard insurance scheme is to implement a consistent and robust data standard through which to report the value and the nature of the assets exposed. In the last week of May 2008, CIRC held a seminar to advance the development of these standards.

In this report, RMS has teamed up with the Institute of Engineering Mechanics (IEM), our partners in China, to elaborate our response to the earthquake. The brief description of the impact of the event leads to some clear conclusions that support the advantages of a robust risk management culture, with the first step represented by investment in the definition and collection of data about the insured assets, supported by the standards being established by CIRC. Alongside the academic community, modeling companies also take away valuable lessons from analyzing how buildings and people are affected by earthquakes, and future models will reflect this knowledge. This heightened awareness of the value of risk management is a precious opportunity to strengthen the dialogue between the insurance and the modeling communities to work toward solutions to include risk metrics into the decision process. The opportunity is also at hand to leverage the strength of models to encourage mitigation, and reduce the losses from future earthquakes in China. ■

2008年5月12日发生在汶川的里氏8.0级地震是自1976年唐山大地震之后发生在中国境内的特大地震。灾后，中国人民的救灾行动更是规模具大，史无前例。中国政府反应快速，行动有力，在最短时间内向灾区派遣了大批部队以拯救废墟下的幸存者，并妥善安置受灾群众。灾后六个月的今天，地震的伤口正在慢慢愈合，四川人民正迎接重建的挑战，建设更好、更加坚固的家园。在北京以及全国各地的政府办公室中，汶川大地震正成为一个警示，一方面提醒人们中国前几年的大举措并没有能使国家免受自然灾害的侵害，另一方面也激励着新的防灾减灾措施的出台。各地政府官员也着手演练紧急救灾计划，为可能发生在自己城市的灾害作准备。同时，在金融区的办公大楼里，银行与保险公司一边为他们的风险暴露在震区规模较小而庆幸，一边在为加快灾区重建提供经济上的帮助。在董事会议中，人们关心的问题是如果下一个灾害将直击中国的经济中心，我们到底能承受多大的经济损失？

作为中国保险监督机构，中国保监会正成为公认的防灾减灾阵营中的重要一员。中国保监会应对巨灾的策略是竭力促成巨灾保险架构的形成。从多国的经验来看，建立巨灾保险架构的第一步是建立一个统一而强劲的数据标准，来报告资产暴露的真正价值与实质。今年5月底，中国保监会就已组织了研讨会来促进这个标准的建立。

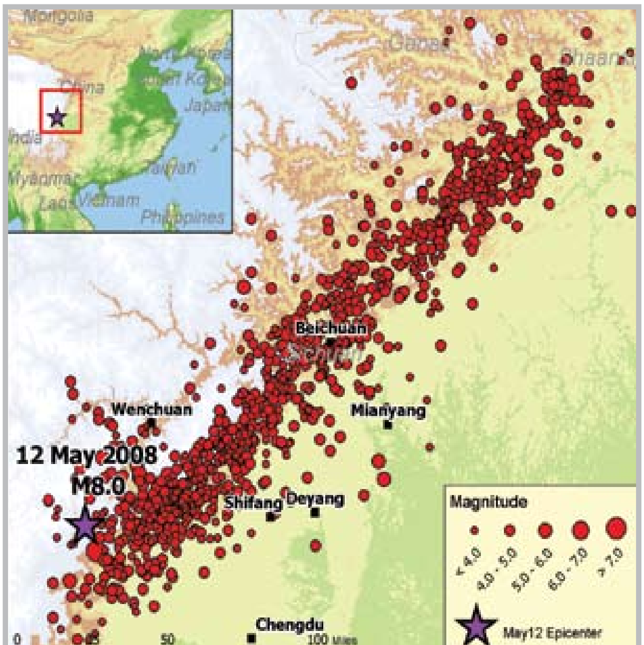
在这份报告中，阿姆斯风险管理公司与工程力学所--我们在华合作伙伴一起详尽阐述了我们就汶川地震的回应。这次汶川地震的影响揭示了一个清晰的结论，就是要建立一个强劲风险管理机制的前题是加强保险资产数据的采集与清晰度上的投入,这与保监会所要建立的标准是统一的。与学术界一样，风险建模公司也从分析建筑物与人在受到地震影响后的反应中学到重要的一课。从而，未来的风险模型将反映出这次所积累的知识。这次地震后对风险管理价值认识的提高，为加强保险公司与风险建模公司之间的对话，从而合作解决在决策过程中运用风险机制的问题提供了一个黄金契机。这个机会同时也即将使风险模型在今后的地震减灾和降低损失中发挥重大作用。■

1 SETTING AND DAMAGE OF THE WENCHUAN EARTHQUAKE

1.1 Western Sichuan, Afternoon of May 12, 2008

The magnitude (M) 8.0[1] earthquake that struck Sichuan Province on May 12, 2008 was the strongest earthquake to occur in China in over 50 years, and caused the largest loss of life since the Tangshan earthquake killed 242,000 people in 1976[2]. The earthquake occurred in Wenchuan County, a rural and mountainous region in western Sichuan Province, around 50 miles (80 km) west-northwest of Chengdu.

Based on field reports, the epicenter region experienced extreme shaking of intensity IX–XI on the Chinese Intensity Scale, capable of causing heavy to very heavy damage. Due to the mountainous terrain, numerous landslides destroyed roads and blocked access to the affected region, making search and rescue efforts painstakingly slow. It wasn't until rescue workers and emergency services were able to gain access to all of the damage-stricken areas eight days after the event that the true extent and severity of the earthquake emerged, revealing a catastrophic disaster. The slow progress of search and rescue efforts compounded the death toll, as many people were trapped beneath collapsed buildings with no access to medical aid, food, or water. The official death toll indicates that close to 70,000 people died, approximately 18,000 are still missing, and almost 375,000 were injured during the earthquake.



