The 1976 Great Tangshan Earthquake

30-Year Retrospective

RMS

ACKNOWLEDGEMENTS

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Image Sources

Atlas of Natural Disaster System of China
China Earthquake Administration
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There are two principal objectives in publishing this report commemorating the 30th anniversary of the Tangshan Earthquake. The first is to remind us of the event so as to ensure that the lessons from the tragedy continue to be learned, in particular outside of China. Secondly, this report emphasizes the continuing need for worldwide collaboration in research on earthquake engineering, so that collective knowledge can be applied to reducing the impacts of future earthquakes wherever they occur.

In 1971, the People's Republic of China established the Chinese Earthquake Administration (then known as the State Seismological Bureau) to manage earthquake risk in China, the country with the highest earthquake risk of any nation in the world. At the Chinese Earthquake Administration (CEA), there are three main areas of work: earthquake monitoring and prediction, earthquake preparedness, and emergency response. While earthquake monitoring and prediction and emergency response are important, it is earthquake preparedness, both in terms of seismic design and training, which most directly reduces property and casualty losses.

A number of successful examples outside of China have demonstrated the important role of earthquake insurance as a key element of earthquake preparedness, with the potential to help drive a reduction in earthquake losses and casualties over time. Earthquake insurance can assist in spreading the risk from the consequences of earthquakes, encourage seismic retrofitting of existing structures and infrastructure, and enable a rapid recovery after a disaster. Earthquake insurance also requires the development of accurate methods for loss estimation. Therefore, it is essential to initiate research on earthquake loss modeling to develop a well founded system of earthquake insurance in China.

The Institute of Engineering Mechanics (IEM), part of the CEA, is the sole national non-profit research institute working on earthquake and safety engineering, while Risk Management Solutions (RMS) is the leading company in the field of the research and application of earthquake risk modeling for insurance applications. The collaboration of IEM and RMS marks the beginning of a partnership between two leading institutions with the potential to transform how earthquake insurance develops in China. ■

在唐山地震30周年之际，IEM和RMS共同出版了这本小册子，一方面让我们，特别是国外的朋友，回忆历史、记忆教训，另一方面也想强调国内外地震工程领域持续不断的共同合作和利用各方面的知识来有效地减轻未来地震灾害损失的重要性。

1971年，饱受地震灾害的中国政府为了减少地震灾害设立了中国地震局（时称国家地震局）。中国地震局的防震减灾工作主要有三个方面的任务：监测预报、震灾预防和紧急救援。虽然监测预报和紧急救援对于减灾有着重要的作用，震灾预防，特别是抗震设计和防震知识普及教育等，则是对减轻生命财产的损失有着更加积极的意义。

国外的几次成功经验表明，为了有效地减轻地震灾害，作为震灾预防的主要因子之一，引入地震保险的分担风险功能，对于分散地震灾害风险、现有建（构）筑物的增强加固和震后的快速重建有着举足轻重的作用。地震保险需要能够准确地估计地震损失，因此，特别需要开展地震损失估计方法的研究，从而开发出一套建立在坚实科研基础上的中国地震保险系统。

中国地震局工程力学研究所（IEM）是国内唯一一家从事震灾预防方面研究的国家级研究所，美国的RMS公司是世界上从事地震保险研究和应用的先驱者。IEM和RMS的合作开启了两个单位的协作研究与开发，希望能够以此引导中国地震保险的发展和成长。■

Hemant Shah
President & CEO
Risk Management Solutions

Risk Management Solutions (RMS) is honored to partner with the China Earthquake Administration's Institute of Engineering Mechanics (IEM) in developing a fully probabilistic earthquake model for China. With the Chinese economy expanding at an exponential pace and the property exposure in China becoming more privatized, there is a growing need for insurance-based models to accurately assess the risk from earthquake hazard. The release of the RMS® China Earthquake model in 2007 will be an important milestone in the emergence of a state-of-the-art risk market in the most dynamic economy in the world.

In preparation for the model release, RMS and IEM have collaborated on this report commemorating the 30th anniversary of the Tangshan Earthquake. The destruction experienced in Tangshan in 1976 was an ill-fated combination of the location of the fault and the high density of the population in the vicinity of the epicenter. The fault rupture occurred directly below the heart of a city of over a million people, in an area of assumed low seismic risk, where the buildings were not designed to withstand ground shaking. Alarmingly, as cities across Asia have rapidly increased in population over the last 30 years, a much greater proportion of the overall population now lives in cities like Tangshan. It is only a matter of time before a major shallow earthquake strikes one of these cities, potentially leading to devastating effects like those seen in 1976.

RMS catastrophe models have helped to advance the culture of exposure management and analysis of risk, creating increased awareness, preparedness, and risk mitigation. As leaders in our field, RMS remains committed to the continual research and implementation of sophisticated approaches to modeling potential catastrophic losses around the globe. Upon reflection of the anniversary of the Tangshan Earthquake, our hope is that our work with IEM will serve to improve the understanding of the potential risk in China, and lead to the reduction of economic consequences and casualties in the future. ■

RMS公司感到十分荣幸能与中国地震局工程力学研究所（IEM）合作来开发全概率的中国地震模型。随着中国经济的迅猛发展和物业的不断私有化，对精确评估地震风险的保险模型的需求也不断增长。RMS中国地震模型将于2007年完成， 它的发行将标志着在经济迅速发展的中国出现最先进的风险管理系统。

在开发中国地震模型之同时， RMS和IEM一起发表纪念唐山大地震30周年的报告。1976年唐山经历的惨痛灾难是地震发生在人口密集地区的不幸结果，也是地震直接发生在被预估为低烈度区，建筑无抗震设防的百万人口城市之下的结果。随着过去30年内亚洲人口的迅速增长，现有人口的很大一部分居住在类似唐山的大中城市，一旦浅源地震发生，象1976年唐山大地震那样惨绝人寰的悲剧还可能重现。

RMS的巨灾模型，对促进风险的分析与管理，提高风险意识，防震减灾方面起到了很大的作用。作为巨灾风险分析的领头人，RMS将继续为全球巨灾损失的模型加强研究。在追思唐山大地震之际，我们希望我们与IEM的合作将改善对中国潜在风险的认识，从而减轻巨灾的经济损失和伤亡。■

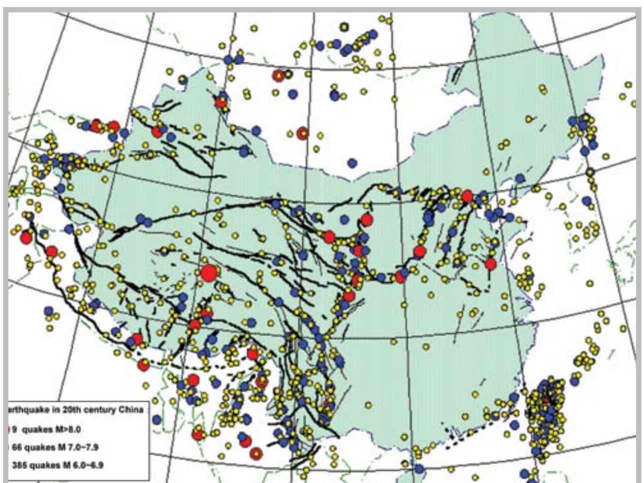
1 THE 1976 GREAT TANGSHAN EARTHQUAKE

On July 28, 1976 at 3:42 am local time, a moment magnitude 7.5 earthquake occurred below Tangshan city in the Hebei Province of northern China, causing extensive damage to the industrial city and its surroundings. The earthquake ruptured 100 km (62 mi) of the Tangshan fault, a right-lateral strike-slip fault trending in the north-northeast direction. The area experienced 10 km (6 mi) of extensive surface faulting running through downtown Tangshan with horizontal displacements up to 1.5 m (5 ft).