Location of the May 12, 2008 Wenchuan Earthquake epicenter and associated aftershocks (Catalog source: Harvard University)

Damage to buildings in Wenchuan (Source: IEM)

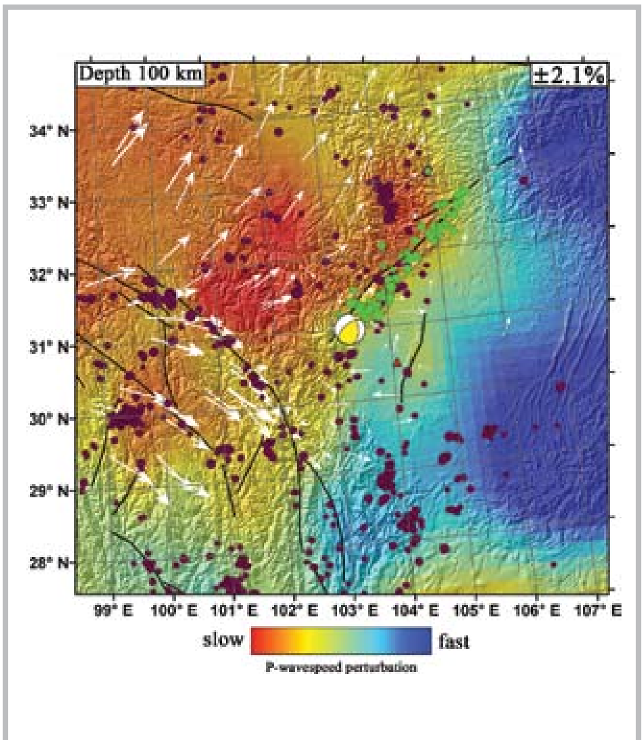
The Wenchuan Earthquake occurred at 2:28 p.m. local time on Monday, May 12—a time when the majority of adults were at work and children were at school. Though there is no official number published to date, reports indicate that at least 10,000 school children perished when approximately 100 schools collapsed. The collapse of so many schools and the deaths of so many children was one of the most disturbing consequences of the earthquake, and parents and communities are demanding answers and inquiries regarding the quality of construction for school buildings.

Over 138,000 businesses were damaged during the earthquake, leading to extensive business interruption. Damage to energy production facilities caused power outages across the affected region and continues to cause disruption to the energy sector today.

As of September 8, more than 28,000 aftershocks were recorded, of which 156 were recorded as M4 or greater, 39 as M5 or greater, and 8 as greater than M6, with the largest aftershock of M6.5 occurring on Sunday, May 25. These strong aftershocks contributed to the collapse of many of the buildings damaged during the main quake, causing further loss of life.

1 *M8.0 represents surface wave magnitude (M_S), the national standard used by the Chinese government for earthquake magnitude. The USGS reports M7.9 for the Wenchuan Earthquake, which represents moment magnitude (M_W).*

2 *For more information, see the RMS report, The 1976 Great Tangshan Earthquake: 30-Year Retrospective: http://www.rms.com/Publications/1976Tangshan.pdf*



Map of the Longmen Shan fault system (black lines) depicting the direction of plate motion (white arrows); as well as the Wenchuan Earthquake epicenter (yellow/white sphere); the rupture zone extending northeast from the epicenter; and aftershocks (green circles) (Source: MIT)

1.2 Tectonic Setting

The M8.0 Wenchuan Earthquake occurred on the Longmen Shan fault system in a mountainous region to the northwest of Chengdu, at the eastern margin of the Tibetan Plateau, resulting from motion on a northeast-striking reverse fault (also known as a thrust fault) along the northwestern margin of the Sichuan Basin. The earthquake occurred along a 240 km rupture zone extending northeast from the epicenter with a maximum estimated slip of 9–12 m.

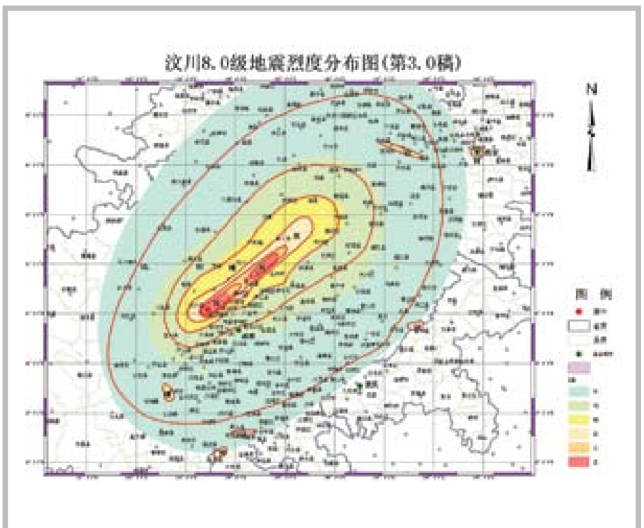
The rupture represents the release of slowly building tectonic stresses generated by the convergence of crustal material from the Tibetan Plateau to the west with the strong crust of the Sichuan Basin and southeastern China. This region is roughly coincident with the position of a Mesozoic collisional plate margin that developed during the closure of the Paleo-Tethys Ocean during the Late Triassic Indosinian Orogeny (approximately 230–200 million years ago) and continued into the Late Cretaceous (Densmore et al., 2007, Burchfiel et al., 1995). The crustal shortening caused by the collision was initially accommodated largely on the Wenchuan-Maowen and Beichuan faults but later migrated southeastward onto the Pengguan Fault, which forms the Longmen Shan fault system. Although the rate of slip along the eastern margin is low, at about 1–3 mm/yr, this region has the potential to generate large magnitude events due to accumulation over long time periods.

1.3 Property Damage: Surveys and Observations

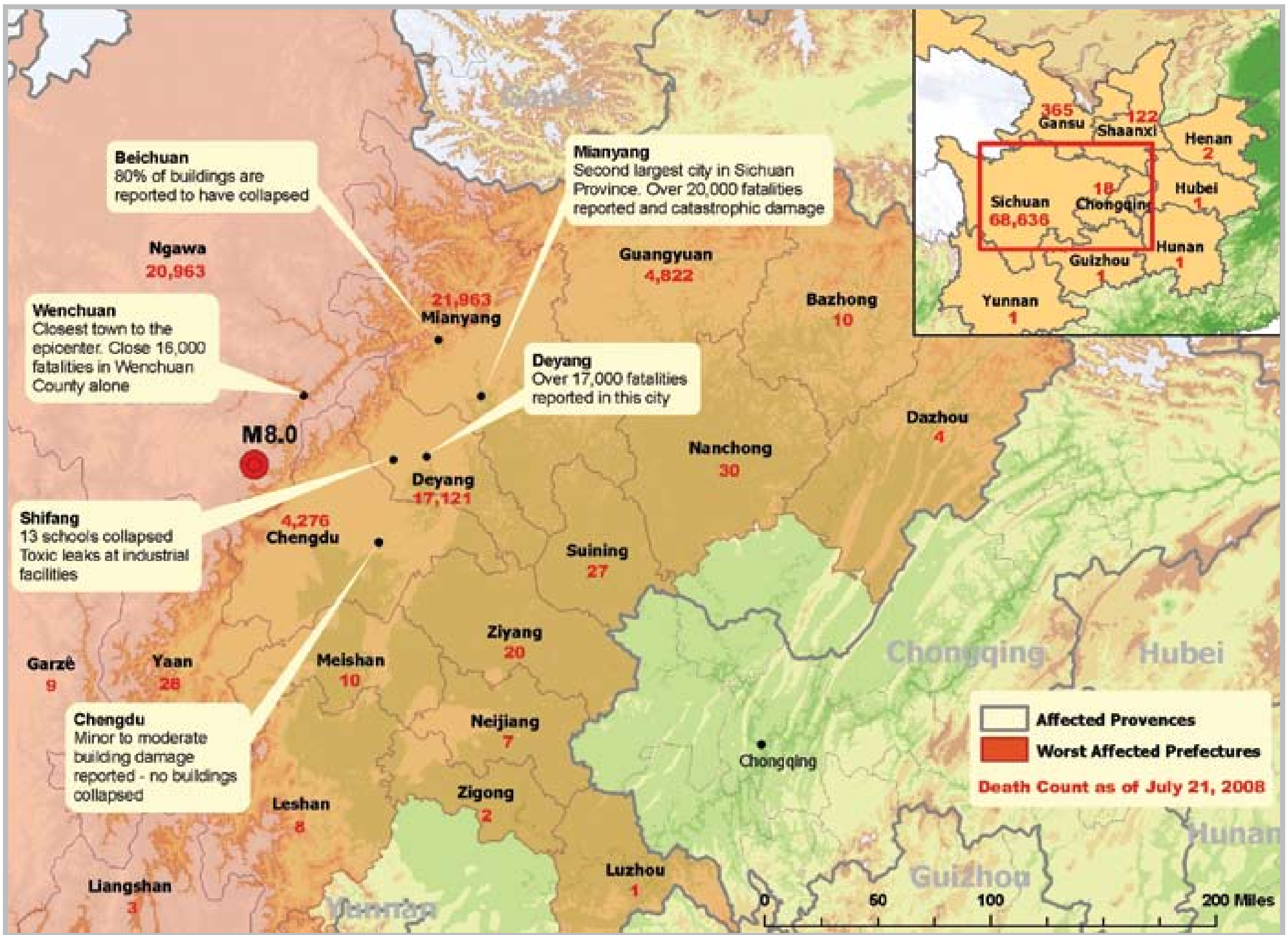
The Wenchuan Earthquake exhibited an extremely high intensity with sustained impact over a large area. The affected area includes the provinces of Sichuan, Gansu, Shaanxi, and the Chongqing Municipal area—comprising in total 417 counties in 16 provinces and municipals with an area of more than 440,000 square kilometers and a population of 45.61 million—a region so large that close to half of China was impacted. More than 15 million housing units collapsed during the earthquake and resulted in direct losses to buildings and infrastructure of over US$150 billion.

The event impacted the development of the planned economic zone on the edge of the Chengdu-Chongqing area, a region poised to become the biggest city cluster in western China and aiming to become another regional economic powerhouse like the Yangtze River Delta, Pearl River Delta, and the Bohai Bay Region.

The Chinese Intensity Scale contour map depicting shaking levels in the region illustrates that there are a number of large cities affected, including Chengdu and Xi'an as well as a number of medium-sized cities, such as Dujiangyan, Mianyang, and Deyang, where the damage was more severe. The area is known to be rich in both cultural and natural resources, and the recent earthquake not only destroyed many artifacts of cultural heritage but impacted the region's natural heritage as well, as quake-induced landslides scarred many beautiful landscapes. The city of Dujiangyan has been an attraction known around the world for its famous dike, built over two thousand years ago, as well as its picturesque scenery. The severe shaking levels of Chinese Intensity IX caused by the quake inflicted



Official Chinese Intensity Map (Source: IEM)

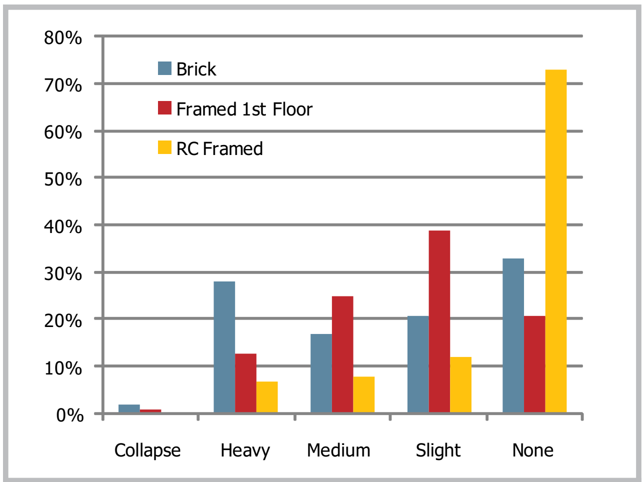


Distribution of casualties from the Wenchuan Earthquake, showing affected provences and worst-affected prefectures as of July 21, 2008 (Casualty numbers from SINA)

extensive damage on the city and the surrounding landscape. The Zipingpu dam, located on the Min River near Dujiangyan, endured severe shaking from the earthquake resulting in a settlement at the center of dam at around 74 cm. Although the observed peak acceleration on top of the dam well exceeded 1 g, there was only slight damage to the concrete slab and to the joints along the dam.

The damage experienced by structures in the Wenchuan Earthquake was largely dependent on construction type. In the mountainous rural areas, most of the buildings are one to two-story masonry structures composed of bricks or concrete blocks that do not contain reinforced concrete elements. These structures are highly vulnerable to earthquakes, and consequently, many collapsed. In the larger towns in the mountain valleys, including Beichuan and Wenchuan, multi-story buildings form the majority of the building stock. The form of construction of these buildings is typically reinforced concrete, but three or four-story masonry buildings are not uncommon. A similar building stock makes up the towns and cities at the foothills of the mountains on the edge of the Chengdu plain, such as Dujiangyan, Mianzhu, Pengzhou, and Shifang. In these cities the buildings that were not designed and built with sufficient provisions to resist earthquake shaking suffered varying degrees of damage. A survey of Dujiangyan shows that close to 10% of multi-story reinforced concrete buildings collapsed or were heavily damaged during the earthquake. Chengdu, the capital city of Sichuan Province, was sufficiently distant from the epicenter to only experience small shaking intensity, and thus the damage to buildings in Chengdu was minor.

To assess and model the losses from the Wenchuan Earthquake, RMS employs a number of resources, including firsthand accounts and damage surveys from the Institute of Engineering Mechanics (IEM), the government agency responsible for assessing the aftermath of the earthquake in affected areas. The IEM is RMS' development partner in China and co-developer of the RMS® China Earthquake Model. RMS staff also conducted earthquake reconnaissance in conjunction with the U.K.-based Earthquake Engineering Field Investigation Team (EEFIT), which was one of the first foreign teams to visit the epicentral area.



Performance of different structures in Dujiangyan during the earthquake (Source: IEM)

As there are numerous public reports[3] available that discuss the performance of both buildings and infrastructure during the Wenchuan Earthquake, this report does not present the full and detailed findings of the surveys. The key observations that follow provide a general overview of the impact of the earthquake on the region's building stock.