Many buildings collapsed as a result of the intense ground shaking. Due to the earthquake's occurrence in the middle of the night, this damage led in turn to very high casualties among the inhabitants of the city and the surrounding communities. The event also caused major damage in the city of Tianjin located 100 km (62 mi) southwest of Tangshan, and moderate damage in Beijing approximately 140 km (87 mi) to the west. The 1976 Great Tangshan Earthquake remains the deadliest earthquake in modern times with an official death count of approximately 242,400.

1.1 Seismic Tectonics of Northern China

The tectonic environment of China is driven by the ongoing collision of the Indian-Australian plate into the Eurasian plate. As a result of the prolonged collision, zones of active deformation fan out across northern and northeastern China into Mongolia and toward the Korean peninsula. Across much of China, including the region around Beijing, the active tectonics are driven by distributed strike-slip shear systems predominantly involving horizontal movements on nearby vertical faults.



Distribution of earthquakes in China with magnitude 6 or above since 1900

The active tectonics of northeastern China are manifest in the landscape of mountains and plains, separated by fault systems that create disrupted river gradients and large subsided areas prone to extensive flooding. The Beijing-Tianjin-Tangshan area is located in the northern region of the North China plain, with Yanshan Mountain to the north, and Bohai Bay to the southeast.

With over 2,000 years of chronicled history, the spatial and temporal occurrence of historical earthquakes is particularly well studied in northern China. Since 1000 C.E., strong crustal earthquakes have occurred in this region over four distinct high activity time periods, separated by decades of quiet seismic activity. The active periods span 1011 to 1076 C.E., 1290 to 1368 C.E., 1484 to 1730 C.E., and 1815 to the present. Research has found that over the four active periods, seismicity was concentrated in one or more distinct areas and the strongest earthquakes appeared to have been clustered. For example, during the fourth period, which is still active in 2006, one concentration of strong earthquakes occurred along the north-northeast trend from Tianjin to Tangshan. A series of major events also occurred between 1966 and 1976: the 1966 Xingtai earthquakes, the 1970 Tonghai Earthquake, the 1975 Haicheng Earthquake, and the 1976 Tangshan Earthquake.

While strong earthquakes had previously occurred in the region around Tangshan, there had never been a significant earthquake on the active fault under Tangshan before. The Sanhe-Pinggu Earthquake in 1679 (M_S 8) occurred on another active fault in the region, to the west of Tangshan, closer to Beijing. In fact, before the 1976 earthquake, Tangshan was considered a low seismicity region and the building stock had been constructed under this assumption.

Following the earthquake, research on dating geological fault displacements within China led to the identification of recurrence intervals for major earthquakes on a number of the principal faults in China, including the Tangshan fault. For instance, the fault that ruptured in the 1679 earthquake has an estimated recurrence interval of 6,500 years while the Tangshan fault's recurrence is estimated at 7,500 years. In general, slow moving faults in northeastern China that have suffered major earthquakes within the past few centuries have very low probabilities of a repeat earthquake in the immediate future. As with Tangshan before 1976, it is now recognized that the highest hazard is likely to be on faults without historical fault rupture.

Seismic fault sources and historical seismicity in the Tangshan region (Source: Atlas of Natural Disaster System of China)

1.2 Precursors to the Tangshan Earthquake

The region around Tangshan was not completely quiet before the 1976 event. A total of 22 earthquakes of magnitude M_S 4.75 or greater had occurred in the surrounding area since 1485 (i.e., during the third and fourth seismic active periods), including the 1679 Sanhe-Pinggu Earthquake. In the ten years prior to 1976, the occurrence of earthquakes in Tangshan and the neighboring regions had begun to increase, reaching a maximum rate in 1969. Moreover, although no obvious foreshock struck, a series of earthquake swarms occurred in the areas around Tangshan and Tianjin throughout the six month period before the Tangshan Earthquake, from February to July 1976. These earthquake swarms occurred over a large area and comparisons have been made to similar earthquake distributions before the Sanhe-Pinggu Earthquake.

On June 29, 1974 a medium-term prediction was issued by the Chinese State Council to the "leading public administrators of Beijing, Tianjin, the provinces of Hebei, Shanxi, Shandong, and Liaoning, and the autonomous region of Inner Mongolia." The forecast indicated that "within this year or next year, earthquakes of magnitude 5 to 6 may occur in: the Beijing-Tianjin area," among other regions. Based on the consensus of the seismologists working in the Beijing, Tianjin, Hebei, and Liaoning provinces, this medium-term prediction preceded both the 1975 Haicheng Earthquake and the 1976 Tangshan Earthquake. While there was also an imminent prediction later issued before the 1975 Haicheng Earthquake in the north Bohai area, there was no short-term or imminent prediction issued prior to the 1976 Tangshan Earthquake. Subsequent analyses of the pumping records from the Kailuan Coal Mine in

Earthquake Prediction in China

The scientific study of earthquake prediction was a key initiative in China starting in 1966, when premier Zhou En Lai launched a major scientific program under the slogan "Prevention First, Cooperation between Experts and the Masses." The Chinese State Seismological Bureau (SSB), currently the China Earthquake Administration (CEA), was given the task to train the masses (reportedly 100,000 seismic amateurs) to recognize the warnings associated with the imminent arrival of a seismic event (e.g., ground noises, unusual animal behavior, abrupt well water changes). From 1966 through the mid-1970s, increasing confidence grew around the program as various categories of earthquake predictions were issued by the SSB.

The most widely cited imminent prediction was issued by the Liaoning Provincial Seismological Bureau in 1975. The prediction, based on the combination of indicators including strong foreshock activity, spurred worldwide scientific debate around the science of predicting earthquakes and saved innumerable lives when an earthquake occurred within hours of the forecast. The Bureau called for an evacuation of the population of Haicheng, China on the morning of February 4, 1975. Later that day, at 7:36 pm local time, an M_W 7.0 earthquake struck the region. While over

Replica of the Chinese ground motion meter, the world's first seismograph invented in 132 C.E. by the Chinese mathematician, Cheng Heng

2,000 individuals died and close to 25,000 were injured in the earthquake, government officials indicated that casualties would have been far greater if the warning and evacuation had not been issued.