Proper Seismic Design and Risk Mitigation

In the aftermath of the earthquake, it became evident that the buildings properly designed for earthquake resistance performed better than those that did not adhere to the building codes. In particular, a significant number of buildings suffered only slight damage in areas that experienced shaking levels of VIII and above on the Chinese Intensity Scale. The buildings still standing to date in Beichuan are a testament to this. The design intensity level established by the building code in most of the epicentral region before the earthquake was VII, implying that these buildings were able to resist shaking greater than what they were designed for. This sends a strong message in support for seismic design: even under large shaking, buildings that have been designed and built with full consideration of seismic loadings will inherently be safer buildings than those where little consideration is given. A building with a configuration of plan and elevation that avoids concentrations of horizontal loading, and the size and strength of the structural elements to deal with horizontal loads, has a good chance of resisting seismic shaking even in excess of the levels it was originally designed for. These findings further support the enforcement of seismic building codes and proper construction practices as the first and most effective means to reduce casualties and losses due to earthquakes, no matter how exceptional the earthquake may be.

Effects of Long Duration Ground Motion

Ground motion observations from the earthquake indicate a long duration of ground shaking—over 100 seconds in most areas, and in rare cases as high as a few hundred seconds. The long duration of ground motion is a challenging issue in earthquake engineering because of its continuous impact, accumulating the damaging effects and compounding the development of fractures within engineering structures. As seismic waves travel through the ground, they produce both vertical and horizontal ground shaking effects, which have different structural impacts that must be accounted for in building design. Earthquakes typically have a larger horizontal component of shaking compared to the vertical, and building codes are established to reflect this—but at some locations the Wenchuan Earthquake exhibited the opposite effect, generating a larger vertical component of shaking compared to the horizontal component. This poses another challenge in seismic design because in the current Chinese design code, the maximum vertical component is stipulated to be less than two-thirds of the corresponding horizontal components. The vertical component of shaking adds to the gravity loading to increase the demand on the building's structure. During an earthquake, when the building is experiencing unusually high horizontal loading, this additional vertical loading exacerbates the potential damage.

Poor Building Configuration

Many of the buildings collapsed because they were of soft story configuration—reinforced concrete moment resisting frames with masonry infill, where the ground floor is cleared of walls to make space for commercial purposes or car parking. Reducing the number of walls on the ground floor is a flaw in the configuration design of a building in respect to its ability to resist the earthquake's horizontal forces. When the stiffness provided by the walls at the upper floors is removed at the ground floor, the remaining columns and beams at this level experience a severe concentration of loading, and failure of these structural members at the joints is a common cause of collapse. This poor consideration of seismic forces in the design and use of reinforced concrete-framed buildings

3 A selection of additional reports on the Wenchuan Earthquake is available from the following organizations: Earthquake Engineering Field Investigation Team: http://www.istructe.org/eefit/files/Wenchuan_Preliminary_Report.pdf ; Earthquake Engineering Research Institute: http://www.eeri.org/site/content/view/358/35/; MCEER: http://mceer.buffalo.edu/infoService/disasters/china-earthquake-sichuan.asp; National Center for Research on Earthquake Engineering: http://mceer.buffalo.edu/infoService/disasters/china-earthquake-sichuan.asp

Soft-story failure of a six-story reinforced concrete residential building in Dujiangyan (Source: EEFIT)

is not new and has caused a large number of casualties in recent earthquakes, the 1999 Kocaeli Earthquake in Turkey and the 2001 Gujarat Earthquake in India being clear examples of this. The vulnerability of these structures has been further proven in this earthquake, increasing the concern for the safety for the large number of existing similar building in earthquake zones, and the call for soft story configurations to be strongly disincentivized in any new building project.

Impact on Industrial Buildings

Because the larger industrial centers in Chengdu were nearly 100 km away from the epicenter, few buildings with industrial production facilities were located in the immediate footprint of the greatest shaking. Individual examples of damage were observed, but did not significantly impact the overall production in the region.

Partially collapsed five-story unreinforced masonry school building in Ying-Xiu (Source: EEFIT)

Vulnerability of Schools and Hospitals

The collapse of so many schools and the deaths of so many children was one of the most disturbing consequences of the earthquake. Though there is no official number published to date, reports indicate that approximately 100 schools collapsed, killing at least 10,000 school children. School buildings and hospital structures are expected to conform to building design standards that are higher than design codes for standard residential and office buildings, and thus the collapse of such a large number of these buildings has been a major factor in pushing the Chinese government to move quickly to assess the earthquake resistance of existing schools and hospitals in other seismically active parts of the country.

Vulnerability and Age of Buildings

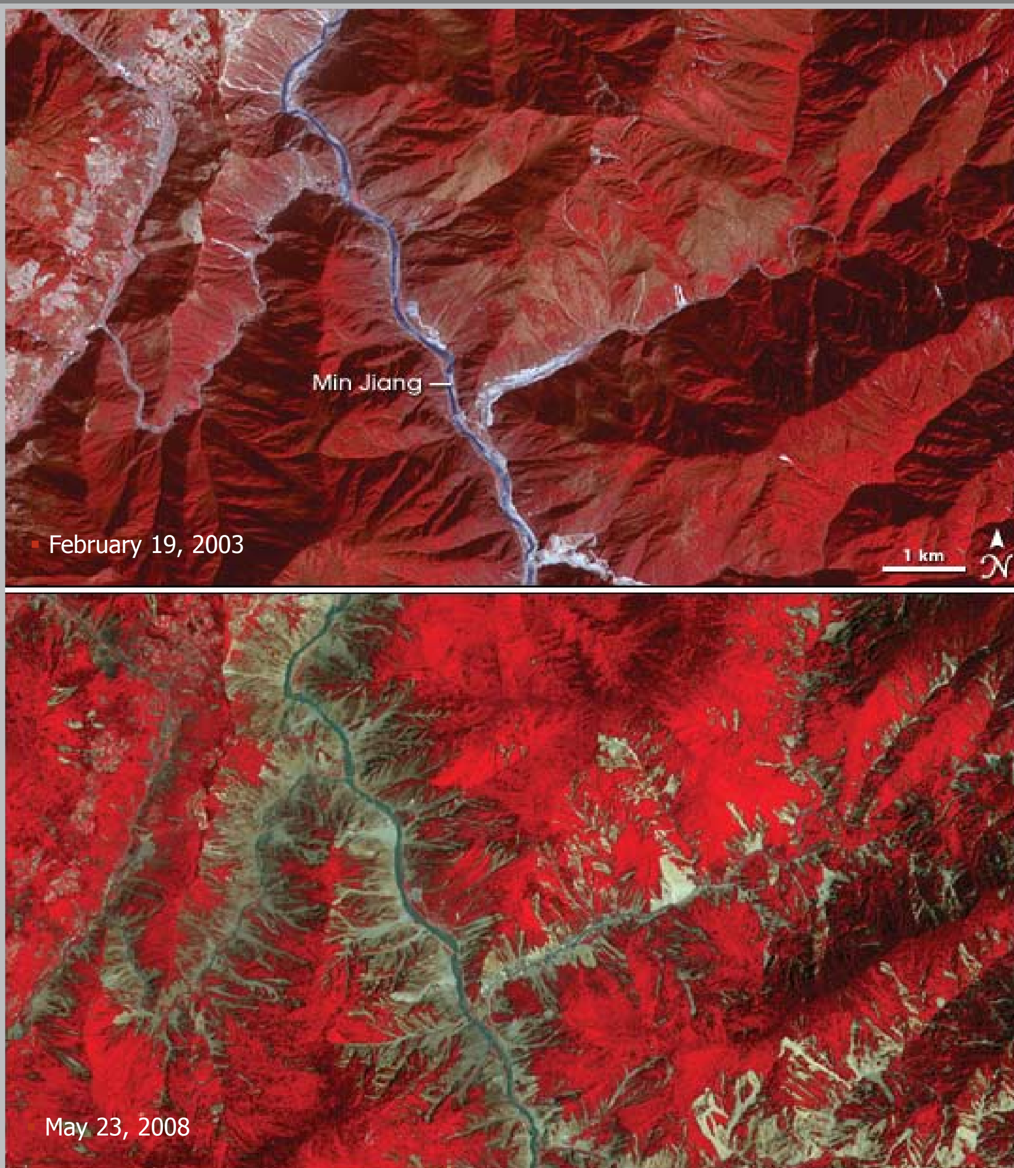
The early results from the survey indicate that the older reinforced concrete buildings were generally more susceptible to damage from ground shaking. The reasons for this lie both in the continued improvement of building construction standards and quality, and in the more stringent seismic requirements in the more recent building codes. ■

Landslides

Wherever major earthquakes occur in mountainous areas large landslides are triggered, filling valleys and damming rivers. The Wenchuan Earthquake triggered numerous landslides and rockslides. The damage caused by these landslides occurred on numerous levels.

Firstly, environmental damage was caused as the landslides permanently changed the landscape, damaging or possibly even destroying vulnerable ecological networks. Secondly, direct physical damage to buildings, vehicles, and infrastructure was caused by failing slopes or falling debris. The toll on humans was evident as many people were buried or crushed by the landslides.

Lastly, the landslides caused a significant amount of indirect damage. Damaged businesses suffered not only losses due to physical damage, but also losses sustained from business interruption. Blocked and damaged roads disrupted transportation to affected areas, isolating communities, hampering relief efforts and cutting off much-needed supplies. Landslides caused significant damage to infrastructure—including road networks, communications equipment, and power stations—leading to downed communications and power outages.



Beichuan County: Landslides are responsible for a large proportion of the damage. Satellite images illustrate landslide damage triggered by the earthquake near the city of Mianyang: before (top) and after (bottom) (Source: NASA)

Creation of Yansai Lake in Beichuan County: Normal springtime conditions, May 14, 2006 (top); two days after the Wenchuan Earthquake, May, 14 2008 (middle); one week after quake, May 19, 2008 (bottom) (Source: National Space Organization)

Quake Lakes

Landslides triggered by earthquakes can send debris into riverbeds, potentially blocking and damming the river. Massive amounts of water pool at a high rate behind the earthen dam, creating a so-called "quake lake"—a landslide-induced reservoir—that can often become a permanent feature of the landscape.

The threat from quake lakes occurs both upstream and downstream. Flooding upstream occurs as the river pools behind the blockage, inundating settlements located on the riverbanks. For a majority of earthquake dams, water permeates through the landslide material or the slide begins to erode slowly once it is overtopped. However, in a minority of cases, the erosion or collapse of the dam is catastrophic. The collapse of the Deixi landslide dam on the Min River in China in 1933 ultimately flooded 250 km of the river valley, killing more than 2,400 people.

The 2008 Wenchuan Earthquake created 35 landslide-induced quake lakes[4], 34 in Sichuan Province alone, forcing evacuations in some villages downstream of the affected rivers. As of July 17, 31 of the 34 quake lakes in Sichuan had been stabilized[5]. Beichuan County, near the epicenter, was particularly affected by quake lakes, the largest being the Tangjiashan quake lake. The lake was originally highly unstable, threatening 1.3 million people downstream, and necessitating the evacuation of 250,000 people from the city of Mianyang as authorities worked to stabilize the dam. The lake was stabilized in early June, and plans to build a hydropower station or to develop the lake as a scenic area in an effort to rebuild the earthquake-devastated Beichuan County are under consideration.

4 Source: Embassy of the People's Republic of China in the United States: http://www.china-embassy.org/eng/gyzg/t458627.htm
5 Source:World Heath Organization: www.wpro.who.int/sites/eha/disasters/emergency_reports/chn_earthquake_latest.htm

2 MODELING THE WENCHUAN EARTHQUAKE

Catastrophe Modeling Fundamentals

Catastrophe models quantify the likelihood of disasters occurring and estimate the extent of incurred losses, both from single events and multiple events averaged over a year. The four basic components of a catastrophe model are hazard, exposure, vulnerability, and loss[6]:

- **Hazard:** characterizes the event itself using parameters such as epicenter and magnitude for earthquakes
- **Exposure:** defines the individual properties at risk by their location and value/coverage
- **Vulnerability:** calculates the physical damage from the event to each property in the inventory
- **Financial (loss):** translates the physical damage into a monetary loss estimate

Catastrophe models simulate the impact of historical events as well as tens of thousands of possible event, or stochastic events, allowing a probabilistic view of risk.

2.1 Deriving a Modeled Loss

In the wake of a devastating event such as a major earthquake, it is important to obtain a timely estimate of potential losses. Catastrophe models are integral tools for assessing both the potential economic and insured losses from catastrophic events.

To replicate the Wenchuan Earthquake, the event was characterized by its epicenter, magnitude, and depth, as well as by relevant hazard parameters in the model that most closely correspond to the actual event.

The hazard component also comprises information regarding attenuation—the decay of ground motion intensity with distance from the event source—and geotechnical hazard, such as soil type and landslide and liquefaction susceptibility. When the analysis is performed, the model retrieves the geotechnical data for the earthquake footprint from a variable resolution grid (VRG)—a proprietary RMS geographic indexing system. The model also calculates the amplification of ground motions caused by the different soil types that underlie exposure—certain soil types can exacerbate a quake's shaking effects, leading to differing degrees of observed damage, an effect particularly evident during the Wenchuan Earthquake.

Next, the portfolio of properties affected by the earthquake is retrieved from an economic exposure database of replacement values. Location, along with other factors that describe the property, such as construction and occupancy type, and building height and age, are used to characterize the inventory. The model then uses both the typical hazard for that resolution and the average vulnerability for that county for loss calculations.