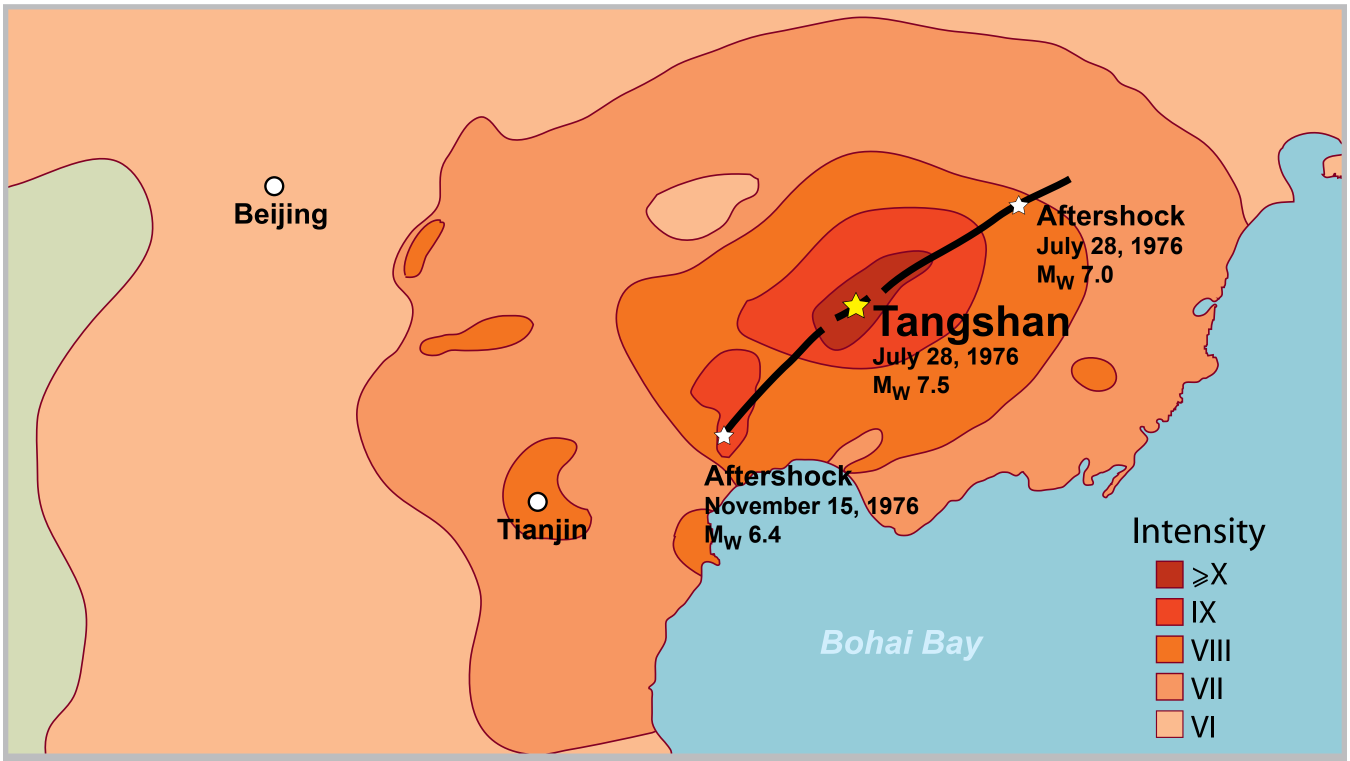
Bolstered by the success of the 1975 Haicheng Earthquake prediction, research by the SSB intensified. Unfortunately, on July 28, 1976 an earthquake struck Tangshan with no warning. In retrospect it is clear that while some earthquakes may present indications that can be used for issuing a warning, many large earthquakes arrive without significant precursors.

Tangshan indicate that there was a consistent drop in the pumping rate (and hence groundwater levels) in the years before the event with a sharp increase in the days prior to the earthquake. Additionally, survivors interviewed following the earthquake noted that well water levels changed abruptly in the hours before the event – e.g. with rises of over a meter in at least one village in the region.

1.3 Earthquake Sequence and Intensity Distribution

The Tangshan Earthquake was initiated at a shallow depth (11 km or 6.8 mi) below the city, with the fault rupture extending to northeast and southwest along the fault system for a total length of approximately 100 km (62 mi). The total energy released by the earthquake indicated a moment magnitude (M_W) of 7.5. By the end of September 1976, accelerographs in the region set up by the Institute of Engineering Mechanics recorded over 200 events. In all, over 850 aftershocks occurred through the end of 1978. The aftershocks were distributed throughout an area approximately 140 km (87 mi) in length and 50 km (31 mi) in width along a northeast trend, indicating the Tangshan fault as the main fault rupture. There were two major aftershocks (or triggered earthquakes), which caused additional damage to the region. On July 28, 1976 at 6:45 pm local time an M_W 7.0 earthquake struck, centered in Shangjialin Luanxian to the northeast of Tangshan. This aftershock caused a 50 km (31 mi) rupture along the Luanxian-Laoting fault. The second major aftershock of M_W 6.4 struck on November 15, 1976 at 9:53 pm local time. Centered south of Lutai to the southwest of Tangshan, this aftershock ruptured 20 km (12 mi) of the Jing Canal fault.

An extensive evaluation of the levels of damage and ground shaking was completed to determine the extent of ground motion intensities during the 1976 Tangshan Earthquake. Damage to brick smokestacks, water tanks, and various types of buildings, as well as observed ground failure and personal accounts, were used to determine intensities. According to the Chinese Seismic Intensity Scale (approximately consistent with Modified Mercalli Intensity Scale), maximum intensities exceeded X throughout downtown Tangshan and caused irreparable damage. Along both sides of the railway in Tangshan, as well as at the railway station itself, ground shaking intensities were at their peak. Overall, the earthquake was felt in twelve provinces or autonomous regions and in the cities of Tianjin and Beijing. Ground motion attenuated rapidly to the north but attenuated more slowly to the south, giving rise to liquefaction along the coast of Bohai Bay. The earthquake was felt for at least 800 km (497 mi) in all directions, totaling over 2 million km^2 (772,200 mi^2). Intensities reached IX in small portions of Tianjin with most of the city subject to intensity level VII. In Beijing, intensities were primarily VI with localized areas reaching VIII mainly relating to soil liquefaction. ■



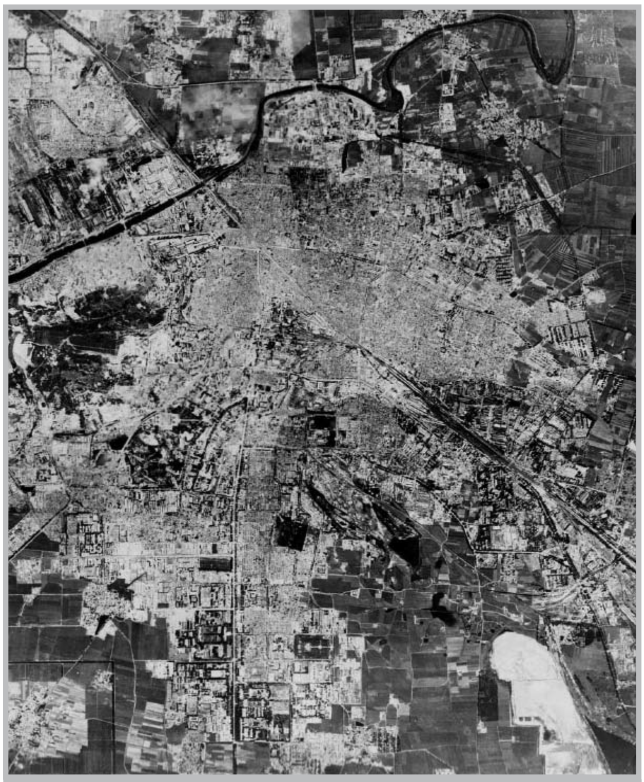
Intensity map of the 1976 Tangshan Earthquake, showing the Tangshan fault system and the epicenters of the July 28, 1976 M_W 7.5 event, the M_W 7.0 aftershock (northeast of Tangshan) and the M_W 6.4 aftershock (southwest of Tangshan)