Based on this measure of vulnerability, the hazard and inventory components of the model enable the calculation of loss, a quantification of the physical impact of the natural hazard phenomenon on the structures and individuals at risk. Finally, the direct and indirect losses to the inventory are quantified. Direct losses include the cost to repair and/or replace a structure. Once total losses are calculated, estimates of insured losses are computed by applying policy conditions (e.g., coverage deductibles and limits) to the total loss estimates.

An inventory can also consider human populations at risk. The location of individuals throughout a given day (e.g., home at night, at work or school during the day, or en route between work and home) is an important indicator of risk, as casualties vary significantly according to a population's location at a particular time of day. The Wenchuan Earthquake occurred in the middle of the day, and as a result a disproportionate number of school children died when numerous school buildings collapsed during the earthquake.

2.2 Loss Estimates

Immediately after the Wenchuan Earthquake, RMS estimated that the economic property losses resulting from the event would range between US$10 and $15 billion. This figure includes insured and non-insured damage to property structures and contents, but does not account for losses that may have occurred as a result of business interruption, or wider economic effects such as infrastructure damage. At the time, casualty figures were evaluated to be between 18,000 and 34,000. As more information on the extent of damage and casualties became available through reconnaissance missions and media reports, it became clear that these preliminary estimations were too low.

A key reason for this undervaluation is that the proportion of low-performance rural and old structures in the overall building inventory for the affected region

6 For more information on modeling earthquake risk in China, see the RMS report, Creating a Technical Foundation for Earthquake Insurance in China: https://www.rms.com/Publications/ChinaStudy_Final.pdf was underestimated. The poor performance of these vulnerable structures severely impacted the number of the casualties as well as the damage level. Another reason for the underestimation is the low geographic resolution at which the inventory was assessed. Currently the inventory data used for the estimate is only at the county level—but, as seen from the earthquake damage, there is a vast difference among villages within a county, especially in the areas close to the rupturing fault. The third reason is the compounding effect of geotechnical damage, such as that from landslides. Geotechnical failure not only magnifies the damage to infrastructure, but also causes direct damage to buildings.

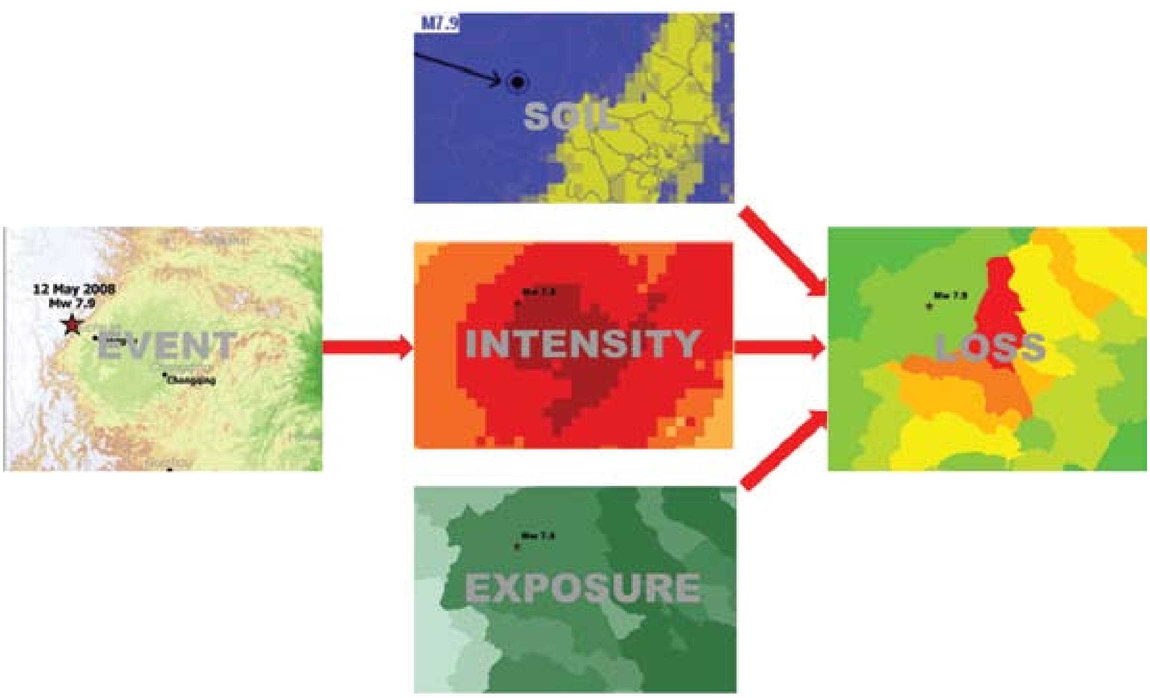
Although only a fraction of the property loss will be borne by the insurance industry, this earthquake is still likely to cause the highest insured losses in the country to date. Insurance penetration varies significantly by line of business, ranging from negligible for residential property, to approximately 50% for high-end commercial buildings in Chengdu, and full coverage for the industrial facilities owned by multinational companies. Additionally, business continuity is a fundamental issue, as the areas affected are burgeoning manufacturing zones for hi-tech companies and a key resource for the energy industry. As of August 28, Chinese insurers had paid out nearly US$90 million in claims with an additional US$54.5 million in deposits for future payout, according to the China Insurance Regulatory Committee (CIRC).

2.3 Use of Modeled Results

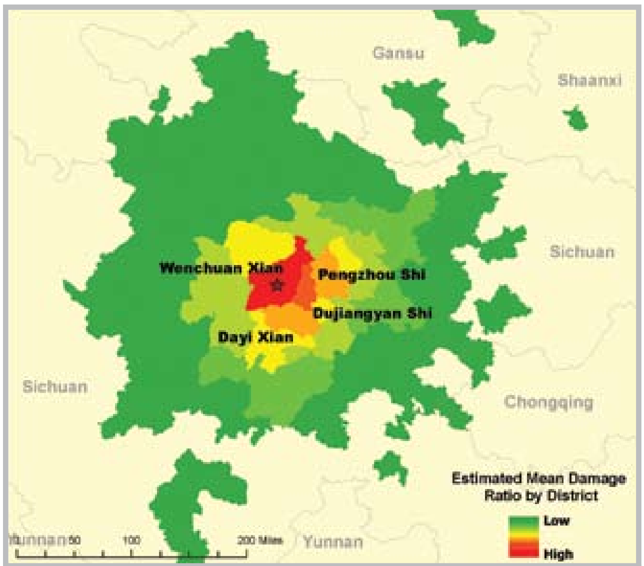
Catastrophe models can be used for risk management in a number of ways. Under everyday circumstances, the quantitative loss metrics produced from the model can be used to quantify risks and determine the appropriate design levels for earthquake resistance, as well as to devise strategies for mitigation, such as insurance, reinsurance, and catastrophe bonds. Following a catastrophic event, parameters describing the magnitude and location can be entered in the model to estimate the potential economic and insured losses and casualties from the event. The distribution of damage and casualty can also be used for effective dispatching of emergency personnel and relief efforts, as they indicate the areas most impacted, where emergency relief is needed most.