2 PHYSICAL AND HUMAN IMPACTS

2.1 Building Exposure and Damage

At the time of the 1976 earthquake, the area encompassing Beijing, Tianjin, and Tangshan in northern China was heavily developed. Among the various buildings in the impacted region, there were many older buildings constructed before the founding of the People's Republic of China (i.e., before 1949) and buildings of various structural types built after this time. In general, buildings constructed before 1949 sustained more damage than those built after this date, as the study of earthquake resistant design did not begin in China until the 1950s and the first seismic design code in China was not published until 1955.

However, while there was some improvement in the design code over time, the seismic design code in force at the time of the earthquake (the 1974 code) designated the Tangshan area as a low seismicity region. Structures were built to design intensity VI with no consideration for earthquake resistantance. (It is only for seismic design intensities VII, VIII, and IX that earthquake resistance is considered.) As a result, no buildings in the region were able to resist the lateral and vertical loads produced by the strong ground motions of the Tangshan Earthquake. Many residential unreinforced masonry buildings collapsed due to the lack of proper connections between the walls and roof, as did many reinforced concrete and masonry industrial buildings with heavy roofs.



Aerial view of damage in downtown Tangshan

2.1.1 Tangshan

In 1976, Tangshan was an important industrial city with an estimated gross industrial output of around 2.9 billion RMB ($1.1 billion USD), based on the metallurgy, coal, electric power, ceramics, and building materials industries. Additionally, the railroads in and around Tangshan connected major factories and mines in the area with the main line that passed Tangshan city and connected Beijing to the northeastern part of China. The city was divided into the old urban district (Lunan district and Lubei district) and the east mining district, which is currently the Guye district. The districts had an area around 50 km^2 (19 mi^2), with the built up part covering approximately 15 km^2 (6 mi^2). Over half of the construction was residential structures, one quarter was industrial structures, with the remaining construction consisting of schools, hospitals, and other public buildings.

The residential structures in Tangshan consisted of older, single-story brick or stone wall homes and newer multi-story brick apartment buildings and reinforced concrete frame structures built in the 1960s. The majority of the residential structures in the city were single-story, unreinforced brick or masonry construction. In the rural region outside the city, the overwhelming majority of residential buildings were also single-story unreinforced masonry with some cobblestone and adobe structures.

Typical building damage to a multi-story brick apartment building in Tangshan

Within the areas of highest intensity in the city, over 95% of the multi-story brick apartment buildings and virtually all of the single-story unreinforced masonry buildings collapsed, killing a large percentage of the population while they were asleep in bed. The highest death rate was on the campus of the Institute of Mining and Metallurgy, where all of the multi-story brick dormitories collapsed, killing over 1,000 students and faculty. Nearby villages suffered total destruction as well, as houses were erected without any consideration for earthquake resistance.

The industrial structures in Tangshan were primarily reinforced concrete or masonry structures for the chemical, textile, and machinery industries. Nearly all industrial buildings were severely damaged within the areas of highest intensity, resulting in significant production delays. For example, the Tangshan Rolling Stock Plant, which manufactured and repaired diesel and steam locomotives and railway carriages, stopped production for six months following the disaster and was restored to full production only after two years. A porcelain factory belonging to the Tangshan Ceramic Company stopped production for 10 months and was not restored to full production until the end of 1977.

There were, however, some pockets of lesser damage. Where the soil deposits were rock, such as north of Tangshan city near the mountains, some buildings at the Qixin Cement Factory suffered only slight damage. The underground tunnels of the Kailuan Coal Mine, which had been in operation for over 100 years and played a crucial role in Tangshan's economy, suffered severe flood damage when the pumps stopped. However, the structure of the underground tunnels remained relatively intact. Over 10,000 miners were on the night shift working underground at the time of the earthquake and the majority survived. While it took until early 1977 to resume production on seven out of the eight coal mines, had any of the tunnels collapsed the damage could have been far more extensive causing a much longer recovery period.

2.1.2 Tianjin and Beijing

Two other major cities in northern China – Tianjin and Beijing – sustained various levels of damage in the Tangshan Earthquake. As was the case in Tangshan city, earthquake resistance was not generally considered in the design of buildings with the exception of the more recently built structures. According to the 1974 seismic design code, Tianjin had a basic design intensity of VII, indicating that some earthquake resistance was being considered in construction methods. The 1966 seismic design code specified a basic design intensity of VII in

Collapse of industrial buildings at the Tangshan Rolling Stock Plant

Beijing as well, although some important buildings in Beijing were being designed to withstand intensities VIII or IX.

Tianjin suffered fairly severe damage in areas of softer soils, as the city was located 100 km (62 mi) from Tangshan on the Bohai coast. Older residential buildings in densely populated areas, which were mostly single-story brick and wood frame construction, sustained the most damage. At the time of construction, the wood frame members were often simply placed on walls without any anchorage. In addition to this already weak structure, the strength of the mortar had deteriorated by the time of the earthquake. In contrast, newer buildings with seismic capacity and any buildings strengthened after the 1975 Haicheng Earthquake performed much better than those designed without seismic design considerations.

In Beijing, located 140 km (87 mi) to the west of Tangshan, damage was much less severe. Residential buildings built before 1949 sustained moderate to heavy

Old brick and wood structures were seriously damaged (on left) and newer brick and concrete structures remained intact (on right) in the city of Tianjin

Minor damage to the Ministry of Finance building in Beijing, where tiles fell of the roof

damage. However, most of the construction in Beijing was built after the founding of the People's Republic of China and was overwhelmingly multi-story brick buildings. The damage to these buildings was mostly minor, visible through wall cracks on construction joints (e.g., cracks around door or window openings). Shear cracks, indicating more severe damage, did not occur in many of these buildings.

2.2 Casualties

Due to the very high number of casualties, the Tangshan Earthquake is often referred to as the most disastrous earthquake event in China since the 1556 Shanxi Earthquake. Before the earthquake, the total population of Tangshan city was approximately 1.2 million, with 2 million within 40 km (25 mi) of the epicenter and 5.5 million across the felt region. The official death count from the earthquake was 242,400 with an additional 164,600 people severely wounded, 3,800 people disabled, and 360,000 people suffering minor injuries in need of medical treatment. In Tangshan city, the death toll included 135,900 people living in Tangshan (representing 13% of the total population) and 13,000 of the mobile population. Additionally, within the city, over 7,200 households (or 4.5%) were entirely destroyed. Sadly, 3,600 women became widows and 4,200 children emerged orphans due to the death of their parents.