Catastrophe models are widely used in the insurance industry. Models inform the pricing and underwriting of insurance policies, and help in managing portfolio aggregations. With the advent of catastrophe bonds, the capital markets have become increasingly active in using catastrophe models for pricing and exposure management.

As mentioned previously, the use of models can extend well beyond the insurance industry, with applications in areas including governmental policy decisions, development agendas, and emergency planning and response efforts. Immediately after the event, confirmed fatalities were still in the few thousands. RMS' initial



Probabilistic catastrophe models estimate the losses caused by earthquakes by establishing event parameters and assessing the exposure and hazard for a given location



Estimated mean damage ratio (MDR) distribution of the preliminary loss estimate in Sichuan Province by district

economic and casualty loss estimates, $US10–15 billion and 18,000–32,000 thousand casualties, respectively, were presented to Premier Wen Jiabao through the IEM and CEA, and contributed to the decision to immediately deploy an additional 100,000 soldiers to the disaster area for search and rescue efforts.

The previous sections have discussed how loss estimates for the Wenchuan Earthquake could be generated a few hours after the event using the RMS® China Earthquake Model and in-house databases of economic exposure developed by RMS during the development of this probabilistic loss model. Model results can also be used to consider how the experience of events such as the Wenchuan Earthquake can reinforce how insurance companies can be empowered in their risk management decisions through the output of catastrophe models. Observations from the event in particular demonstrate that robust risk management starts by capturing and managing exposure in a database that accurately represents the location, replacement value, and building attributes of the properties in an insured portfolio.

The insurance industry is heavily dependent on accurate exposure information. For responsible insurance companies, several key pillars of risk management underlie their governance and culture: pricing based on real risk, identification and accumulation of exposed risks, adequate capital allocation and solvency, and robustness and transparency of information flow. All of these imply the proper treatment, interpretation, and presentation of data that represents the physical properties and the insured value of the portfolio. Risk quantification, related risk-based pricing, and the contingency of data on the accuracy of the analytics are addressed in the following section. Observations from the Wenchuan Earthquake present excellent talking points to explain the advances catastrophe modeling has undergone to address the uncertainty in the likelihood of any particular building experiencing damage. Earthquakes never fail to intrigue some observers as to why some buildings are reduced to a pile of rubble while others stand strong and unscathed by the quake. The engineering knowledge embedded within the models strives to explain these observations, and the exposure data entered into the model provides access to this knowledge for each of the properties in the portfolio. ■

3 IMPROVING MODELING BY INCORPORATING OBSERVATIONS

3.1 Location, Location …

The effects of seismicity are highly dependent on the soil or rock type upon which a structure is built. Similar buildings, located in areas that experience similar levels of seismicity, can be subjected to very different degrees of shaking depending on the level of amplification generated by the underlying soil (or rock). For instance, in Dujiangyan, two 2–3 story reinforced concrete frame residential buildings with masonry infill performed differently during the earthquake because they were built on different soil types. The building located on stiff soil (rock) at the northeast corner of Dujiangyan collapsed, while the building in the city center close to the river where the sub-surface soils are marine deposits was virtually undamaged. In this case, building height also had an impact on performance—low-rise buildings are particularly vulnerable on stiff ground conditions. Stiff soil and low-rise buildings have very similar vibrational periods, creating an add-on effect where the building and ground shake in tandem during the quake, greatly amplifying the shaking and, in this case, leading to collapse.

Catastrophe models capture these differences by analyzing the hazard for analysis locations at varying levels of resolution. The latest generation of RMS modeling tools leverages a technique known as variable resolution grid (VRG) technology. Hazard analyses are carried out in each of the grid cells, which vary in size depending on the severity of hazard or concentration of exposure in a region. For earthquake risk, grid resolution increases in areas of high seismic risk to capture the differences in risk at small distance increments for the most dangerous faults. Similarly, the grid is refined in cities where the risk differential to high value exposures could have a large impact, as in Chengdu. The model maps the exposure data onto this grid of cells by geocoding the data. Geocoding is the process through which the model translates the verbal description of the address, or "local coordinates," into "global coordinates" such as latitude and longitude or a common administrative boundary. In China, the geocoding engine recognizes and matches a hazard value to locations entered at province, prefecture, county/district, four and six digit postcode, city name, and location latitude and longitude levels of resolution. With this information at hand about the insured portfolio, the model can reduce the uncertainty in results.

3.2 Why Did This One Collapse?

Among the tasks undertaken by survey engineers in the epicentral region is the assessment of the damage experienced by buildings and infrastructure. This knowledge travels through the academic community and is translated into models that differentiate the performance of different types of buildings. The pricing

Similar buildings performed differently during the earthquake due to the type of soil on which they were constructed: the building built on rock (left) collapsed, while the building built on softer soil (right) was virtually undamaged. (Source: EEFIT) metrics that insurers calculate from the models for their portfolios reflect these findings. What did the Wenchuan Earthquake tell us about the most important piece of information we need to know about the insured property?

Two buildings can display differing damage states despite their similarities: for example, two buildings constructed of reinforced concrete were located close enough together that the soil type upon which they were built and the ground shaking they experienced were similar. However, one building was severely damaged, while the other appears undamaged. Though many other construction factors could have influenced this outcome, one dominant attribute that differentiates the buildings is the year in which they were built. Better understanding of the material and construction methods has, as a whole, improved the quality and resistance to lateral forces of reinforced concrete buildings. The building codes that dictate how resistant a building should be to earthquakes are regularly updated and improved—in China, major updates took place in 1978, 1990, and 2001. So is age the most important attribute that describes the resistance, and therefore the seismic risk? The vast majority of buildings that are likely to be insured in China are reinforced concrete, and most of them are engineered to building codes. Age is therefore an important attribute as there will on average be a close link between the age of a building, and its vulnerability to ground shaking.