There are a number of reasons why casualties were so high in the Tangshan Earthquake. First, as previously discussed, buildings were designed without consideration for seismic reinforcement. Although Tangshan is now known as being in a high seismicity region, sitting directly on top of a fault zone, in the past the seismic intensity level to which buildings were designed was only VI. Therefore, building structures and lifeline systems in the city and surrounding region had not been designed to withstand the high levels of ground shaking in the 1976 earthquake.

Second, the construction quality and design of residential structures in particular was deficient. Before the earthquake, 80% of residential buildings in Tangshan were built with flat heavy roofs, where each square meter could weigh as much as 400 kg (890 lbs). Many residential structures were designed without sufficient shear walls to withstand the lateral load from an earthquake and some structures were built with flawed construction methods, where beams were placed on top of walls without proper connections. These types of buildings lacked overall strength and structural integrity. The density of buildings and population in Tangshan city was extremely high. In the epicentral area where ground shaking intensities were highest, buildings occupied as much as 70% of the total ground surface and the population density for each square kilometer was 15,400 people. This concentration contributed to the seriousness of the loss in particular because the source of the earthquake was directly beneath the heart of the city.

Another reason as to the high casualty rate was the timing of the event: the earthquake occurred in the middle of the night at 3:42 am local time. The majority of inhabitants in Tangshan were still sleeping in their houses and many did not have enough time to respond. Around 80% of people were buried under the rubble and were unable to dig themselves out or survive to be rescued.

Finally, the city lifelines were fragile. Before the earthquake, the hospitals, water and power supply systems, communication, fire prevention, and public transportation did not take measures to mitigate for future earthquakes. When the earthquake struck, these systems lost their function completely, causing delays in emergency operations after the earthquake, which in turn increased casualties. ■

	Total	Tangshan City
Death	242,400	149,000
Severely Wounded	164,600	81,000
Disabled	3,800	1,700

Summary of casualties from the Tangshan Earthquake

Ten Days After the Earthquake: Weimin Dong

Weimin Dong, chief risk officer of RMS, was in Harbin when the Tangshan Earthquake struck at 3:42 am on July 28, 1976. At the time, he was working for the Design Institute of the Ministry of Machine Building, designing factory buildings. Approximately 960 km (600 mi) from the epicenter, Weimin did not feel the main shock but felt the aftershocks following the event. He recalls that at first no one, including the Chinese government, knew where the earthquake had occurred. Weimin describes a story where Yu Ling Li, the Deputy Chairman of Worker's Union at the Kailuan Coal Mine, survived and let the government know of the seriousness of the event by "driving a red ambulance to Beijing to inform the head of the central communist party." In the meantime, the head of the State Seismological Bureau in Beijing, knowing that the epicenter was near Beijing but unclear on the exact location (as all the seismographic instruments nearby were either destroyed or out of range), sent four reconnaissance teams in four directions – due north, due south, due east, and due west to search for the epicenter. After traveling for two hours, the team sent eastward saw the beginnings of the earthquake damage in the form of chimney collapses and other structural damage.

Weimin visited Tangshan ten days after the earthquake as part of a survey team for the Design Institute. As there was no place to stay overnight, the team spent one day surveying the factory buildings. Weimin's survey focused on factories, but he saw many collapsed buildings. He recalls that, "It was devastating…to see the collection of the bodies pulled from the rubble."

The event also had a personal impact on Weimin, as he recalled his own early experiences with earthquakes in China and other earthquake warnings following the Tangshan Earthquake. In particular, Weimin remembers being in Tianjin working on a factory retrofit on November 15, 1976, when the M_W 6.4 aftershock struck the region. It was in the evening and he and his coworkers were in the guest house of the factory. This was one of his first "real earthquake experiences" where the "building squeaked" and the "lights were swinging."

Weimin Dong in 1976

Four Years After the Earthquake: Haresh Shah

Haresh Shah (left) with the Chinese delegation to the 2nd National Conference on Earthquake Engineering

Haresh Shah, co-founder of RMS and Obayashi Professor (Emeritus) at Stanford University, was invited to visit Tangshan by the Chinese delegation that came to Stanford in 1979 for the 2nd U.S. National Conference on Earthquake Engineering. When he visited in September 1980, Haresh recalled that he and his colleague were the "first foreigners allowed in the city of Tangshan."

He found the city "still totally devastated" four years after the event. He recalls that it was "like Dresden after the war…with nothing left standing." Haresh recalls seeing many local motor, coal, and steel factories destroyed, as well as buildings belonging to the Institute for Mining and Metallurgy. Tragically, the last day of school at the institute was the same day that the earthquake struck, and "sixty to seventy percent of the students died when the dormitory buildings collapsed."

While visiting Tangshan, Haresh interviewed families to get their perspective on the event. Over four days, he found that "not a single family in all of the city remained totally intact." At least one person in each family had died or was disabled. Moreover, based on an admittedly "non-scientific" survey, Haresh assessed that close to 50% of the people died in the city. Officially, a number of individuals remained missing in 1980 as the government could not account for some people and could not identify others. Some individuals had been cremated before they could be identified, as there was a concern over outbreaks of cholera or other diseases.

At the time of his visit, while there were plans to rebuild, there was only one area with newly constructed buildings for the survivors. There had been a lot of reconstruction outside the city within four years, but most people within the city were still in tents, sheds, or portions of collapsed buildings. Haresh was heartened, however, at the "stoicism of the Chinese in the face of adversity" and the commitment of the Chinese government to the reconstruction of the city of Tangshan.

3 LEGACY OF THE TANGSHAN EARTHQUAKE

Due to the number of collapsed and damaged buildings, the Tangshan Earthquake led to a major update to the seismic design code, which was released in 1978. The study of the Tangshan Earthquake and its tectonic setting also resulted in the reclassification of hazard zonation of the Hebei province (particularly the Tangshan region). However, the recovery of Tangshan city following the earthquake is the true legacy of the event.

3.1 Seismic Design Code Revisions

The first building code that addressed the design for seismic resistance of buildings in China was published in 1955. It was a translation of the seismic design code for regions of the former Soviet Union and was only a recommended code. In 1959, the first required seismic design code was published. The code has undergone a series of revisions since its publication. First, in 1964 as a draft, then in 1974, 1978, and 1989, and again in 2001, which is the current design code. Revisions are common with any building code as the understanding of structural behavior is improved with the occurrence of a significant earthquake event.

A major upgrade to the code took place as a result of the 1976 earthquake, covering a wide spectrum of scope. Updates included performance criteria increases with the raising of expected ground shaking intensity, introduction of a new understanding of how the liquefaction of underlying soils impacts building foundations, and the inclusion of increased vertical forces from seismic loads. Generally speaking, the lessons learned about good building practice from the collapsed buildings in Tangshan were incorporated into the new design code.

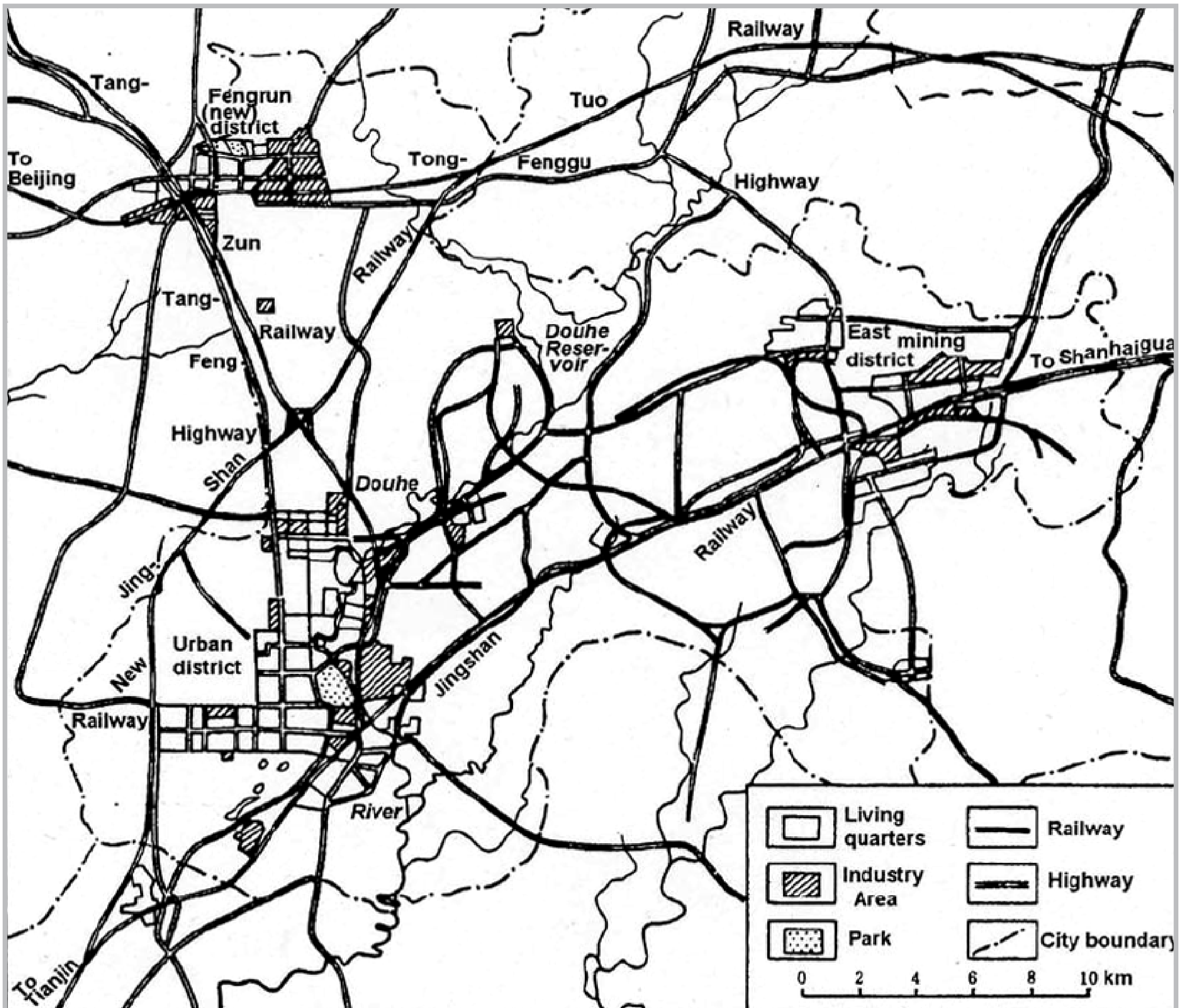
3.2 Lessons for Response and Recovery

The relief operations that followed the Tangshan Earthquake matched the scale of the disaster itself. An incredible number of volunteers and army personnel gravitated to the city to try to rescue any survivors from the collapsed buildings and bring aid to the homeless and injured. An operation of such an enormous scale helped identify many areas for possible improvements in emergency response and taught many lessons about earthquake disaster relief. One such lesson, also emerged from the 1966 Xingtai earthquakes, was that the manpower of the rescue workers needed to be accompanied by the appropriate equipment in order to rescue people from the collapsed buildings, as well as a pre-established plan to coordinate the effort. Accessing heavy equipment also required controlling the amount of vehicular traffic, a problem that brought the few clear streets of Tangshan to a standstill in the days following the earthquake.

Temporary shelter of the homeless posed a burden on land use and resources. The Tangshan experience, and many successive major disasters, confirmed that reconstruction and re-housing of displaced populations cannot be completed until several years after the event. The economic, social, and psychological effects from long periods in temporary shelters can be reduced by housing the population in permanent dwellings at the earliest opportunity. Examples include retrofitting damaged houses immediately after the disaster, as well as developing building systems that can be expanded incrementally to become complete dwellings and provide core housing and the necessary shelter during the early stages after a disaster. The availability of written material on the nature of earthquakes and the resistance

Rescue operations immediately following the Tangshan Earthquake

Due to liquefaction of the underlying soil, a concrete frame tilted, seriously damaging a transformer substation in Tangshan



Planned layout of the new Tangshan city following the earthquake of 1976

of buildings to earthquakes, along with a successful campaign of public education, are the ideal conditions to promote a rapid and earthquake-proof reconstruction, driven by the population affected by the disaster.

Failure of lifelines can exacerbate the distress to the survivors as well as paralyze factory production, slowing down the economic recovery after the disaster. The Tangshan Earthquake severely damaged key road and railway bridges, as well as interrupted water and electricity supplies. Shortfalls of the power supply stopped ventilation in the deep mines, threatening the lives of the 10,000 miners underground. The event highlighted the requirement for redundancy in the provision of lifelines, accompanied by the assessment of the appropriate design standards to guarantee the minimum necessary function of roads, bridges, or utility supplies following a disaster.

3.3 Reconstruction of Tangshan City

The sheer scale of the devastation and the conditions of the suffering population of Tangshan required the government to think about reconstruction on a scale rarely witnessed in the modern history of China. In a planning meeting held in August 1976, two scenarios for the complete reconstruction of Tangshan city were presented. One scenario purported the abandonment of the site of the city of Tangshan. The volumes of debris and the newly gained knowledge that an active fault lay beneath the city were strong incentives to consider moving all the industries to neighboring counties and relocating the population. The second scenario favored rebuilding Tangshan on its original site, as there was a strong economic incentive to re-establishing the city and its industries close to the rich coal mines.

In September 1976, it was decided that Tangshan would be rebuilt on the same site. Three districts would form the new Tangshan: the residential city, with its parks and public buildings, the Fengrun industrial district to the north, and the mining district to the east. The lessons learned from the earthquake that destroyed so many buildings would inform the design process of the new city. This was the perfect opportunity to build and incorporate increased earthquake resistance for future seismic events, as well as to implement an urban plan to reduce the traffic congestion and pollution from the nearby industries that plagued the city before the earthquake. Moreover, the layout of the city was planned to reduce both the number of casualties and injured, in addition to increasing the efficacy of emergency relief and disaster rehabilitation. Parks and open spaces were created to serve as sites for temporary shelters and hospitals for the displaced people.