3.3 Data Quality—Where to Begin?

Exposure data travels through an insurance company throughout the cycle of the risk—from the point of underwriting to the transfer on the international markets. In the aftermath of an event, as discussed above, observations confirm the difference in damage levels and financial loss to apparently similar properties. The value of understanding these differences clearly adds value to the risk decision processes, and can give significant competitive edge. The advantages of quality exposure data describing the location and attributes of insured exposure extend beyond the ability to generate more accurate risk quantification using a loss model. The importance of exposure data is realized throughout each stage of the risk cycle:

- Monitoring exposure concentration and accumulations, which might be geographic or in certain occupancies
- As a currency to report underwriting guidelines across the company
- To output technical rates by location
- To improve the company's standing among rating agencies
- In price setting and determining availability of capacity

Differences in damage levels due to building age in Dujiangyan: The older building (center), designed with no seismic code, collapsed, while the newer building (right), designed to seismic code standards, remained intact (Source: IEM)

Geographic levels of geocoding resolution used in RMS models

The Chinese Insurance Regulatory Commission (CIRC) is working to develop a data standard that will allow a single currency for insured exposure to be used throughout the industry. Risks will be defined in terms of the policy structures, replacement values, and types of occupancy as well as specific physical attributes of the buildings. Insurance companies with aspirations for robust growth in China are encouraged to engage in the definition of these standards and adapt their systems to handle this new data. The benefits from the implementation of the standards will soon be noticed throughout the organization. ■

4 CONCLUSIONS

The Wenchuan Earthquake was the strongest and most devastating earthquake to hit China in the past thirty years. The shockwaves of the event will be felt for many years to come. Almost half of the population of China was impacted by the earthquake, and the widespread destruction and loss of life will leave an everlasting imprint on the landscape and the people of Sichuan Province.

In the aftermath of the event, it became evident that there were many commonalities in the levels of damage experienced by buildings during the earthquake:

- Structures built to seismic design codes invariably performed significantly better than those without earthquake engineering
- A building's characteristics, such as age and location, were found to be key determinants of a structure's vulnerability to earthquakes
- An unexpectedly high proportion of schools and hospitals collapsed, causing a high fatality rate among the more vulnerable population groups
- Numerous soft-story configuration buildings collapsed due to their weakened structure
- The long duration of the ground motions experienced during the earthquake, as well as the unusually high vertical component of the shaking exacerbated the damage caused by the earthquake

In the wake of an event, catastrophe models are integral tools for assisting governments and the insurance and reinsurance industries in assessing the potential losses from the event. The Wenchuan Earthquake highlighted the importance of data quality in estimating these potential losses. Two characteristics in particular were found to play key roles during the earthquake: location, which affects the level of shaking, and building age, which can be closely correlated to resistance to shaking offered by the seismic design level.

Large devastating events such as the Wenchuan Earthquake send tremors far beyond the area affected by ground shaking. Modeling companies have the duty to respond to such events and revisit the science and assumptions that underlie the results to the loss models.

There is still uncertainty around many of the finer details of the event that contribute the most valuable learning points:

- What do the ground motion recordings say about the attenuation assumptions?
- Does the detailed damage survey validate the vulnerability functions?
- How will any revision to the seismic hazard map of China change the frequency and severity of the earthquakes assumed in the model?
- How can we model the risk from landslides and the secondary loss impact these can have?

Some of these questions may take several months to answer. IEM, who is responsible for surveying the damage, only just completed their work in the field in September 2008, and publication of ground motions is still pending. In discussing upgrades to the current RMS® China Earthquake Model, originally released in 2007, it is clear that one aspect deserving further research is the maximum magnitude possible on each fault structure, and the impact the uncertainty of maximum magnitude has on the modeled results.

Modeling companies have also acknowledged that the insurance industry in China is set to become a driving force on the global scene and that the demands from this growth necessitate solutions that are bespoke and achievable within the challenges of rapid growth. Encouraging dialogue, establishing a presence, and listening to the risk management needs in China have escalated to the top of the modeling companies' strategy agendas. The establishment of an office in Beijing further strengthens RMS' commitment to supporting the growth of the insurance industry in China.

FOCUS: Energy Disruption[7]

The disruption of a nation's power supply impacts the economy in many ways, including interrupting business activity, the cost of which is likely to be borne by insurers. How bad could the business interruption cost be from power outages or damage to the power infrastructure? The implications of the Wenchuan Earthquake extend over all sectors of the energy industry in Sichuan:

Hydropower

Hydropower provides more than 20% of China's total installed energy capacity. China's ambitous energy targets have this number doubling by 2020, and Sichuan Province is one of China's key development regions for growth. Before the earthquake, hydroelectric dams in the region generated 62% of Sichuan's total energy production. However, hydropower operations in Sichuan Province were hit hard by the earthquake: up to 481 dams (803 nationwide), and many power stations along the river systems were badly damaged. Two weeks after the quake, 69 reservoirs were on the verge of collapse, and 310 reservoirs were in "highly dangerous" conditions. Several major reservoirs were drained as emergency measures to prevent their dams from failing.

Wind Turbines

Dongfang Turbine, in Sichuan Province, is China's largest steam turbine producer and the third largest domestic manufacturer of wind turbines. Dongfang suffered severe damage during the earthquake, seriously impacting the production and selling of wind turbines domestically and globally. Dongfang estimates that direct losses from the quake will reach US$1 billion—indirect losses from factors such as business interruption and the impact on the global economy are more difficult to quantify.

Natural Gas

Natural gas currently accounts for only 3% of the national energy mix, and prior to the Wenchuan Earthquake Sichuan was to play a key role in increasing this percentage to 10% by 2020. In 2007, Sichuan Province supplied 27% of the country's natural gas production. While the Wenchuan Earthquake caused some damage to natural gas exploration and production facilities, overall, the effect of the earthquake on the natural gas industry is not expected to be severe. Once reconstruction efforts are completed, China is expected to return to full production.

Nuclear Power

China has ambitious nuclear development plans that have many provinces vying to participate—Sichuan Province was intending to begin construction on a new nuclear plant in 2010. However, the danger of having a nuclear plant in an earthquake-prone region has prompted a rethinking of China's nuclear development agenda. Officials reported that several facilities in Sichuan were damaged; however, there has been no mention of any radioactive leaks.

On the whole, experts believe the overall impact of the Wenchuan Earthquake on China's energy production will be relatively minor due to the country's capacity to supplement energy shortages from damaged hydroelectric facilities by increasing usage of the less affected energy sources, such as oil, natural gas, and particularly coal, while hydropower facilities are repaired. This method, however, puts a greater toll on the environment and drains precious natural resources.

The earthquake's greatest impact on the energy sector will be to China's ambitious long-term energy development plans. China will need to examine how these elaborate plans—particularly the resources needed to implement them—coincide with the country's risk from natural hazards. History has shown us that building numerous large hydropower dams or nuclear facilities in a region with high seismicity can be a disaster waiting to happen.

7 The information in this section has been compiled from the following sources: "China Quake Batters Energy Industry," BusinessWeek: http://www.businessweek.com/global-biz/content/may2008/gb20080519_901796.htm; "China's Renewable Energy Plans: Shaken, Not Stirred," Energy Bulletin: http://www.energybulletin.net/node/45778; "Quake Lakes Under Control: Situation Grim," Embassy of the People's Republic of China in the U.S.A.: http://www.china-embassy.org/eng/gyzg/t458627.htm; "Energy Implications of the 2008 Sichuan Earthquake," Global Terrorism Analysis: http://www.jamestown.org/terrorism/news/article.php?articleid=2374284

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