The choice of structural configuration for the new residential buildings was twofold. It was informed on one hand by the abysmal seismic performance of the unreinforced masonry buildings of the old city, and on the other by the urban planning design which aspired to maintain a safe distance between buildings to allow escape paths and a pleasant environment. The seismic performance criteria prescribed no damage to the buildings in the case of intensity VIII and no collapse at intensities IX and X. Many of the new districts were built using reinforced concrete frame structures. Where masonry buildings were proposed, the load bearing bricks were contained by concrete columns and ring beams at floor level. The scale of reconstruction offered a unique opportunity to standardize and modularize production, allowing sections of floor plate to be assembled off site, making construction faster and cheaper.

Construction of new reinforced concrete frame buildings in Tangshan after the 1976 earthquake

Commemorative site in Tangshan city, serving as a reminder of the devastation following the Tangshan Earthquake

The logistics of the reconstruction were complicated both by the temporary shelters and the mounds of debris from the collapsed buildings. Full scale construction of residential buildings started in 1979, but the clearing of the debris did not begin in earnest until September 1981. Only in 1985 was the vast majority of the population living in permanent housing.

The memory of the fatal earthquake is kept alive by seven commemorative sites around the city, including ruins of two buildings destroyed by the earthquake and two buildings that withstood the earthquake as a testimony to good quality construction. ■

4 MODELING EARTHQUAKE RISK IN CHINA

China has the largest concentration of earthquake risk out of any country in the world. Almost half of the population of China is located in areas of moderate to high hazard, where significant earthquake ground shaking can be expected every one to a few hundred years. This proportion is far higher than in other large countries such as the U.S., Canada, or Russia.

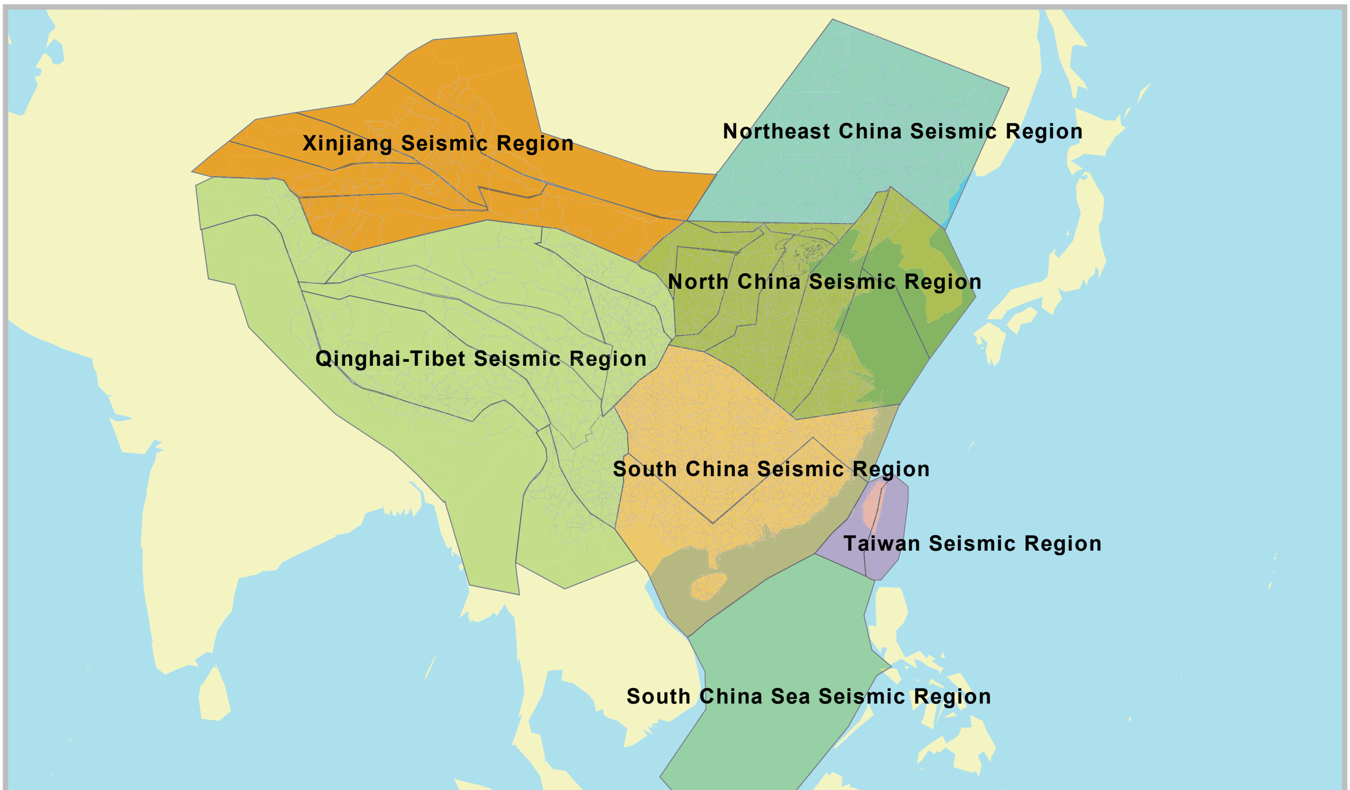
4.1 Comprehensive Risk Management

Such enormous potential for catastrophic loss calls for a comprehensive risk management strategy. Starting in the 1950s, a map of the earthquake risk in China was created by the China Earthquake Commission and was based on the distribution of historical earthquakes in the country. Over time, newer maps were developed with a better understanding of the seismicity and tectonic structures in China. The latest generation of the map was issued in 2001, estimating the peak ground acceleration expected at a 10% probability of exceedance over the next 50 years.

Such nationwide seismic risk maps are important for engineering decisions and the application of seismic design codes. However, earthquake insurance, which is a cornerstone of a comprehensive risk management strategy, also requires the financial quantification of potential outcomes. How likely is it that a whole city, or even a series of towns and cities, might experience destruction and losses in the same large earthquake? What would the levels of damage and economic losses be?

To answer such questions requires the development of a fully probabilistic catastrophe loss, or 'Cat' model, in which tens of thousands of potential earthquakes on various seismic sources are sampled and an annual rate of occurrence is attributed to each one. Output from the Cat model can be used to determine the probability that many separate locations could be affected within the same earthquake event. It can also determine the technical price for risk, whether for a single property or a whole portfolio of properties across multiple locations. Cat models perform at their optimum when details on a building and its location characteristics are available. A procedure to capture and transfer this information is also an important element of any risk management strategy.

As the Chinese economy expands at an exponential pace and the property exposure in China becomes increasingly privatized, Cat models have the potential to play a vital role in helping to preserve and maintain



The seven seismic regions across China which form the basis of the RMS® China Earthquake Model, containing over 900 seismic sources the economy following a significant earthquake event by helping to establish a strong earthquake insurance market.

4.2 Role of Earthquake Insurance

In 2006, China's economy is ranked 4th globally, having outpaced Great Britain. In addition, between 2001 and 2005, the average growth in non-life insurance premiums was 15.3% per year. High-valued construction is taking place throughout the country and is a major contributor to the growth of China's economy and insurance industry. To date, the vast majority of commercial and industrial risks are insured. International reinsurers functioning in China are supporting the development of a strong insurance market. Sharing risk with the global reinsurance market has the benefit of providing global support sufficient to fund the losses from a local catastrophe.

The financial burden of a natural disaster can also be supported by the internal management of resources. In general, the largest concentrations of exposure in China, such as in Shanghai or Hong Kong, are in areas of relatively low earthquake risk. This aspect of diversification can be captured in detail in a probabilistic Cat model and serve the development of a nationwide earthquake pool. An earthquake pool guarantees that funds will be available rapidly after a disaster to support reconstruction and rehabilitation programs. This reduces the burden on the government and results in a more streamlined compensation process through well-established claims handling procedures.

However, in 2006, residential property insurance is minimal in China and is unlikely to increase significantly in the near future. There is no insurance requirement for home loans, placing the liability on the banks. Moreover, the belief that the government will intervene to fund the recovery from a catastrophe is strong, and unlikely to be dispelled in the near future. As is true for many disaster-prone countries, only a major catastrophe prompts preparedness and the protection in the form of insurance coverage. Insurance companies aiming at increasing their presence in the residential sector in China can use Cat models to develop a fair and attractive pricing strategy. If an event of the magnitude of the Tangshan Earthquake were to recur, insurance companies that have managed their portfolio by controlling their accumulations and maximizing diversification will be at a distinct advantage.

Business center of Tangshan in 2006

4.3 Significance of the 1976 Tangshan Earthquake

The Tangshan Earthquake highlighted the extraordinary potential for loss of life and economic disruption when a major earthquake occurs directly beneath a large city. However, there are two main points that must be highlighted about a repeat of this event: the expected recurrence and the building stock.

First, given the release of strain associated with the earthquake, a repeat of a similar event on the Tangshan fault has an extremely low probability. The same is not true for other regions of China and the world, reinforcing the need to further the scientific research in this area of tectonics.

Second, given the nearly total reconstruction of Tangshan city after 1976, the quality and vintage of the building stock in 2006 is unique in the Chinese landscape. The inventory of buildings in most other cities in China is comprised of structures built over a long period of time. Beijing and its neighboring provinces are prime examples of areas with a wide variety of building types and vintages, including structures built before seismic design codes were established.

In 2006, China has over 100 cities with one million inhabitants or more. The increase of areas of concentrated exposure means the increased likelihood of a direct hit on a city of an earthquake on the scale of the Tangshan Earthquake. Thirty years following this tragic event, the improvements in the understanding of seismic hazard, coupled with the capability to model possible loss scenarios on current exposure, gives us the opportunity to take all the necessary steps to ensure that the loss of life and disruption to the economy of a similar event can be greatly mitigated. ■

Tangshan City: 1976 to 2006

RMS is in the midst of an intense development process, in collaboration with the Institute for Engineering Mechanics (IEM), to develop a Cat model for China Earthquake hazards. As part of the development work, the Tangshan Earthquake has been revisited and estimates of casualties and loss recalculated for today's exposure.

Exposure

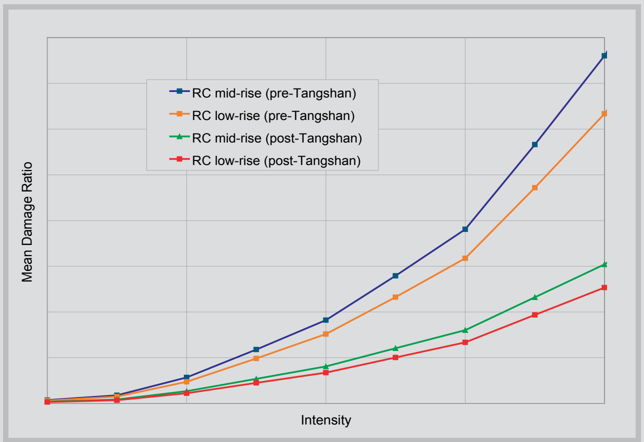
The area affected by the Tangshan Earthquake included Hebei province, which contains Tangshan, as well as Beijing, Tianjin, and several counties of Liaoning province. The area with intensity greater than or equal to VII in the Chinese Seismic Intensity Scale was 33,300 km^2 (12,860 mi^2). According to government statistics, the total population in 2006 in Hebei province, Beijing, and Tianjin is over 89 million. The population of Tangshan is 2.96 million, nearly three times the population in 1976.

At the time of the earthquake, the building types in Tangshan were not much different than buildings in other cities in northern China. The only difference at the time was the zoned intensity for the city. However, as the building code zoned Tangshan for intensity VI, this did not require buildings to be designed for earthquake forces. In contrast, Beijing was zoned for intensity VII and some earthquake resistant design was used for construction.

After the Tangshan Earthquake, the zoned intensities were adjusted to VIII in Tangshan, Beijing, and Tianjin, and earthquake resistant building designs were widely used in these areas, especially in Tangshan. After the event, hardly any older unreinforced masonry buildings remained in Tangshan. All of the buildings in the newly planned Tangshan, which were primarily reinforced concrete or reinforced masonry construction, were designed to resist intensity VIII.

Property Damage

If a similar event were to recur today, the performance of the buildings in Tangshan would be much better than the old building stock. In particular, the reinforced concrete structures designed according to the newer codes (1978 and after) would be much less vulnerable to damage and collapse. This increase in structural integrity has been confirmed in the recent past, for example during the 1996 Lijiang Earthquake in the Yunnan province, where buildings designed to withstand intensity VIII suffered only slight damage in areas of VIII ground shaking intensity. Moreover, based on the study of earthquake damage prediction for buildings within China, the vulnerability index of pre-1978 structures is estimated at 3.4, meaning the earthquake damage ratio of buildings today will be 3.4 times lower compared with buildings



Fragility of reinforced concrete (RC) low-rise and mid-rise structures before and after the earthquake

in 1976. This drop reflects a substantial improvement in the seismic capacity of newer structures.

Casualties

As earthquakes generally occur with little or no warning, the resulting casualties are dependent on a number of factors including the number of people in the affected area, the severity of ground shaking, and the vulnerability of the structures in which those people live and work. The time of day and day of week are also very critical in determining the physical whereabouts of people, whether they are in their homes, at work, or traveling. The random nature of earthquake timing combined with the significant daily displacement in population gives rise to significant variability in the likely number of casualties.

Casualty rate curves are a function of construction type, building height, and year of construction with a primary focus on totally and partially-collapsed buildings. Data from global earthquakes, particularly in Japan and Taiwan, were used in developing casualty rate curves for a repeat of the 1976 Tangshan Earthquake. It is expected that there would be more than a 50% reduction in casualties if the event would to recur today. Whereas there is threefold increase in population, the vulnerability of buildings has decreased considerably.

Economic Losses

The direct economic loss from the Tangshan Earthquake has been estimated at around 28 billion RMB or \$10 billion USD (1976 dollars). If the event would to recur today, this figure would be significantly higher due to increases in building and population density even though the seismic resistance of buildings is improved. At today's values and rapidly expanded building stock, it is expected that the economic loss from a repeat of the earthquake would be comparable to the loss following the 1995 Kobe Japan Earthquake, in the range of \$100 billion USD.

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